THE IMPACT OF INTER-BASIN WATER TRANSFERS ON THE WATER SECURITY OF ISTANBUL AND SURROUNDING WATERSHEDS

by

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ABSTRACT

THE IMPACT OF INTER-BASIN WATER TRANSFERS ON THE WATER SECURITY OF ISTANBUL AND SURROUNDING WATERSHEDS

In the face of climate change, urbanization, and population growth, water provision has become critical for many cities. Istanbul, the largest city in Turkey, faces water security challenges due to its location far from major water resources, rapid urbanization, and increases in population and in-migration. Droughts in the early 1990s and mid-2000s lead decision makers to rely on large-scale interbasin water transfers (IBTs) to maintain supply. This study draws from socio-hydrology to incorporate both quantitative and qualitative analyses to understand the human-water interactions that drive water security in the region. The Natural Efficiency Index and Social Efficiency (Stress Relief Index) developed by Duan et al. (2022) are used to quantify the impact of IBTs to the water security of both Istanbul and the provinces where Istanbul's IBTs are located, Düzce, Tekirdağ, and Kırklareli, from 2000 to 2020. Based on the indices results, transfers from the Istranca Streams in Tekirdağ, and Kırklareli are considered inefficient while the Melen transfer from Düzce is more efficient. To understand the full impacts of the IBTs to water security in the region, the indices are complemented by document analysis to understand the impacts of the IBTs to the regions' water security using approaches from political ecology, hydrosocial, and water justice studies. The document analysis found that IBTs to Istanbul led to negative environmental and socio-economic impacts to the water-exporting regions, while increasing supply to Istanbul only accelerates the megacity's growth, leading to increased water demand, a higher vulnerability to water-related hazards and climate change, and governance challenges through managing water over such a large area.

ÖZET

HAVZALAR ARASI SU TRANSFERLERİNİN İSTANBUL VE ÇEVRESİNDEKİ HAVZALARIN SU GÜVENLİĞİNE ETKİSİ

İklim değişikliği, kentleşme ve nüfus artışı karşısında, su temini birçok şehir için kritik hale gelmiştir. Türkiye'nin en büyük şehri olan Istanbul, ana su kaynaklarından uzak konumu, hızlı kentleşme ve artan nüfus ve iç göç nedeniyle su güvenliği sorunlarıyla karşı karşıyadır. 1990'ların başındaki ve 2000'lerin ortalarındaki kuraklıklar, karar vericileri arzı sürdürmek için büyük ölçekli havzalar arası su transferlerine (HAT'ler) güvenmeye yöneltti. Bu çalışma, bölgedeki su güvenliğini yönlendiren insan-su etkileşimlerini anlamak için hem nicel hem de nitel analizleri birleştirmek için sosyo-hidrolojiden yararlanmaktadır. Duan ve diğerleri (2022) tarafından geliştirilen Doğal Verimlilik Endeksi ve Sosyal Verimlilik Endeksi, HAT'lerin 2000'den 2020'ye kadar hem Istanbul'un hem de Istanbul'daki HAT'lerin bulunduğu illerin, Düzce, Tekirdağ ve Kırklareli'nin su güvenliği üzerindeki etkisini ölçmek için kullanılmıştır. Endeks sonuçlarına göre, Istranca Derelerinden yapılan transferler Tekirdağ ve Kırklareli'de verimsiz olarak değerlendirilirken Düzce'den Melen transferi daha verimli. HAT'lerin bölgedeki su güvenliği üzerindeki tüm etkilerini anlamak için, politik ekoloji, hidrososyal ve su adaleti çalışmalarından yaklaşımlar kullanılarak HAT'lerin bölgelerin su güvenliği üzerindeki etkilerini anlamak için endeksler belge analizi ile tamamlanmıştır. Belge analizi, İstanbul'a yönelik HAT'lerin su ihraç eden bölgelerde olumsuz çevresel ve sosyo-ekonomik etkilere yol açtığını, İstanbul'a artan arzın ise yalnızca megakentin büyümesini hızlandırarak su talebinin artmasına, suyla ilgili tehlikelere karşı daha yüksek bir kırılganlığa ve Böylesine geniş bir alanda suyu yöneterek iklim değişikliği ve yönetişim zorlukları.

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LIST OF SYMBOLS/ABBREVIATIONS

BIPOC	Black, Indigenous, and People of Colour
CH_4	Methane
CO_2	Carbon dioxide
DIO	Difference between transfer-in and transfer-out
DSİ	*Devlet Su İşleri* (State Hydraulic Works)
FAO	Food and Agriculture Organization
FLK	Falkenmark Water Stress Index
GWP	Global Water Partnership
HDI	Human Development Index
HELP	Hydrology, Environment, Life and Policy issues
hm^3	Cubic hectometer (million cubic metres)
İBB	*Istanbul Büyükşehir Belediyesi* (Istanbul Metropolitan Municipality)
IBT	Inter-basin water transfer
IMC	Istanbul Master Plan Consortium
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
İSKİ	*Istanbul Su ve Kanalizasyon İdaresi* (Istanbul Water and Sewage Administration)
IWRM	Integrated Water Resource Management
NGO	Non-Governmental Organization
P	Population
RWH	Rainwater harvesting
SDG	Sustainable Development Goals
SRI	Stress Relief Index
SWAT	Soil and Water Assessment Tool

T	Transfer amount
TESKİ	*Tekirdağ Su ve Kanalizasyon İdaresi* (Tekirdağ Water and Sewerage Administration)
TF(e)	Freshwater availability in the water-exporting watershed
TF(r)	Freshwater availability in the water-receiving watershed
TI	Transfer-in
TO	Transfer-out
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UWSI	Urban Water Security Indicators
WD	Water demand
WEAP	Water Evaluation and Planning
WPI	Water Poverty Index
WS	Water stress
WSI	Water Security Index
WSSI	Water Security Status Indicators
λ	Weighing factor

1. INTRODUCTION

Our world is facing complex interrelated challenges such as water scarcity, food insecurity, extreme weather events, biodiversity loss, air and water pollution, and income inequality, all of which further exacerbates and is exacerbated by climate change. Given that the earth is a finite resource, rapid growth creates pressure on available resources, further worsened by climate change. These challenges will only grow as the global population is predicted to exceed nine billion by 2050 in tandem with a doubling of per-capita buying power which puts further pressure on available resources (Liu et al., 2018). Urban areas are growing at a disproportionate rate as they become centres for economic and political power. In the last 70 years the percentage of the world's population living in cities increased from 0.8 billion (29.6 %) in 1950 to 4.4 billion (56.2 %) in 2020 (He et al., 2021). By 2030 it is predicted that an additional 1.2 billion people will live in urban areas and 70 % of the world's population will live in cities by 2050 (McDonald et al., 2020). As cities grow, they demand more resources, such as water. Currently many of the world's urban areas face water scarcity, where demand exceeds availability, and 18 of the 30 megacities around the world (i.e., population >10 million) are located in regions with some level of water scarcity (He et al., 2021). Water scarcity is a key component of water security and impacts the urban environment, the health and wellbeing of those in cities, and socioeconomic development, not only of urban areas but also in the rural areas that surround cities (He et al., 2021). Urban industrial and domestic water demand is expected to increase by 50-80 % by 2050 as a result of increased population growth, in-migration, urbanization, and socioeconomic development, while climate change is also expected to impact the temporal and spatial distribution of water availability (He et al., 2021). He et al. (2021) argue that urban water security will become a greater challenge in the future and may impact the possibility of achieving the United Nations Sustainable Development Goals (UN SDGs) especially SDG Goal 6 "Clean Water and Sanitation" and SDG Goal 11 "Sustainable Cities and Communities" (UNDP, n.d.).

Current mainstream solutions increasingly focus on increasing water supply to urban centres, known as supply management, instead of demand management to optimize the use of existing water supplies which reduces the need to find new resources (Savun-Hekimoğlu et al., 2021). One of the most common supply-side management policies is the development of inter-basin water transfers (IBTs), the large-scale hydraulic connection of two or more river basins that otherwise would not connect (Gupta and van der Zaag, 2008; Burak et al., 2021). IBTs create path dependency where the reliance on large scale infrastructure becomes difficult to reverse due to the high cost of investment and the observed supply-demand cycles in which increased supply leads to increased demand increases as water availability promotes increased economic activity and in-migration (Di Baldassarre et al., 2018). The reliance on large megaprojects leads to increased energy and water resource use, competition for land use, and limits the drive and opportunities to create more sustainable alternative solutions to manage demand (Seto and Shepherd, 2009). Large scale water transfers impact the ecology and water quality of both donor and receiver river basins and often lead to displacement of people and disruption of livelihoods in the process (Işlar and Boda, 2014). The distribution of trade-offs connected to IBTs and the unknown long term impacts in the face of climate change remains a governance challenge (Işlar and Boda, 2014; Gupta and van der Zaag, 2008).

This trend is noticeable in the Turkish megacity Istanbul, with its population of over 15 million, concentration of industry, and location in a seasonably water scarce region (He et al., 2021). Istanbul has struggled with water supply since its inception as a city approximately 2000 years ago and faces more recent challenges related to droughts and geographic disparity between the location of the main settlements along the Marmara Sea coast while the majority of water resources are around the periphery or outside of the city boundaries. Istanbul is a relevant case study to examine the challenges facing urban water supply and demand in cities around the world and is relatively under-researched compared to many other megacities (Güvenç, 2023). It is an extreme case given its large and ever-increasing population, importance for the country's economy, and large reliance on water resources far from the city centre. In 2021, IBTs met 57 % of Istanbul's water needs, a number that grew dramatically after the droughts in the mid-1990s and 2000s, and is expected to grow to 70 % by 2040 (Işlar and Boda, 2014; İSKİ, 2021). The city is still developing new water resources, including the next phase of the Melen Project which will increase water taken from the Melen watershed 180 km away from Istanbul (Daloğlu Çetinkaya et al., 2022; İSKİ, 2021). The development of the IBTs from the Kazandere, Pabuçdere, and Istrancalar Streams to the west of the city, as well as the Melen in the east have led to communities in the region losing their homes, farmland, and sources of income, while investments in the regions have been delayed or cancelled in order to prioritize water flow to Istanbul (Işlar and Boda, 2014; İlhan, 2021a).

While many researchers study Istanbul's water security and potential impacts from socio-economic and climate change in the future, there has been little analysis on the water security of the broader region including the provinces that house the water resources that supply water to the city. Socio-hydrology studies argue that there is a need to understand the feedback between water resources and human actions at every scale. This aligns with more current definitions of water security which include socioeconomic and governance aspects in addition to water availability, water quality, ecological considerations, and water-related hazards. Many socio-hydrology researchers recommend supporting water scarcity and hydrology studies with social science theories and case study approaches (Sivapalan et al., 2012; Mostert et al., 2018; Haeffner et al., 2021). Given competing users and uses, governance challenges, spatial and temporal variations, and uncertain impacts of climate change on water security, large-scale water scarcity indices have a limited ability to account for the complex interactions regarding water security (Jaeger et al., 2013).

Therefore this study takes on a socio-hydrological approach to studying Istanbul's water security by using a quantitative water security index and a desktop qualitative document analysis to assess the impact of IBTs to both Istanbul and the water-exporting provinces of Düzce, Tekirdağ, and Kırklareli who are underrepresented in the current literature. The Literature Review provides a background on the concepts, definitions, and approaches in water security studies and introduces IBTs as a supply-side management approach that is studied in this thesis, including a background on Istanbul's water management and previous research on the region. The Study Area section explains the present day water resources and water security challenges facing Istanbul, Düzce, Tekirdağ, and Kırklareli. The Methodology section introduces the water security indices used to study the impact of Istanbul's IBTs and the document analysis approach to identify the key themes examined in researching the region's water security. The indices assess IBT efficiency by comparing the transfer amount to water availability of each province (natural efficiency), as well as the impact to their respective populations, water demand, and water availability (social efficiency, or Stress Relief Index) (Duan et al., 2022). The quantitative analysis is complemented by a document analysis of selected literature that studies Istanbul's water security and governance to identify the impact of IBTs to the receiving and exporting basins using a broader assessment of water security including ecological and socioeconomic impacts, the effect of continuing to increase water supply to Istanbul, as well as the political framing and associated governance challenges that come with the continued reliance on supply-side water management decisions. The Results and Discussion show that, while in some contexts the IBTs to Istanbul do not have a strong negative impact on the water-exporting provinces according to the indices, a deeper qualitative analysis was required to capture all aspects of water security that may be overlooked using a quantitative analysis. The Discussion shows that Istanbul and the region's water security is threatened by IBTs due to the loss of land, homes, and economic opportunities that were damaged to create the IBTs, while Istanbul itself becomes more vulnerable to water scarcity and climate change impacts as IBTs create a false sense of water security that increases in-migration and water demand. The thesis concludes with a section on Future Research recommendations to broaden the research field.

2. LITERATURE REVIEW

2.1. United Nations Sustainable Development Goals

The availability and access to sufficient clean and potable water is a “prerequisite for the health, economic development and social well-being of any society” (van Leeuwen and Sjerps, 2016, p. 2). Water is an integral aspect of the United Nations Sustainable Development Goals (UN SDGs), adopted in 2015, as a “universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity” (UNDP, n.d.). There are 17 SDGs which are integrated to reflect that actions are all interconnected and that sustainable development must incorporate social, economic, and environmental aspects and many of them overlap with ideas of water security (UNDP, n.d.). SDG Goal 6, “Clean water and sanitation”, acknowledges that though water and water sanitation access has improved in the last few decades, drinking water supplies are decreasing across the globe. As more countries experience water stress, achieving SDG 6 requires investments in infrastructure while also protecting and restoring water-related ecosystems, reducing pollution, increasing water-use efficiency across all sectors, implementing integrated water resources management at all governance levels, and increasing participation of local communities in water and sanitation management. In addition to Goal 6, many other SDGs mention the importance of water. Goal 3 “Good health and well-being” has targets to reduce illnesses and death from water pollution and contamination. Goal 11 “Sustainable cities and communities” recognizes that as cities grow, more action is required to reduce the adverse per capita environmental impact of cities due to rapid urbanization, such as to support positive links between urban, peri-urban, and rural areas through strong participatory development planning, and to mitigate impacts of water-related disasters in urban areas. SDG 13 “Climate action” shows the need for countries to adapt to and mitigate the impacts of climate change, particularly natural disasters, including water-related hazards. Goal 15 “Life on land” calls for urgent action to reduce the loss of biodiversity and natural habitats which support global food and water security. Thus we see that water security is important for all aspects of human and environmental life and many goals beyond Goal 6 may be impacted by urban water scarcity.

2.2. Water Security Approaches and Challenges

2.2.1. Conceptualizing Water Security

There has been increasing interest in the concept of water security over the past two decades in both policy and academic discourses (Cook and Bakker, 2012; Pahl-Wostl et al., 2013). Given the complexity of water availability on multiple physical and temporal scales and competing interests of water users, water security itself is difficult to define. This complexity is reflected in the UN SDGs whose varied goals reflect how water security impacts all aspects of life; even SDG 6 for clean water and sanitation has a target goal to protect and restore water-related ecosystems (UNDP, n.d.). In their comprehensive review of the concept of water security, Cook and Bakker (2012) found that the use of the term "water security" in academic literature has increased steadily in the last few decades, with different disciplines focusing on different scales and defining "security" based on their respective goals. For example, development-focused institutions often focus on the national scale, social scientists on the regional level, and water scientists on the watershed level. During the 1990s, water security research focused on specific human interests, such as military and food security, with less interest in environmental security (Cook and Bakker, 2012). In 2000, the Global Water Partnership (GWP), a global action network with the goal of a "water secure world" proposed an integrative definition of water security at the Second World Forum convened by the World Water Council. Their definition included both ecological health and human needs, specifically access and affordability of water (Table 2.1). Following this, Cook and Bakker (2012) note that a variety of academic research and international organizations began using the term. Some used discipline-based definitions while others approached the concept with a broader, integrative focus. In this review, Cook and Bakker's (2012) study found four interrelated themes to water security: "water availability; human vulnerability to hazards; human needs (development-related, with an emphasis on food security); and sustainability" (p. 97). The authors then argue that a more integrative definition of water security that addresses these themes paves the way for good governance to implement water security and manage these multiple stressors (p. 100).

Table 2.1. A review of various water security definitions.

Source	**Definition**
Global Water Partnership (2000, p. 12)	Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced. The term 'water security' aims to capture the complex concept of holistic water management and the balance between resource protection and resource use.
Grey and Sadoff (2007, p. 545)	Water security is "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies."
UNESCO (2009)	To achieve water security, we must protect vulnerable water systems, mitigate the impacts of water-related hazards such as floods and droughts, safeguard access to water functions and services and manage water resources in an integrated and equitable manner.
UN Water (2013)	The working definition of water security is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.
Canadian Water Network (Bakker and Allen, 2015)	Water security is an overarching concept of integrated water management that balances resource protection and resource use. It takes a broad look at all demands placed upon a watershed, including quality, quantity (including climate change and allocation), aquatic ecosystem health, human health, risk and adaptive governance. Water security examines the watershed as a whole and demands a greater priority for water. We define water security as "sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health".

At the most basic level, water security is often equated with human's access to water. The water availability viewpoint of water security is often used by those who work on water security assessment tools, where water supply for human use is prioritized. Water security as availability can be defined at an individual level, where a person has sufficient and affordable water to satisfy their needs (Rijsberman, 2006, as cited in Cook and Bakker, 2012, p. 97), or at a broader scale where water scarcity threatens human societies and sustainable development (UN Water, 2015, as cited in Burak et al., 2021). For example, Australian water policy generally focuses on water availability, prioritizing action on climate change, conserving water use, securing water supplies, and supporting river and wetland health due to the country's arid climate (Cook and Bakker, 2012). Water scarcity is usually defined as the lack of available water to meet human and environmental needs, and is often used as justification for accessing and utilizing more water resources (Faundez et al., 2022; Johnston, 2003). The most often used indicator of water scarcity is the amount of renewable freshwater per person (Daloğlu Çetinkaya et al., 2022). Countries are considered "water rich" or "not water stressed" if the freshwater availability per person is above 1,700 m^3/year, “water scarce” or “water stressed” if the annual water availability is below 500 m^3/year (FAO, 2012, as cited in Daloğlu Çetinkaya et al., 2022; Falkenmark et al., 1989). However, water scarcity also depends on the quality of the water, freshwater availability may be high but resources at a high enough quality for drinking water may be scarce due to pollution from agriculture, industry, urban life, and other sources (Johnston, 2003). Jaeger et al. (2013) proposes to consider water scarcity as the “marginal value of a unit of water” to highlight the variability of water scarcity across spatio-temporal scales, its different values and uses, and the costs associated with its provision, a holistic view that complements the multiple views of water security (p. 4516).

The second theme, human vulnerability to hazards, involves an infrastructure and systems approach to water security. The UNESCO – Institute for Water Education (2009) advocates that to “achieve water security, we must protect vulnerable water systems, mitigate the impacts of water-related hazards such as floods and droughts, safeguard access to water functions and services and manage water resources in an integrated and equitable manner”. The concern surrounding water-related hazards is demonstrated in many governments’ approaches to water security, particularly with regards to ensuring water supplies are maintained and floods are mitigated. The US Environmental Protection Agency expresses their responsibility “to improve the ability of water utilities to prevent, prepare for, and respond to water contamination that threatens public health” as water security[1] and US federal law views drinking water infrastructure security as a “cornerstone of homeland security (Shermer, 2005, p. 359, as cited in Cook and Bakker, 2012, p. 97). China’s water security research also focuses on availability and pollution, predominantly at the urban or regional scale (Cook and Bakker, 2012). Furthermore, early uses of the term of water security explicitly focused on geopolitical security issues in the Middle East and North Africa, where water security is expressed as being critical for stability and sustainable development of the arid region (Cook and Bakker, 2012).

The third theme relates water security to human needs in terms of agricultural production and economic development. Cook and Bakker (2012) cite a definition from the early 1990s: “*[w]ater security is a condition where there is a sufficient quantity of water at a quality necessary, at an affordable price, to meet both the short-term and long-term needs to protect the health, safety, welfare and productive capacity of position (households, communities, neigh-borhoods [sic], or nation)*’’ (Witter and Whiteford, 1999, p. 2, as cited in Cook and Bakker, 2012, p. 97). The Food and

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[1] https://www.epa.gov/emergency-response-research/water-security

Agricultural Organization (FAO) also focused on crop water security where water quantity is crucial to agricultural production (2000). This aligns with Turkey's development-focused water security policy which "comprises a set of strategic objectives, such as increasing agricultural production and ensuring food security, meeting the growing water needs of urban and rural populations as well as industry, phasing out dependence on imported energy sources, eliminating regional, economic and social imbalances within the country and raising the population's living standards" (Kibaroglu, 2022). Similarly to the previous themes, water security is still conceptualized on prioritizing meeting human needs.

Cook and Bakker (2012) identified the fourth theme in water security literature as environmental sustainability and human and ecosystem health as institutions began to acknowledge the role of ecosystem services in water availability. This is included in the widely used definition of water security by the Global Water Partnership (GWP), "*[W]ater security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced*" (2000, p. 12). Cook and Bakker's study revealed that most academic scholars use the GWP's definition or a similar framing which includes "human and ecosystem needs, accessibility, continuity, and affordability" (2012, p. 97). The Canadian Water Network defines water security as "*sustainable access on a watershed basis to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health*" (Bakker and Allen, 2015, p, 1). Grey and Sadoff (2007) define water security as '"*the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies*" (p. 545). These definitions address water availability and human and environmental needs, while also acknowledging the need to mitigate water-related hazards. Under the broad lens of sustainability, water security is then achieved through "balancing water use for human development with protection of vital eco-systems [sic] and the ecological services they provide" (GWP, 2000, p. 12).

2.2.2. Urban Water Security

Although water security impacts all regions and sectors, the concentration of people in cities makes the sustainable supply and governance of clean freshwater an especially important priority for science and policy (Keys et al., 2018). Urbanization is one of the "most significant trends of the 21st century, affecting global development, energy consumption, natural resource use, and human well-being" (McDonald et al., 2014, p. 96). As cities grow, they demand more resources beyond the available supply within the city boundaries, making water security of cities particularly important. By 2030 it is predicted that an additional 1.2 billion people will live in urban areas and, by 2050, 70 % of the world's population will live in cities (McDonald et al., 2020). Fast paced urbanization, in particular, strains municipal resources and unplanned expansion, leading to the loss of agricultural land, wildlife habitat, changes to regional hydrology and climate, and increased emissions (McDonald et al., 2020). As a result, many risks of climate change concentrate in urban areas such as heat stress, extreme precipitation and flooding, air, soil, and water pollution, drought, and water scarcity (IPCC, 2014). Urban industrial and domestic water demand is expected to increase by 50-80 % until 2050 as a result of increased population growth, in-migration, urbanization, and socioeconomic development, while climate change is also expected to impact the temporal and spatial distribution of water availability (He et al., 2021). The Intergovernmental Panel on Climate Change (IPCC, 2014) expects renewable surface and ground water resource quantity and quality to decrease significantly in many regions due to climate change, increasing competition amongst sectors, and impacting food security, ecosystem services, human health and livelihoods. As cities concentrate the water demands of millions of people and competing sectors, freshwater resources near the city become stressed, affecting water security unless new sources can be found or serious governance improvements to conserve water can be made (Sivri et al., 2017). Even if there are available water resources within the city borders, intensive and unplanned urbanization and industrial activities could lead to pollution, also reducing water availability (Johnston, 2003).

Furthermore, cities also concentrate economic and political power, leading to the ability to build urban infrastructure to meet rising demands such as large scale water supply projects (McDonald et al., 2014) creating a false sense of security at the expense of outlying regions that may provide the city with resources. Water security is often prioritized in urban settings over the hinterlands and neighbouring regions as a result of this concentration of economic and political power. Urban water security is a relative concept: water scarcity must be considered not only in the quality and quantity of supply and consequences of demand but also as an aspect of social relations and changes in centres of power over local water resources (Johnston, 2003). "Developing" or "managing" water resources for urban centres leads to centralization and privatization approaches (Johnston, 2003). Once a common resource, water becomes a commodity to meet urban demands and support growth in the national and global economy, of which the city is the centre. Johnston (2003) argues that this centralization of influence and power is accompanied by an increase in distance between those making water resource development, distribution, and management, and those that bear the consequences of these decisions, leading to the potential for local conflicts.

2.2.3. Water Security Indices

While discussion surrounding the concept of water security is a fairly recent development, measuring and quantifying stress, vulnerability, and risks to water resources have been around for much longer (Srinivasan et al., 2017). Indices have been used as policy tools since the 1920s to quantify something which is difficult to measure directly (e.g., the water stress of a household) and to measure changes (e.g., the impacts of economic growth, specific policies etc. on water availability) (Sullivan, 2002). Indices use indicators, qualitative or quantitative variables, to provide a reliable method to measure the results of certain actions (Mason and Calow, 2012). Indices such as the UNDP’s Human Development Index (HDI) have been used for over twenty years to provide a simple, robust method to assess the educational, life expectancy, and income information of municipalities, states, and countries (Chaves and Alipaz, 2007). Similarly to the concept of water security, water security-related indices have evolved over time, with early indices mostly focusing on human needs at the national level. Over time indices were developed to account for ecosystem requirements, risk assessments at the watershed level, and, more recently, the role of governance in achieving water security, mirroring the more holistic approaches to understanding water security over time (Norman et al., 2013; Table 2.2). Assessing water security through indices and indicators support information sharing amongst groups, aid in decision making, allow researchers and governments to analyze trends and fulfil international commitments, while also providing an avenue to measure the progress of water security-related actions (Bakker and Allen, 2015; Norman et al., 2013; Babel and Shine, 2018).

Table 2.2. Examples of water security indicators and indices.

Indicator/ index	**Summary**	**Indicators**	**Scale**
Water Stress Index (FLK) (Falkenmark et al., 1989)	Water stressed countries are defined as: No stress: FLK > 1700 m^3/person/year Stress: FLK < 500 m^3/person/year 500	Annual renewable freshwater available per capita	Country
Water Resources Vulnerability Index (Raskin et al., 1997)	Countries are considered water scarce if the ratio of total annual withdrawals to available water resources is more than 40 %.	The ratio of available water resources to total annual withdrawals	Country
Water scarce countries (Seckler et al., 1999, as cited in Veetil et al., 2022)	Absolute water scarcity: Countries without sufficient water resources Economic water scarcity: Countries that only have capacity to withdraw <25 % of water	Available water resources, current water withdrawals, and the economic capacity to improve infrastructure to increase withdrawals	Country
Water Poverty Index (Sullivan, 2002)	Countries and regions are considered "water poor" when there is not adequate and efficient water supplies.	*Composite index approach:* Water availability, access to safe water, clean sanitation, time taken to access domestic water *Gap method:* ecosystem health, human health, community well-being, economic welfare	Country, region
Water Sustainability Index (WSI) (Chaves and Alipaz, 2007)	Water security is assessed using the HELP framework (hydrologic, environment, life, and policy issues) and a pressure-state-response function to determine cause-effect relationships. Each parameter is given a score between 0 and 1, with 1.0 being optimum.	WSI = (H+E+L+P)/4 *Hydrology:* Per capita water, biochemical oxygen demand *Environment:* Proportion of natural vegetation in basin *Life:* Per capita income, HDI *Policy:* Institutional capacity in IWRM	Basin, sub-basin
Water Security Status Indicators (WSSI) (Norman et al., 2013)	Water security is assessed through the quality and quantity needed for human and aquatic ecosystems health with a focus on local scale assessment and multi-stakeholder participation to define their relevant indicators.	Water quality and quantity for human and aquatic ecosystems health (various water quality standards, supply and demand indicators, baseflow, riparian forest integrity etc.)	Watershed, sub-watershed
Urban Water Security Indicators (Jensen and Wu, 2018)	Urban water security is assessed through quantifiable indicators (water resources, access, and risks) as well as qualitative measurements to asses governance capacity and management.	• Resource availability (surface and groundwater) • Access for human use • Risk (flood, health, etc.) • Capacity (management of supply, demand, and risks)	Administrative boundary of a municipality

Indicator/index	**Summary**	**Indicators**	**Scale**
Water Security Index (Babel and Shinde, 2018)	Water security is assessed through a quantifiable framework to facilitate operationalization of water security (e.g., a water secure basin has no water-related issues and governance and management instruments yield their intended results).	• Sustainable basin exploitation • Economic value of water • Water-related disasters • Watershed health • Water governance (management and adaptability)	Basin
Stress Relief Index (Duan et al., 2022)	Water security is assessed through quantifying the efficiency of IBTs by measuring the impact of water redistribution on the overall water stress levels in the receiving, exporting, and downstream watersheds. The Index is also used to understand how future stressors such as increasing populations, reduced runoff, and increased demands for other water users such as energy production and irrigation will change IBT efficiencies.	• Transfer magnitude as a ratio of freshwater availability in exporting and receiving watersheds over time • Water consumption/demand • Population changes • Ecosystem factors or water scarcity of the watershed is also measured using a weighing factor	Watershed, region

A water security index is generally quantified based on water availability, consumption, population, water usage in different sectors, and environmental requirements (Veettil et al., 2022). One of the first indices was the Falkenmark Water Stress Index which assess water scarcity at the national scale through measuring per capita annual renewable freshwater availability and is still used today as the easiest measure of water scarcity (Falkenmark et al., 1989; Daloğlu Çetinkaya et al., 2022). This index captured hydrological constraints on water supply, however demand was calculated by minimum human needs rather than actual withdrawal levels (Srinivasan et al., 2017). The Water Resources Vulnerability Index was then created to account for total annual withdrawals compared to available water resources (Raskin et al., 1997). However as noted by Srinivasan et al. (2017), these early indices only assessed physical water scarcity and not inadequacies in water infrastructure that may limit access to water across the country or in specific areas. For example, using these indices, Canada with its large amount of freshwater resources, would be considered water secure at the national level, however many regions in the country do not have access to clean water (Cook and Bakker, 2012). To account for the role of infrastructure in improving access to water, the concept of "economic water scarcity" was introduced by the International Water Management Institute (IWMI) which identifies countries which do not have the appropriate infrastructure to access freshwater resources (Seckler et al., 1999, as cited in Veettil et al., 2022). Similarly, the Water Poverty Index (WPI) also aimed to account for infrastructure challenges and is often used by multilateral financing organizations, like the World Bank, to detect regions and countries facing severe water stress (Sullivan, 2002; Chaves and Alipaz, 2007). Results of this index also somewhat correlate with the countries' HDI (Chaves and Alipaz, 2007).

In line with early conceptualizations of water security, the majority of early indices emphasized human needs without accounting for the environment or the long term impacts of increasing water resource development and extraction. As noted earlier, since water is a mobile, common resource, achieving water security in one area may reduce water availability in a different area or scale (Vorosmarty et al., 2010). Early indices do not account for these feedbacks and the emphasis on improving water access can damage water security in the long-run if investments are made in water infrastructure without accounting for ecosystem services and impacts on increased demand, hence the need to also assess sustainable water use for aquatic ecosystem health (Srinivasan et al., 2016). Furthermore, with the focus on surface water, indices may exclude critical aspects of the hydrological cycle which impact water availability such as interactions with the atmosphere, groundwater, and soil moisture (Mason and Calow, 2012). Many indicators rarely integrate ecosystem and human health issues and land use and water management, showing that while indicators may be operationally useful for water management bodies, addressing complex water issues holistically requires a deeper assessment (Norman et al., 2013). The Habitat Conservation Trust Fund (2003, as cited in Chaves and Alipaz, 2007, p. 885) states that watershed indicators should be:

- *Available*: the indicator data shall be available and easily accessible. They shall be collected throughout the watershed, published in a routine basis, and made available to the public.
- *Understandable*: indicators shall be easily understood by a diverse range of nontechnical audiences.
- *Credible*: indicators shall be supported by valid, reliable information, and interpreted in a scientifically defensible manner.
- *Relevant*: indicators shall reflect changes in management and in activities in the watershed. They shall be able to measure changes over time.
- *Integrative*: indicators shall demonstrate connections among the environmental, social and economic aspects of sustainability.

More recent water security indices align with the Habitat Conservation Trust Fund's criteria to move beyond a method for comparison or benchmarking purposes towards providing information that can facilitate operationalization of water security, often using a combination of past indices as one of the many indicators describing water security (Babel and Shinde, 2018). Chaves and Alipaz (2007) developed the Water Sustainability Index based on UNESCO's International Hydrologic Program's "HELP" (hydrology, environment, life and policy issues) framework to encourage integrative and effective actions by different basin stakeholders. This Index applies a pressure-state-response model to the four HELP indicators in a matrix scheme to incorporate cause-effect relationships which help stakeholders and decision makers see interconnections between the various indicators. Norman et al. (2013) created the Water Security Status Indicators (WSSI) assessment method based on the principles of adaptive management and good governance using participatory methods to allow for operation on the local water management community scale. The WSSI allows communities to choose their assessment indicators based on their priorities at the watershed and sub-watershed level using the main framework of water quality and quantity for human and aquatic ecosystems health. With a similar aim to ensure their water security index was tailored to the local level, Jensen and Wu (2018) developed the Urban Water Security Indicators (UWSI) approach. The USWI approach involves undertaking an overview of the urban water sector of the study area, defining urban water security, and developing indicators based on that definition to be populated using official government data, the results of which were then verified through review and stakeholder consultation. Selected indicators included water resource availability, diversity, quality, access to resources, risks, and governance concerns however environmental-related water security concerns were not included. Babel and Shinde's (2018) Water Security Index (WSI) attempts to include all forces that impact water security. Their dimensions are: a) water availability (sustainable basin exploitation); b) water productivity (economic value of water); c) water-related disasters (drought, flood); d) watershed health (water quality, vegetation cover); and, e) water governance (management, adaptability).

Additional indices have been developed for specific contexts, such as Duan et al.'s (2022) natural efficiency and social efficiency (Stress Relief Index, SRI) of inter-basin water transfers (IBTs). Duan et al. (2022) studied the efficiency of 200 IBTs across the USA using their indices which measures the impact of IBTs on the overall water stress level of exporting and receiving watersheds and the watersheds downstream of the transfer. The SRI can be used to measure future stressors such as increasing populations, reduced runoff, and rising demands for water from other sectors such as energy production and irrigation, as well as impacts from climate change under the Representative Concentration Pathways (RCP) 4.5 (intermediate scenario) and 8.5 (worst case scenario) as developed by the IPCC. These two indices are useful because they require less data which can be difficult to access in certain regions, while the results can be used to extrapolate other impacts to environmental or social factors.

2.3. Additional Concepts and Approaches in Hydrology and Water Security Studies

2.3.1. Water Governance and Water Security

This short review shows that approaches to water security are complex and diverse and all components, such as competing users, degradation of water resources and ecosystems, water-related hazards, and uncertainty related to climate change, must be considered. While understanding the different facets of water security is important, addressing these threats and enhancing water security is ultimately a governance challenge and there is a need to translate the often abstract concept of water security into a meaningful tool to guide policy and management practices (Cook and Bakker, 2012; Mason and Calow, 2012; Pahl-Wostl et al., 2013; Harris et al., 2017; Owens et al., 2022). The United Nations Development Programme (UNDP) defines water governance as "*the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use,* *development and management of water resources and the delivery of water service delivery at different levels of society*" (as cited in Pahl-Wostl et al., 2013, p. 677). Proper water governance in achieving water security then becomes a larger issue of maintaining equitable water distribution amongst human, economic, and environmental needs and ensuring just participation in water management decision-making. Good governance requires integration of policy formulation, impact assessments of projects, the strong and equitable water management laws and institutions, across the decision-making process regarding the use of freshwater resources and activities that may impact them (Chaves and Alipaz, 2007). It should include integrative arrangements to support fair and transparent negotiations and follow evidence-based decisions about trade-offs between water users (including ecosystem services) and changing timelines to manage future uncertainties (Cook and Bakker, 2012; Pahl-Wostl et al., 2013).

Over the past few decades, research has shown an increased awareness and interest in looking at water security through all aspects mentioned in this review, moving beyond just water availability and scarcity towards looking at human and environmental health, water-related hazards, economic importance, and governance. These developments have implications for the questions raised by those studying water, like hydrologists, and how best to address challenges related to water security taking into consideration both hydrological data and socio-economic implications and actors (Reddy and Syme, 2014). Water scientists have begun to develop and adopt more interdisciplinary or transdisciplinary approaches to improve water management due to global challenges in water governance such as the impact of climate change, increased intensity and frequency of water-related hazards, rising populations and water consumption, spread of more water-intensive agricultural and industrial development, changes in precipitation patterns, pollution concerns, and equitable access to water issues (Wesselink et al., 2016). Given this complexity, it is helpful to utilize additional key concepts to better understand, and respond to, water security and governance issues.

2.3.2. Integrated Water Resource Management

Integrated Water Resource Management (IWRM) is one method used to more sustainably manage water resources and has been recognized around the world as a framework for establishing good water governance, including in the UN SDGs (UNDP, n.d.). Traditional water management approaches treat water as a productive resource to be secured and controlled; IWRM was developed in order to address additional aspects of water management such as fluctuations in water availability, social and economic inequalities, and loss of biological diversity (Neal et al., 2014). Similarly to water security, IWRM offers a paradigmatic approach to water system analysis that "integrates across scales (from the local to the global) and incorporates both quality and quantity concerns (including hazards and water access)" to reduce negative externalities in traditional water management (Cook and Bakker, 2012, p. 98). The GWP defines IWRM as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems*'' (2000). IWRM also requires integration at multiple government levels and disciplines and entails coordination amongst city planners, engineers, scientists, policy makers, and stakeholders (van Leeuwen and Sjerps, 2016).

IWRM can be used for sustainable development, allocation, and monitoring of water resources and considers social, economic, and environmental needs (Biswas, 2004), addressing the main themes of water security: water availability, human vulnerability, human needs, and sustainability. Cook and Bakker (2012) argue that IWRM and water security are complementary however perhaps no definition can fully encapsulate the complexity of water-related issues and both terms require a balance between broad and narrow framings. Critiques of IWRM included the difficulty of implementation, an over-reliance on regulation, and a focus on the process of "integrated management" rather than the end goal of water security (Cook and Bakker, 2012). Biswas (2008) critically engages with the GWP's definition of IWRM, asking what is exactly meant by equitable, who decides what is equitable, and how will this be determined operationally, all of which lead to governance challenges and opportunities for certain groups to be excluded. Despite these critiques, IWRM still influences governance models in water policy research yet many researchers are unconvinced of its abilities to manage the challenges of proper water management (Biswas, 2008).

2.3.3. Socio-hydrology

In 2012 a set of hydrologists noted that there is a need for hydrological sciences to better understand the human factor effect on hydrology and prevent and resolve conflicts between humans and the environment, and amongst humans themselves (Sivapalan et al., 2012). The researchers defined socio-hydrology as "*the science of people and water, a new science that is aimed at understanding the dynamics and co-evolution of coupled human-water systems*" and relates to the hydro-social concept in that water has inseparable social, political, and physical dimensions (Sivapalan et al., 2012, p. 1271). Socio-hydrology considers humans and their actions as integral to water cycle dynamics and the aim is then to understand and predict human-water system dynamics.

Socio-hydrology at its broadest is the study of dynamic interactions between people and water based on the premise that “societal changes and alterations in water resources evolve in a highly interconnected way” (Carr et al., 2022, p. 831). This information can then be used to support proper water governance and management decision-making.

Socio-hydrology attempts to capture all human-nature interactions and feedback loops quantitatively, often through nonlinear mathematically-based models that are built off of the established field of system dynamics (Wesselink et al., 2016, Carr et al., 2022). Its strength then is in formalizing a conceptual understanding of socio-hydrological relationships and then quantifying its hypothesis. Sivapalan et al. (2012) posit two important questions in socio-hydrology: What drives the human-water system and what are the fluxes and gradients, and can they be related? The authors outline three avenues for socio-hydrology advancement, with the main focus to be on co-evolution of human-water systems and identifying emergent, sometimes unexpected, patterns: Historical socio-hydrology (reconstructing and studying the immediate and distant past); Comparative socio-hydrology (comparing different catchments or human-water interactions across socio-economic, climatic, or other gradients to note spatial differences); and, Process socio-hydrology (studying a system in detail to gain deeper insights into causal relationships). Under these approaches, socio-hydrology follows a more “positivist approach of trying to understand the dynamics of coupled human-water systems, as opposed to the normative approach aimed at solving concrete water management problems” (Pande and Sivapalan, 2017, p. 2).

Following the concept’s emergence, the International Association of Hydrological Sciences (IAHS) selected socio-hydrology as the research theme for 2013-2022, noting the importance of hydrological research to understand and predict interactions between society and water and support sustainable water use given current uncertainties (McMillan et al., 2016). Since 2012, the dominant approach in socio-hydrology has been to develop coupled human-water models, which has been increasing over time (Mostert, 2018). Socio-hydrological approaches have been used to study water shortages related to the reservoir effect in (Di Baldassarre et al., 2018); water transfers in Ceara, Brazil (Frota et al., 2021); stormwater management in Ontario, Canada (Philip, 2021); and, adaptation to drought and effects on the agricultural sector in Alberta, Canada, and transboundary river conflict and cooperation in the Nile Basin (Ghoreishi et al., 2023).

As mentioned, researchers have identified challenges to traditional models, including lack of data and the difficulty of accounting for human decision making and unpredictable behaviour in these models (Xu et al., 2018; Mostert, 2018; Haeffner et al., 2021). Conceptual mathematical models have difficulties accounting for heterogeneous water users and needs, a concern in water justice, equity, and hydrosocial understandings (Wesselink et al., 2016). Capturing human behaviour in a model is difficult due to the "plurality of human values, differing human agency, and path dependency of societal (power) relations" (Wesselink et al., 2016). Existing socio-hydrological models have also not proved to be able to specifically address institutional capacity and governance impacts on water resources through policy and practice nor historical and cultural drivers (Carr et al., 2022). This has led to critiques that socio-hydrological studies' orientation towards sustainable goals such as sustainability may lead to a renewed focus on technocratic and engineering approaches, which was identified as a similar challenge to IWRM (Wesselink et al., 2016). This limitation was acknowledged by Sivapalan et al. (2012) who mentioned that socio-hydrology requires a paradigm shift towards more holistic descriptions and deeper understanding of process interactions.

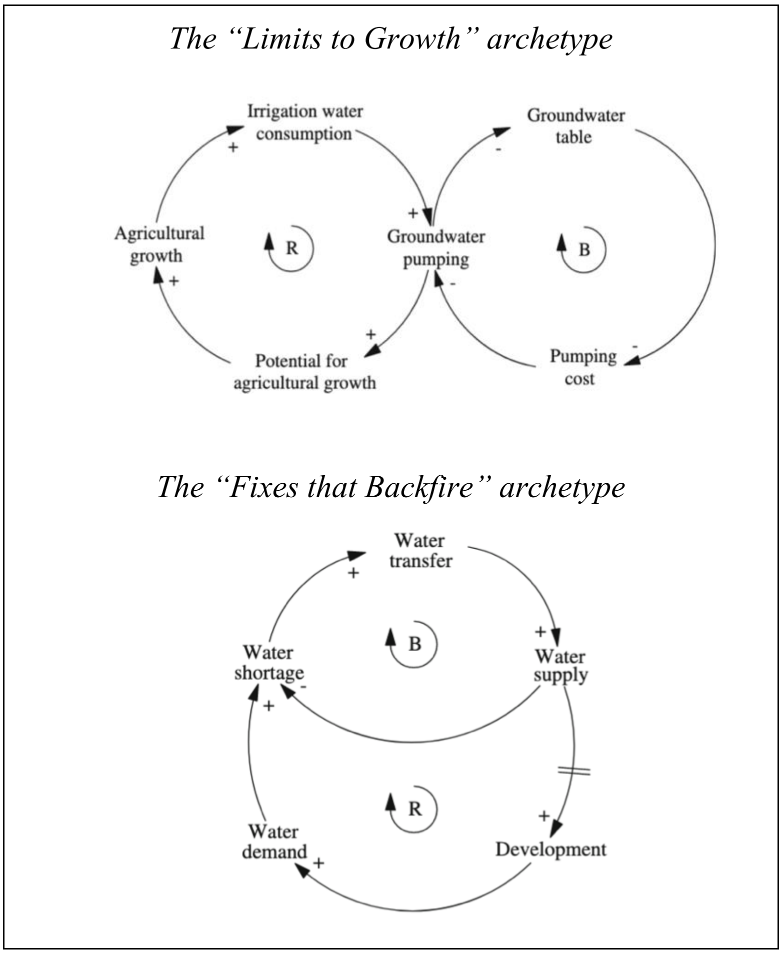
There is a need to include more social science perspectives to fully study human-water systems. Many researchers recommend alternative approaches that do not rely solely on models, such as a historical case study approach (Mostert et al., 2018) and integrating social science theories such as representation justice, feminist political ecology, inequality regimes etc. (Haeffner et al., 2021), into socio-hydrology studies to better understand why certain water decisions are made over space and time and the consequences for hydrological fluxes and flows. Duan et al.'s (2022) Stress Relief Index uses a simple mathematical formula to measure the efficiency of IBTs under different socio-economic and climate change scenarios, looking at the impact on water stress for both the receiving and exporting region as well as those downstream. These approaches align with Sivapalan et al.'s (2012) three avenues for socio-hydrological research advancement and may provide a more encompassing understanding of pressing water governance and security issues.

2.3.4. Quantitative Approaches to Water Security

Given the multi-scalar and multi-disciplinary systems related to water security, effective analyses require the ability to address the bio-physical systems that shape water availability and movement such as climate, topography, land cover, surface water hydrology, soils, water quality, and ecosystems as well as the socio-economic factors that drive water demand and influence how water is stored, allocated, and supplied must also be considered (Yates et al., 2005). In order to assess these dynamics and make predictions based on future factors, many researchers studying water scientists look towards models from a variety of approaches. Hydrological models are a useful tool for assessing future water supply conditions (Avila et al., 2022). These models help in water management decisions, especially in areas with less available data or where the impacts from climate change and land-use change are uncertain.

There are many modelling options to assess water security. The Water Evaluation and Planning Version 21 (WEAP21, n.d.) IWRM model is an easy-to-use, readily available model that integrates water management and watershed hydrology developed by the Stockholm Environment Institute’s U.S. Center (Yates et al., 2005; WEAP21, n.d.). The model takes an integrated approach and can simulate a range of physical hydrological and management processes to calculate water demand, supply, runoff, infiltration, crop requirements, flows, storage, pollution, treatment, discharge and instream water quality under varying hydrologic and policy scenarios (WEAP21, n.d.). Daloğlu Çetinkaya et al. (2022) used WEAP to assess the impacts of climate and socio-economic change to Istanbul’s water supply-demand balance under three different long-term scenarios for water availability for Istanbul from 1986-2100. The Soil and Water Assessment Tool (SWAT) was developed by the US Department of Agriculture to evaluate water resource management strategies and diffuse pollution in river basins (Cüceloğlu et al., 2017). The SWAT method was used by Cüceloğlu et al. (2017) to model Istanbul’s water resources and watersheds to understand the city’s water budget. Researchers also model water security by simulating water supply and demand using a network model that includes precipitation and temperature data, such as the model developed by Burak et al. (2021) to assess future water security in Istanbul.

Recent research in socio-hydrology often relies on system dynamics (Sivapalan et al., 2012; Xu et al., 2018). System dynamics are well suited to supporting water governance challenges and their interactions with other sectors such as agriculture and energy. The use of dynamic simulation models for water management has a long tradition due to the complex nature of water governance (Winz et al., 2009). Water resources, in addition to agricultural land and energy resources, are already exploited and face additional pressures from development, population increases, and climate change thus new tools are required to understand relationships of sectors and the underlying structure which may create current problems (Winz et al., 2009). Mirchi et al. (2012) synthesized available system dynamic tools into archetypes to help conceptualize common water management problems, which can also be applied to other resources such as land and energy (Figure 2.1). These archetypes summarize the standard types of reinforcing and balancing feedback loops that form complex dynamic behaviours which are useful for understanding problematic resource governance behaviour and identifying potential solutions. The “Limits to Growth” archetype shows how groundwater overexploitation for agricultural irrigation may limit future agricultural development. A similar argument can be made for the urban environment where increasing water supply to meet rising demand from rising urbanization and population growth can lead to continued growth, and as a result of overexploitation, may lead to a reduction in water availability from resources. The “Fixes that Backfire” archetype shows that quick-fix solutions without addressing the problem’s root cause can lead to resource overuse and more problems in the future. Supply management is often involved in both archetypes as a way to circumvent potential limits to growth by accessing new resources, which then can become a fix that backfires if all available new sources of water have been exploited but demand continues to increase.



The “Limits to Growth” archetype

The “Fixes that Backfire” archetype

Figure 2.1. Examples of water management system archetypes (Mirchi et al., 2012, pp. 2433-2436).

2.3.5. Qualitative Approaches to Water Security

While socio-hydrology is most often studied through prediction models such as system-dynamics and agent-based models, the first researchers to coin this term, Sivapalan et al. (2012) do not limit the methodologies that can be used to study socio-hydrology and instead recommend a paradigm shift towards more holistic descriptions of systems and their process interactions. Researchers have identified challenges to traditional models, including lack of data and the difficulty of accounting for human decision making and unpredictable behaviour in these models (Reddy and Syme, 2014; Xu et al, 2018; Mostert, 2018; Haeffner et al., 2021). There is a need to include more social science perspectives to fully study human-water systems (Sivapalan et al., 2012). As a result, many researchers recommend alternative approaches that do not rely on models, such as a historical case study approach (Mostert et al., 2018) and integrating social science theories such as representation justice, feminist political ecology, and inequality regimes (Haeffner et al., 2021) into socio-hydrology studies to better understand why certain water decisions are made over space and time and the consequences for hydrological flows. There are opportunities for alternative methodologies to fully study socio-hydrology's focus on observing, understanding, and hypothesizing potential trajectories of the co-evolution and coupled water systems (Sivapalan et al., 2012).

2.3.5.1. Water justice. The varying approaches to water security, indicators, and governance challenges shows that water governance should be conducted within an overall societal and development context, otherwise the main goals of water management such as improved quality of life, poverty reduction, equitable distribution of services, and environmental protection cannot be achieved (Biswas, 2008). While not always central to water security assessments, a justice approach can help understand and mitigate inequalities in water requirements across different uses, users, and physical and temporal and scales (Harris et al., 2017; Owens et al., 2022). The environmental justice movement has risen in the past few decades, first growing as a concept in the fight against environmental racism in the USA where sites of hazardous waste landfill locations often correlated with communities of colour and low-income communities (Agyeman et al., 2016). Environmental injustice is also seen in other examples where construction of uranium mines, nuclear waste sites, military development, nuclear testing, and oil and gas pipelines also are disproportionately close to Indigenous communities in the USA and Canada, Chicano and Latino communities are disproportionately affected by pesticide use, and communities of colour also face disproportionate impacts from climate change. Taylor (2000) argues that the environmental justice paradigm is the first environmental discourse created by people of colour, "framed around concepts like autonomy, self-determination, access to resources, fairness and justice, and civil and human rights", all of which have not been considered in previous mainstream environmental discourses which mainly focused on wilderness and conservation (p. 534). Black, Indigenous, and People of Colour (BIPOC) activists and leaders show that environmental justice is not only a distributional issue with respect to disproportionate environmental impacts, but also an issue of respect and basic recognition of BIPOC communities. Thus environmental justice is also concerned with sustainable and just alternatives to challenge the political, economic, and social injustices and decision-making frameworks that perpetuate this environmental racism (Taylor, 2000). Given that concerns surrounding environmental justice are not limited to North America, the concept has been used around the world in countries such as South Africa, Taiwan, Germany, Brazil, Australia, Nigeria, and Latvia (Walker, 2012).

The environmental concerns assessed through an environmental justice lens are just as diverse; though the concept began through the USA civil rights movement and pollution, it now has been used to examine activities as varied as food and water access, energy, climate, urban planning, gentrification, and displacement, among many others (Agyeman et al., 2016; Harris et al., 2017). Recent environmental justice research shows that the concept has expanded to include age-related differences, rights of Indigenous peoples, differences in power between rural and urban areas, gender differences, participatory concerns of differently abled people, and how current activities will impact future generations (Walker, 2012; Harris et al., 2017). Through this diversity defining the concept of environmental justice becomes more difficult, however given that environmental justice is situational and contextual, a universal definition may not be required and instead perhaps it is more important to focus on the common elements (Walker, 2012). Echoing BIPOC activists and leaders, Schlosberg (2007) called for the theory and practice of justice to expand beyond distributive conceptions of justice as outlined above, but also acknowledge further notions of justice that construct this maldistribution, such as recognition, participation (procedural justice), as well as compensation for groups and individuals. The three main concepts of justice are: *distributive* (the distribution or sharing out of "goods" (resources) and "bads" (harm and risk); *procedural* (how decisions are made, who is involved, who has influence); and *recognition* (who is given respect, who is and is not valued) (Walker, 2012). An additional concept related to environmental justice, climate justice, acknowledges that those who play the least role in causing climate change often bear the brunt of it the most (UNICEF, n.d.). These conceptualizations of justice must be considered together to achieve environmental justice, as Schlosberg notes "the battle for recognition is as large as the one for the fair distribution" (Schlosberg, 2007, p. 21) and continues that there is a need for understandings of justice that moves beyond the individual to be plural, inclusive, and broad.

Given water's importance, particularly for vulnerable and lower-income communities, the notion of "water justice" has also risen in use in the past several decades (Harris et al., 2017). Water is unique given it is fundamental for all biological processes and functions and has no substitution (Neal et al., 2014). Key environmental justice concerns regarding water include unequal water access and quality which varies according to a range of social and spatial gradients for people and the environment (Harris et al., 2017). Examples of unjust impacts related to water include the unequal labour burden of water access at the household level, lack of water access in rural and Indigenous communities compared to larger cities or economic centres, and lack of investments for safe and accessible water supply and higher vulnerability to water-related hazards for lower income, racialized communities compared to wealthier counterparts. Lower-income communities are also more vulnerable to flooding, wastewater pollution, drought, or similar hazards, further exacerbated by climate change (Harris et al., 2017; Walker, 2012). Furthermore, the focus on technical solutions in water management is not only a participation and governance challenge; there is often inequality seen in decision making and impacts related to sanitation infrastructure, large scale damming, development and irrigation infrastructures, and infrastructure at the household level, a clear example of challenges for procedural and recognition-based concepts of justice. Torio et al. (2019) include the concept of cultural justice in their discussion of water equity to recognize that every person has the capacity and right to participate at the same level as everyone else, which may not be recognized by institutionalized ideas of who deserves to participate, similar to the idea of recognition. Cultural justice relating to water then acknowledges that there are non-official water norms and water rights outside the hegemonic organizations and structures that give value to water (Torio et al., 2019). Water injustice is then directly linked to imbalances and inequities in socio-economic status and political power.

2.3.5.2. Hydrosocial studies. As discussed throughout this paper, there is a strong need to understand water and its systems as both social and natural phenomenon (Wesselink et al., 2016). Social scientists have developed the term “hydrosocial” to capture trends in human geography that understand how natural systems relate to the social world. Additional concepts that have emerged from critical human geography include a variety of political ecology focuses (feminist political ecology, urban political ecology, etc.), aligned through its focus on environmental inequalities rather than by common analytical frameworks or theory (Wesselink et al., 2016). Hydro-social research assesses how “power dynamics in social and political processes are fused into the physical and managerial aspects of water governance” (Işlar and Boda, 2014). Additional focuses in hydrosocial research are context-specific and often qualitative social and cultural meanings of water and how these meanings result in different water management decisions. In this perspective, “socio” and “natural” cannot be separated and instead requires a shift from thinking beyond just the impact of human activity on water to understanding the cultural, economic, and political processes that shape the idea of water and thus water is not a neutral, de-localized resource (Wesselink et al., 2016, Boelens et al., 2022). In other words, the hydrological cycle or water management are not neutral scientific concepts but should be studied to understand the consequences of their construction. Hydrosocial research particularly explores how different interest groups and actors understand current territorial arrangements and their imaginaries or visions of how they could be reconfigured (Hommes and Boelens, 2017). Thus hydrosocial territories are conceptualized as "the contested imaginary and socio-environmental materialization of a spatially bound multi-scalar network in which humans, water flows ecological relations, hydraulic infrastructure, financial means, legal-administrative arrangements and cultural institutions and practices are interactively defined, aligned and mobilized through epistemological belief systems, political hierarchies and naturalizing discourses" (Boelens et al., 2016, p. 2, as cited in Hommes and Boelens, 2017, p. 73). Critiques of this approach note that the focus on the wider context and history in case studies may lead to under-emphasizing the importance of the hydrological system and technical interventions while the use of jargon can also be a barrier to other researchers or non-academics (Wesselink et al., 2016).

2.3.5.3. Political ecology. A justice perspective, which aids in understanding local concerns, then can be augmented with a political ecology lens which seeks to assess the multi-scalar and political economic conditions that relate to environmental changes or inequities (Harris et al., 2017). Political ecology emerged as a field of academic scholarship in the 1970s and 1980s to engage with issues of access and control over environmental resources and to understand the processes that lead to land degradation, erosion, water pollution, deforestation, and other environmental problems (Walker, 2012). As Işlar and Boda (2014) argue, political ecology can be used to "uncover the often implicit connections and interactions between political decisions and/or policy choices, their social and cultural context in which they are imbedded, and their direct and indirect effect on the (mis-management) of natural resources" (p. 2). Political ecology asserts that environmental problems are "social in origin and definition, shaped primarily by political and economic forces" (Walker, 2012), aligning with notions of environmental and water justice. Political ecology, hydro-social understandings, and water justice perspectives then can be used to assess water governance from an environmental/ecological, political, and socio-economic perspective, with the hope of identifying potential solutions or insight to prevent similar challenges occurring in the future.

2.4. Addressing Water Security: Supply-side and Demand-side Management

Despite water security's complexity and calls for interdisciplinary and holistic water research and management, many governance bodies, including urban planners, often view water security at its most simplistic, prioritizing water access for human and economic use, particularly in areas where political and economic power is concentrated, such as in urban areas (Işlar and Boda, 2014; Clement et al., 2017). As a result of increasing water demand, drought, climate change impacts, decreasing water quality, and other factors, water management bodies, mainstream solutions increasingly focus on supply management, such as inter-basin water transfers (IBTs), instead of demand management which seeks to optimize the use of existing water supplies, reducing the need to find new resources (Savun-Hekimoğlu et al., 2021). Demand management options include using water-efficient devices, re-using grey-, rain-, and wastewater, voluntarily reducing consumption, and policies such as smart metering, tariff structures for water pricing, and water restrictions (Fielding et al., 2013; Beal et al., 2016; Savun-Hekimoğlu et al., 2021). Most urban governance and management responses to water scarcity still focus on increasing supply, restricted by a "focus on technical solutions, narrow problem framing that neglects complexity, gaps in policy implementation, and lack of vertical and horizontal integration" (Pahl-Wostl et al., 2013, p. 677). This view of water as an engineering or technical challenge to be "solved" can exclude marginalized populations from the governance process, an argument made against IWRM which can consolidate power in top-down groups in water management and therefore obscure aspects of water justice (Clement et al., 2017). Even when decision makers focus on improving water access, water management can still create inequalities particularly if water resources are far from the users.

While supply management may meet water requirements in the short term, there are many long-term impacts to tying growth to unchecked water resource exploitation. Supply management often leads to a false sense of water security, leading to increased demand in the future as population growth and industry demand increases as a result of increased water access (Mirchi et al., 2012). As mentioned earlier, in their analysis of reservoirs and dams across the world, Di Baldassarre et al. (2018) identified two counter-intuitive dynamics that occur with the expansion of supply-side measures to counter droughts and shortages: supply-demand cycles and reservoir effects. Di Baldassarre et al. (2018) found that increasing water supply facilitates urban, industrial, and/or agricultural expansion, leading to increased competition for water resources and as a result, a higher water demand than originally projected from socioeconomic trends alone. The authors argue that this offsets the initial benefits from increased supply. This echoes Mirchi et al.'s (2012) "Fixes that

Backfire" archetype and has been explained as a rebound effect or Jevons paradox in the literature and known in economic studies where, as availability increases, consumption usually increases as well (Di Baldassarre et al., 2018). This rebound effect can potentially produce path dependency and positive feedback loops where, as a result of increased demand caused by increased supplies, new supplies are required to meet this demand. In their study, Di Baldassarre et al. (2018), found that globally water demand has grown faster than storage capacity since the 1960s, therefore negating the initial benefit from increased supply. The second long-term dynamic that the authors identified is the reservoir effect, where the "development of reservoirs reduces the incentive for adaptive actions on other levels (for example, individuals, community), thus increasing the negative impacts of water shortages during severe droughts" (Di Baldassarre et al., 2018, p. 619). The authors hypothesize that increased dependence on reservoirs which can provide long periods of abundant supply in turn increases vulnerability to negative impacts of droughts and water shortages.

2.4.1. Supply-side Water Management

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2.4.1.1. Supply-side management: Inter-basin water transfers. Among the different types of supply-side management solutions, IBTs, the large-scale hydraulic connection of two or more river basins that otherwise would not connect, are the most common large-scale water projects used throughout the world to meet the growing water demand of cities (Gupta and van der Zaag, 2008; Burak et al., 2021). They have been proposed as a solution to water shortages related to drought, climate change, population growth, and environmental constraints (Faundez et al., 2022). Early examples of IBTs include the canal built in 2500 BCE to transfer water from the Tigris to the Euphrates river and the Lingqu canal which connected the Yangtze and Pearl River basins built in 214 CE, though larger scale IBTs can be traced to the industrialization period, reaching their peak in the 1970s and '80s (Rollason et al., 2021). Their benefits include increasing economic activities, guaranteeing water supply in areas of scarcity, supporting ecosystem services of receiving basin, improving the ability to meet demand directly, improve reliability and responsiveness of water systems in the case of water-related hazards such as droughts or floods, improve water quality, overcome the environmental constraints of the receiving basin, and are seen as a more affordable option compared to other water supply solutions such as desalination (Karakaya et al., 2014; Rollason et al., 2021; Faundez et al., 2022). In 2014 there were 155 IBT schemes in 26 countries, moving a volume of 490 km^3 of water per year (Faundez et al., 2022). IBTs are predicted to account for 25 % of global water withdrawals by the year 2025, a large increase from accounting for 14 % of withdrawals in 2005 (International Commission on Irrigation and Drainage, 2005, as cited in Burak et al., 2021). There is an expected increase in the number of IBTs constructed around the world up to the year 2050, mostly within developing countries as a result of increased capacity, driven by arid or monsoonal climate conditions and often rapid industrial development and urbanization (Figure 2.2; Rollason et al., 2021).

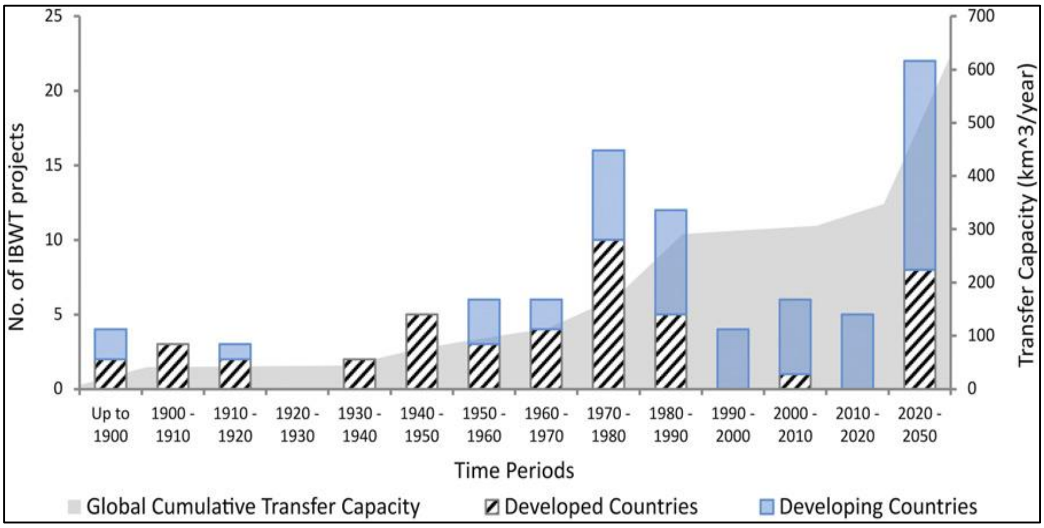

Figure 2.2. Trends in global IBT projects and transfer capacity over time (Rollason et al., 2021, p. 5).

Despite their wide use, IBTs have many trade-offs and uncertain long-term impacts and should be seen as a short-term solution (Burak et al., 2021). IBTs often require the construction of large dams, reservoirs, and sometimes open channels to collect and transport water from donor basins. This infrastructure requires large amounts of land and energy during their development and operation and impact the ecology and water quality of both donor and receiver river basins, often leading to displacement of people and disruption of livelihoods in the process (Işlar and Boda, 2014). Ecological and environmental impacts include changes in downstream morphology, desiccation of wetlands, potential delta retreat leading to seawater incursion of freshwater if sediment flow to deltas is hindered, soil salinization, water logging, landslides, pollution contamination and transfer, destruction of agricultural or forest land for construction, increased emissions during construction and operation, increased energy demand, invasive species insurgence, and changes in aquatic species' distributions, riches, and resilience (Rollason et al., 2021, Faundez et al., 2022). Reservoirs flood organic matter, which releases carbon dioxide (CO2) and methane (CH4) greenhouse gases through diffusion from the surface water, degassing from the water discharge downstream, and the release of CH4 via ebullition from sediments under the water (Soued et al., 2022). Researchers found that in 2020, reservoirs accounted for 5.2 % of CH4 and 0.2 % of CO2 global anthropogenic emissions (Soued et al., 2022). While these reservoirs were created with the goal of increasing water security for recipient regions, studies conducted for the World Commission on Dams (1997-2001) found that 5 % of global freshwater resources is lost through evaporation from reservoirs (Johnston, 2003).

IBTs have also resulted in economic and socio-cultural impacts from the project planning, construction, operation, and maintenance. While Faundez et al. (2022) found that the most cited positive overall impact of IBTs related to economic benefits at the country level, including increased gross domestic product (GDP) in China, Spain, and the US, at the local level the economic, socio-cultural, and environmental impacts were more negative. The study found that many IBTs lead to problems with relocation and compensation policies in the donor basin region, issues with project quality and cost overruns, high pricing of transferred water, and pollution during transfer (Figure 2.3). Additional impacts of IBTs have shown a loss access to water resources both for drinking and economic activities in the donor basin region, loss of livelihoods and reduced economic investments, and lack of participation and involvement in decision making by communities in the donor basin (Işlar and Boda, 2014; Hommes and Boelens, 2017). Such examples include: i) The Central Arizona Project in southwestern USA which led to economic issues since the high water tariffs of the project led to underutilization; ii) The James Bay Project in Quebec, Canada which led to the dispossession of Cree and Inuit communities and mercury contamination from vegetation in the reservoirs led to vast deaths of caribou in the region; iii) India's National River Linking project which resulted in the loss of important habitat, reducing biodiversity; and, iv) the South-North Water Transfer project in China, which, despite large investments, still led to decreased flows in the Hanjiang River from high water extraction and high prices for the transferred water (Faundez et al., 2022).

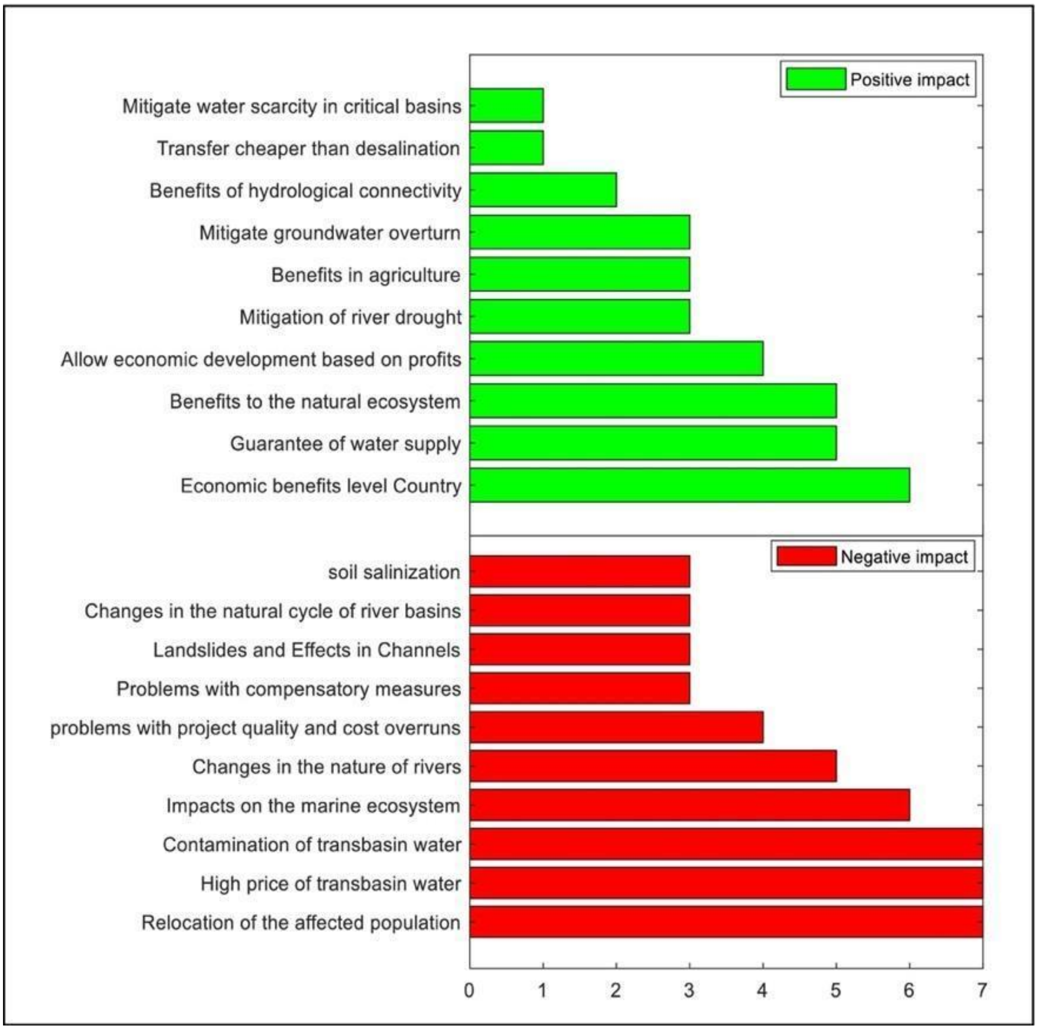

Figure 2.3. Stacked bar graph showing positive and negative impacts of IBTs. The 10 codes for the most found references of positive (green) and negative (red) impacts of IBTs from Faundez et al.'s (2022) systematic review of the sustainability of IBTs across the literature. The horizontal axis corresponds with the number of references (Faundez et al., 2022, p. 8).

While the overall aim of IBTs is to secure water supplies for an area affected by water stress by transferring water from areas with perceived abundance, Rollason et al., (2021) state that this broad claim can mask the underlying justifications used for IBTs. Their analysis of relevant IBT literature, including peer-reviewed research, reports by governments and major international organizations, and government websites, academic theses, and other grey literature websites, found that the most commonly stated driver for IBTs is municipal usage, followed by irrigation. Municipal usage is normally the largest reason for IBTs, which coincides with global increases in urban populations, while intensification of modern farming practices following World War II explains the rise in the development of IBTs for irrigation. The additional drivers for IBTs, hydropower, coincides with global trends in hydropower development, while the less commonly cited reasons for environmental and flood control emerged in the 1980s, most likely during the rise in environmental awareness (Rollason et al., 2021).

As Faundez et al. (2022) discovered in their review of IBT literature, one of the largest positive impacts from these transfers were cited as national economic benefits, which is seen in the high number of IBTs built to supply water to urban centres, also centres of economic activity. Hommes and Boelens (2017) assessed the history and effects of rural-urban water transfers to Lima, showing how specific imaginaries of the city as an abundant "illuminated garden" symbol of progress led to changes in water laws and legislation and development and justification of large scale infrastructure projects. Water transfers to Lima, Peru, from the Mantaro watershed led to inequalities both between the city and rural communities who lost access to water, land, and mostly still do not have access to piped drinking water, as well as inter-urban inequities where the wealthy use drinking water to fill pools and water golf courses while lower income neighbourhoods still have to purchase water from expensive private companies. Similarly, Metropolitan Manila, Philippines, receives its water from a multipurpose reservoir in a different province 58 km away. In times of drought which is common due to El Nino and La Nina, the city has priority over all other uses, leading to loss of irrigation for agricultural uses and less domestic water supply for the residents living in rural areas in the donor basin (Torio et al., 2019). Similar patterns of transferring water from agricultural areas to cities to prioritize urban areas can be seen in the examples of Valencia, Spain, and Arusha and Moshi, Tanzania where the state-based water rights allocation systems prioritized the urban areas at the expense of agricultural water needs (Sanchis-Ibor et al., 2019, Komakech et al., 2012).

In Winnipeg, Canada, rising populations in the "Chicago of the North" at the turn of the 20th century led to the development of an aqueduct to bring water from Shoal Lake, 150 km away, at the expense of the Shoal Lake 40 First Nation community located on a peninsula that was then turned into a man-made island and isolated from land by a channel built to manage water for the aqueduct (Ennis, 2013). Shoal Lake 40 Nation was then only accessible by an ice road during favourable winter conditions or a summer barge until the all season road was built 100 years later in 2019 (Petz, 2021). The construction of the road also allowed for a water treatment facility and system to be built in 2021, bringing reliable drinking water to the community following 24 years of drinking water advisories (Petz, 2021). Similarly, the Owens Valley Paiute/ Shoshone Indigenous community were dispossessed from their land in the Owens Lake area of California, USA, in order to supply the city of Los Angeles, 386 km away, with water (Mendoza, 2019). While the Paiute were able to trade land in the valley to gain some compensation, the promise to negotiate water rights was never fulfilled by the city and the community are still fighting for these rights (Mendoza, 2019).

Pahl-Wostl et al. (2010) note that understanding who makes water system decisions and how they are made is critical for proper water governance. These examples show consistent patterns of the use of supply-side water management developed to favour urban areas; in times of scarcity, the rationale is that allocation should go to uses with the highest returns per unit of water, including human needs, leading to city's gaining priority. All of these case studies show the same pattern of supply-side water management: rising urban populations lead to increased need for drinking water, cities are deemed the highest priority of water usages given their equation with progress and water scarcity, water transfers are then deemed a logical solution to provide water from areas of abundance that are perceived as of less importance, the national government changes laws or administrative arrangements so that the water can be transferred, IBTs are built, and those in donor regions lose access to water and land without perceived proper consultation and compensation. Hommes and Boelens (2017) found that IBTs reconfigured the rural-urban hydrosocial territories in three ways: firstly, IBTs reconfigure ownership arrangements over water and its regulation; secondly, these new arrangements become institutionalized which make it more difficult to critique; and, thirdly, the inherently political and contested nature of water transfers become neutralized by the concept of water scarcity in the city. The authors argue that this pattern of not adequately interrogating ideas of water scarcity and exalting cities as centres leaves little room for further discussion of water rights for all those impacted, participation in decision making, or even exploration of alternative solutions to perceived water scarcity such as demand-side water management solutions. Thus supply-side water management decisions such as IBTs may relieve water shortages in the short term however these "solutions" only postpones the larger management challenge of water supply in large metropolises (Burak et al., 2021).

2.4.2. Demand-side Water Management

Given that supply-side management options such as IBTs come with many drawbacks, many governments and researchers are looking towards options that address current water scarcity while improving water security into the future. One solution is to promote water conservation practices, known as demand-side water management, which promote efficient water use, reduce stress on the environment, and are often already consistent with actions taken by government agencies (Fielding et al., 2013). Demand management options include using water-efficient devices, re-using grey-, rain-and wastewater, voluntarily reducing consumption, and policies such as smart metering, tariff structures for water pricing, and water restrictions (Fielding et al., 2013; Beal et al., 2016; Savun-Hekimoğlu et al., 2021). The IPCC considers demand management a "no-regrets solution to cope with future vulnerability of water supplies in the face of climate change impacts (Bates et al., 2008, as cited in Fielding et al., 2013, p. 344). By reducing demand and conserving water resources locally, urban areas in particular can increase their resiliency against climate change and water-related hazards such as droughts, while reducing the potential negative environmental and socio-economic externalities that make come along with increasing supply, as outlined previously. More details on demand-side water management options are discussed in Section 2.5.3.

2.5. Supply and Demand-side Water Management in Istanbul

2.5.1. Supply-side Management: Inter-basin Water Transfers in Istanbul

Recalling Falkenmark et al.'s (1989) Water Stress Indicator, if per capita renewable water availability is below 1,700 m^3/year, that region is water stressed, if below 1,000m^3 the region is experiencing water scarcity, and below 500 m^3, absolute water scarcity. Using this metric, Turkey is a water stressed country and water per capita is decreasing over time. In 2000, Turkey's water per capita was 1,652 m^3; in 2009 it was 1,544 m^3, and in 2020 it was 1,346m^3 (İSKİ, 2023b). İSKİ predicts that with the projected population increases to 100 million by 2030, water per capita will decrease further to 1,120m^3, almost reaching water scarcity. In the case of Turkey, the majority of the population lives in urban areas after the peak in the urban growth rate in the 1980s (Işlar and Boda, 2014). Similarly to many parts of the world, inter-basin water transfers (IBTs) are the preferred "solution" to provide large Turkish cities with water, though they are also used to supply water for industrial and agricultural activities (Karakaya et al., 2014). Two of the five largest IBTs in Turkey provide water to Istanbul, the Istrancalar and Greater Melen Projects (Table 2.3). Additional water-transfer projects across the country include the Gerede Project, a drinking water transmission line from Bolu to Ankara, 100 km away; the Gordes Dam in Manisa to provide drinking water to Izmir; and, the Blue Tunnel which connects Konya to the Göksu Basin (İlhan, 2021b).

Table 2.3. Some properties of water transfer schemes in Turkey

Project name	**Location**	**Transfer capacity (hm^3/year)**	**Distance (km)**	**Purpose**
Istranca Streams (Istrancalar, Kazandere, and Pabuçdere)	Kırklareli, Tekirdağ, and Istanbul to Istanbul	235.2	~150	Domestic, Industrial
Greater Melen Project	Düzce to Istanbul	575 (as of 2021)	180	Domestic, Industrial
Gordes Dam	Manisa to Izmir	4 (drinking water)	110	Domestic, irrigation
Anamur-Dragon Project	Anamur to Cyprus	75	81	Irrigation, Domestic
Blue Tunnel Project	Göksu River to Konya	414	17	Irrigation, domestic
Gerede Tunnel Project	Bolu to Ankara	226	30	Domestic, Industrial
Kizilirmak Project	Ankara	300	125	Domestic, Industrial
Gembos Project	Lake Beyşehir, Konya	130	4	Irrigation

Istanbul, a city located between the Black and Marmara Seas in the northwest of Turkey and divided by the Bosphorus to stretch over two continents, has long struggled with managing its water supply and demand. Istanbul is Turkey's largest city with an official population of over 15 million as of 2018 and an annual population growth rate of 13.6 % projected between 2017 and 2023 (TUİK, 2018). This is larger than the rest of Turkey, mostly due to rural to urban in-migration, and Istanbul is predicted to reach 21 million residents by 2050 (Cüceloğlu et al., 2017). Given its use of large scale water transfers for over 2,000 years, it is a relevant case study for studying the social and environmental impacts of IBTs and understanding opportunities and challenges in water justice and governance. Istanbul has relied on large scale water transfers since the 2nd century when Emperor Hadrian built aqueducts to bring water from the Belgrade Forest in the northwest to populations concentrated along the south coast (Saatci, 2013). Through the ages, different empires built additional reservoirs and water supply lines to meet the demands of the expanding city. As the first large scale IBT, Emperor Valens (364-378) built a 242 km long transmission line to bring water from the Istranca mountains in Thrace (present-day Tekirdağ and Kırklareli) (Saatci, 2013). These lines were further expanded under the Ottoman rule of Istanbul (1543-1922) and during the early republic period in the 1920s. Water has always had a strong cultural importance in the city, demonstrated by the fact that even during attempts to privatize water in the 19th and early 20th century during rapid population growth, the Ottoman sultans continued to build new free water lines and public fountains (Dinçkal, 2008). At the time, the Ottomans aimed to adopt European knowledge and technology since "urban modernization in the spirit of science and technology became an indicator of a city's progressiveness, a country's political and economic power, and cultural prestige in general" (Dinçkal, 2008, p. 685).

Since the 1990s, Istanbul has faced challenges in meeting increasing demand associated with the population surge in the 1980s further impacted by severe droughts in the early 1990s and mid-2000s and this view of large scale infrastructure projects as progressiveness is represented in the high number of IBTs developed and in development today (Işlar and Boda, 2014; Saatci, 2013). As a result of high population growth and construction-focused neoliberal governmental policies, Istanbul has followed urbanization trends of reduced density and increased urban land use conversion particularly after market liberalization in the 1980s (Cengiz et al., 2019). The city is also host to 40 % of Turkey's industrial activity such as clothing and textile manufacturing (Işlar and Boda, 2014). This puts increased pressure on water, energy, and food resources, while per-capita water use is predicted to increase as lifestyle, income levels, and eating habits change (Cüceloğlu et al., 2017). There is also growing competition over water use between different regions and sectors that will only grow alongside these increases (Işlar and Boda, 2014). These factors contribute to a region that will face climate change-related water scarcity in the future, however the city still relies on supply-side water management and has not focused its efforts to conserve water resources and reduce consumption (Savun-Hekimoğlu, 2021). Due to increasing water demand and droughts, Istanbul built and began operating the Istranca system located in Tekirdağ (1995-97), Kazandere (1997) and Pabuçdere (2000) Dams in Kırklareli, and the Melen Regulators (2007 and 2014) in Düzce (Işlar and Boda, 2014; İSKİ, 2021). In 2021, 57 % of Istanbul's water needs came from these four IBTs, which has steadily increased in the last two decades: in 2017, 33 % of Istanbul's water came from water transfers, and in 2000 after the completion of the Istranca Streams dams, it was only 12 % (İSKİ, 2000-2021). In their assessment of Istanbul's IBTs, Burak et al. (2021) found that continuous urbanization and in-migration increased water demand over the years despite the numerous large scale water transfers built to help meet supply.

2.5.2. Background on Water Governance in Istanbul

In order to better understand the current context for water governance in Istanbul and the surrounding regions, it is important to consider the complex history of water supply in the city. In their letters to the citizens of Istanbul in İSKİ's Annual Reports, İSKİ's General Directors often call upon the history of Istanbul's water supply to justify and legitimize IBTs, for example from the 2014 Annual Report, "[d]ue to the fact that existing resources have always been insufficient, rulers of the city always had to provide water to the city from long distances” (İSKİ, 2014, p. 4). Ward et al. (2020) note that “without its complex and innovative water infrastructure” Istanbul would have only been able to sustain a few thousand people as it did when it was a Greek fishing village two thousand years ago (p. 13).

However, Güvenç (2023) argues that water scarcity in Istanbul is tied greatly to population and water management and should not be considered as a given, echoing previous researchers who argue that drought or water scarcity is often socially produced (Torio et al., 2019; Johnston, 2003). Güvenç (2023) stated that there were no water supply concerns following the founding of the republic in 1923 until the 1950s after which periods of unprecedented population increases, industrialization, and a major cholera epidemic increased demand. This shows that with proper governance and demand-side management, water security can be improved without a single reliance on large scale water supply projects. Ward et al.’s (2020) analysis on historical water supply argue that the water supply technology that allowed for the development of a successful city in the short and medium term is echoed in Istanbul’s current problems; the continual technological innovation used to supply the megacity with water has created a “lock in” and path dependency scenario for continued urbanization and rapidly expanding populations. What makes the city flourish can increase challenges in the future as abundant water availability in turn allows for population growth, increased water consumption, and of course, climate change.

Water has always been an important aspect of cities’ growth. Istanbul, known by many names from Byzantium to Constantinople, served as the capital city for the Roman (330-395), Byzantine (395-1453) and Ottoman (1453-1922) Empires over the course of 16 centuries (Ozis et al., 2020). Prior to becoming Constantinople, the new capital of the Roman Empire in the early 4th century, Byzantium’s local water resources were enough to sustain the population through groundwater wells, rainwater cisterns, and possibly water from the Lycus River (Ward et al., 2020). During the Roman and early Byzantine periods the city was supplied water through long-distance conveyance systems to augment local resources as populations grew, as well as new rainwater cisterns (Saatci, 2013; İSKİ, 2021; Peker, 2023; Ward et al., 2020). The first probable significant water supply infrastructure was created during the Roman era under Hadrian (117-138) in which a conduit transported water from the Belgrade Forest towards the city centre (Ward et al., 2020). The system included the 23 m high and 970 m long Bozdoğan aqueduct-bridge which was also repaired later by Emperor Valens (364-378) and remains a significant symbol of the city (İSKİ, 2021). The first IBT of the city was created by Emperor Constantinus I (337-361) who commissioned a 242 km long water transmission line between the Istranca mountains to Edirnekapı following the shifting of the Roman Empire's capital from Rome to Istanbul in 330, becoming the longest aqueduct in the Roman world (İSKİ, 2015; Ozis et al., 2020; Ward et al., 2020). Later, Emperor Valens (364-378) built further transmission lines to bring water from the Belgrade forest area to the city.

Following the split of the Roman Empire, Istanbul as the capital of the Eastern Roman (Byzantine) Empire, faced numerous political conflicts, wars, and sieges and as a result were not able to build any major investments to the water supply, often relying on cisterns instead of a network system (Peker, 2023). The development of cisterns in tandem with the aqueducts and prior to these sieges also suggest that water demand continued to grow and that the authorities were searching for alternative water supply strategies (Ward et al., 2020). Cisterns have been used as a common water supply technology for thousands of years, however Ward et al. (2020) argue that they reached unprecedented scale and complexity in Constantinople, as they were combined in a network with the aqueduct water supply lines to create a reliable service supply. An account of the chief public works in the 6th century undertaken by Emperor Justinian written by Procopius suggests that the building of the largest covered cistern, known as the Basilica Cistern, with a 80,000 m^3 capacity built near the Aya Sofya in the city centre, was needed to alleviate summer water scarcity and store water during times of abundance (Ward et al., 2020). After the Ottoman conquest of Istanbul, cistern use shifted from urban to rural areas as a result of the Ottoman's centralized water system (Peker, 2023). Early water supply in the Ottoman city consisted of a complex, centuries-old supply system consisting of "aqueducts, dams, mains, water in-take towers, filters, settling basins, and a city-wide distribution network with public fountains" with some parts of the system originating from the Byzantine era (Dinçkal, 2008, p. 679). The Kırkçeşme water system is thought to utilize some parts of the Hadrian Aqueduct (Ward et al., 2020). As populations grew in the 16th century, Mimar Sinan, the famous architect during the Sultan Suleyman reign, was tasked with repairing existing systems and creating new water supply systems to meet growing demand (Sözen et al., 2021). Prior to the Tanzimat reforms, city planners also meticulously managed population numbers and neighbourhoods which also helped reduce water scarcity (Güvenç, 2023).

In 1830 the waterworks were nationalized and assigned to the newly established Ministry of Royal Pious Foundations, which reported to the Council of Ministers (Dinçkal, 2008). This system was not questioned until the 1850s when water supply began to be regarded as insufficient with debate over the merits of developing a new centralized system as a result of rapid population growth, economic challenges, and the need for water to fight fires which were increasing as a result of densification. Further criticisms occurred from comparisons to European cities; “urban modernization in the spirit of science and technology became an indicator of a city’s progressiveness, a country’s political and economic power, and cultural prestige in general” (Dinçkal, 2008, p. 685). The Tanzimat reforms from 1839-76 brought about a number of urban-transformation processes, starting in Istanbul, then the capital of the Ottoman Empire, and spreading to other cities in the empire such as Beirut and Salonica (now Thessaloniki). Dinçkal (2008) states that Istanbul “became the primary arena of experimentation in the state’s movement towards modernization” (p. 676). Following the Tanzimat period, further modernization efforts continued with the development and operation of a private central water supply (Dinçkal, 2008).

In 1881 western European countries, mostly Britain and France, took over public finances of the Ottoman Empire with the purpose to repay debts to foreign investors and used their control to grant concessions to western-owned companies (Hall and Lobina, 2009). The French-owned *Compagnie des Eaux de Constantinople* established central waterworks from Terkos to supply the Beyoğlu and Beşiktaş districts, where many European settlers lived, in 1885, and the *Compagnie des Eaux de Scutari et Kadikeui,* first owned by the Germans and then the French following World War I, supplied the Asian side of the city via the Elmalı waterworks starting in 1893 (Dinçkal, 2008). This led to these districts, particularly Beyoğlu, to symbolize modernism, wealth, and higher social status where the wealthy were prioritized over more equitable water distribution. However, while the central supply was available for those who wanted to pay for it, the European-owned companies were also required by the to provide free water for the public, including public fountains, hospitals, schools, and military facilities in locations specified by the Ministry of Public Works. Dinçkal (2008) argues that

> [a]dopting modern technologies and hygiene standards, the Ministry of Public Works therefore secured (in reference to the system of Ottoman fountains) the enhancement and continued existence of the culturally and socially important public water supply and, with that, guaranteed the supply for the majority of the population, which lived in strained circumstances - much to the regret of the water companies, because they were required to supply this water free of charge (p. 670).

While the companies complained that providing free water led to reduced profits, the municipal administration responded that the companies were not meeting their contractual obligations to provide public water access. The authorities viewed the European companies as inadequate and under Sultan Abdul-Hamid II (1876-1909) a new water main, Hamidiye, was developed to supply free water to institutional buildings, factories, and public fountains, which "intensified competition between fountains and taps” (Dinçkal, 2008, p. 692). This shows that while water was becoming considered an economic good with the development of the European-owned water supply companies, the Ottoman government continued to supply free water based on its cultural and social value.

Following the end of the Ottoman Empire and the formation of the Turkish Republic in 1923, economic and ideological changes at the time led to the desire for the nationalization of the centralized water supply (Dinçkal, 2008). In the 1930s European water supply concessions were terminated and the Istanbul Water Administration (*Istanbul Su İdaresi*, İSİ) was created with supporters believing that municipal control of the water supply would prioritize public welfare rather than profits. The İSİ focused on expanding central waterworks to improve water access across the city, while the municipality also analyzed water quality of the public fountains, finding that many were contaminated, leading to closures of some fountains and water lines. As a result of the closure of many Ottoman-era mains, the İSİ focused on installing domestic supply points for those who could not access the central water supply and in about 1950 the majority of homes had access to the centralized water supply system (Dinçkal, 2008).

As a result of intensive rural to urban migration beginning in the 1980s, there has been rising challenges in water supply and sewerage problems in metropolitan areas across the country, leading to the formation of new organizational models that link water and wastewater systems (Cinar, 2009). The DSİ was established in 1953 to manage drinking water affairs for provinces and towns with a population of less than 3,000, while, under Turkey’s Water Law and Municipality Law, urban water supply and sewage services are the responsibility of the municipality (Cinar, 2009; Harris and Işlar, 2013). Due to increasing rural-urban migration in the 1960s, DSİ’s responsibilities expanded to manage large cities’ financing and restructuring of water infrastructure and services (Harris and Işlar, 2013). During the decentralization period in the 1980s, DSİ’s operational and maintenance responsibilities were gradually transferred back to the municipalities and other bodies (see 1983’s Law No. 2824 for industrial and domestic water supply) (Işlar, 2012; Harris and Işlar, 2013). Domestic and industrial water supply became the role of municipalities, irrigation under Water User Associations (developed previously but expanded under the World Bank 1993 irrigation transfer programme), and irrigation, ground, and spring water supply was increasingly managed by the private sector (Işlar, 2012; Harris and Işlar, 2013). İSKİ was created in 1981 to manage the planning, design, construction, and operation of all water and sewerage services in the city. Following an earlier period of independence from the Istanbul Metropolitan Municipality (İBB), the two were merged in 1984 and İSKİ remains under the İBB although with an independent budget (Cinar, 2009).

At the same time policies were put in place to reduce Istanbul's industrial output (Doğruel and Doğruel, 2018). The first known urban-development plan was created in 1933, the 1966 Development Plan for Regulating Industry (1966 *Sanayi Nazım İmar Planı*), which attempted to organize industrial activities in Istanbul and designated new industrial areas in the East Marmara and Thrace regions. The 1980 Metropolitan Area Development Plan (1980 *Metropolitan Alan Nazım Planı*) then called for deindustrialization of the city, with the main justification being to reduce environmental pollution (Doğruel and Doğruel, 2018). Policies aimed to remove manufacturing facilities from Istanbul's residential areas and then to move them out of the city completely, relocating to regions on either side of Istanbul in Kocaeli and Bursa (east of the city) and Tekirdağ (west) (Acara, 2019). In the 1990s the emergence of economic liberalization and Turkey's bid to join the European Union furthered this push, as Istanbul began to be seen as the centre for Middle Eastern and Eastern European countries for the service, finance, and trade sectors. This occurred in tandem with rising land prices within the city of Istanbul and affordable labour and available natural resources in the hinterland regions accelerated industrial relocation to the Thrace and Marmara regions (Sonmez, 1999, as cited in Acara, 2019).

During the 2000s, financial and real estate sectors were encouraged, replacing manufacturing, coming out of the 2001 economic crisis. Financial institutions, including the headquarters of leading national banks, normally based in Ankara, were advised to relocate to Istanbul. Doğruel and Doğruel (2018) argue that this encouraged construction activities and stimulated the real estate sector. These policies were formally regulated in the early 2010s with the 2010-2013 Istanbul Regional Plan stated its goal to become one of "the top 20 financial centres in the world" (p. 192). The events of the last few decades led to the areas on the periphery of Istanbul to become industrial hotspots, reducing agricultural land and putting further pressure on water resources, while water demand continues to increase in Istanbul from in-migration to the city, land speculation and real estate-based economies, reflected in the fact that both İSKİ and the Istanbul branch of the DSİ (14th Regional Directorate) have mandate over Istanbul, Kırklareli, Tekirdağ, Kocaeli, Sakarya, and Düzce provinces.

2.5.3. Demand-side Management Policies in Istanbul

While the city is continuing to expand its water supplies, in recent years local governments are attempting to put demand-side management policies in place as well to manage water scarcity concerns. Demand-side water management refers to the control of water demand, through improving distribution infrastructure, encouraging responsible water consumption, and reuse management, such as through wastewater and rainwater treatment and reuse (Savun-Hekimoğlu et al., 2021). İSKİ reports its vision as "[t]o be the leading utility of integrated water management in a water-sensitive city" (İSKİ, 2021, p. 19). The "water-sensitive city" approach is a concept for sustainable water resource management, calling for "a city that is a 'watershed for water supply', provides 'ecosystem services' and is home to 'water sensitive communities'" (Burak et al., 2021, p. 14). Planning for a "water sensitive city" requires a whole of government approach, integrating land-use planning and urban water management (Serrao-Neumann et al., 2017, as cited in Burak et al., 2021). İSKİ's mission is "[e]ffective management of the water cycle from source to end user" and has a mandate to protect water resources with "environmentally friendly, public health-oriented, fair, reliable, transparent, participatory, and innovative" values (İSKİ, 2021, p. 19). İSKİ acknowledges the threat to water resources of the city including population growth, urbanization, and climate change and proves its commitment to increased wastewater treatment, reuse, and watershed protection. In addition to the actions listed below, İSKİ runs water conservation campaigns and events for the general public to learn about Istanbul's water and ways to save water[2]. Currently İSKİ is developing the İSKİ Master Plan 2023-2053 to make water, wastewater, and stormwater services environmentally sustainable and beneficial in the long run (İSKİ, 2021).However, as Burak et al. (2021) note, institutional and legal aspects need to be improved to support İSKİ's vision of a "water sensitive city".

Savun-Hekimoğlu et al. (2021) conducted a multi-criteria decision making (MCDM) analysis combined with demand forecasting to model five different water supply alternatives, further validated through discussions with experts and stakeholders from different water-related sectors. The water supply alternatives discussed were increasing IBTs; rainwater capture, storage, and reuse; greywater (water from bathing, sinks, washing machines etc.) reuse; desalination; and, irrigation with reused water. They found that two demand-side management alternatives, reuse of greywater and irrigation with reused, treated water, were most preferred, while the two supply management alternatives, IBTs and desalinisation were the least tenable solutions for the city. Amongst the interviewed experts from academia, public, and private sectors, there is a general consensus for a need to shift towards water demand management instead of increasing reliance on IBTs (Savun-Hekimoğlu et al., 2021). Additional options for demand-side water management are reducing water losses from the system, wastewater reuse, and rainwater harvesting.

Reducing water loss is one of the most significant demand-side management practices since it reduces waste and does not require additional infrastructure to transport or treat water coming from

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[2] https://www.İSKİ.Istanbul/web/en-US/kurumsal/haberler/haberler-detay/saving-water-in-21-ways1

currently used resources. İSKİ has significantly reduced water loss in the distribution network over the last 3 decades. Prior to 1994 water loss ratio was more than 50 % which was reduced to 34 % by 2000 (van Leeuwen and Sjerps, 2016). By 2008 the ratio was improved to about 25 % and currently is around 20 % as of 2021 (İSKİ Annual Reports, 2008-2021). Another action recommended by the IMC (1999) is to reduce water loss from onsite water leakages in tandem with repairing leaks in the system. İSKİ reports that leaky taps could waste as much as 6 m^3 per year and a leaking toilet reservoir could result in a loss of 700 litres of water per day (İSKİ, 2023b). The IMC (1999) recommended that to support uptake by citizens, İSKİ could provide the labour hosts with households only needing to pay for the replacement parts and materials, though current research could not identify if this solution had been implemented.

Given that residential use is the largest share of total water demand in Istanbul, greywater reuse is a viable alternative resource (Savun-Hekimoğlu et al., 2021). İSKİ is continuously developing more wastewater treatment plants and increasing treatment capacity (İSKİ, 2021). Out of the 1,498 million m^3 of treated wastewater for 2021, 62 % underwent primary treatment and 38 % underwent biological and tertiary treatment before being released into the Bosphorus and Sea of Marmara (Burak et al., 2021). As of 2021, there are 89 wastewater treatment plants in the city, 11 of which are advanced biological (tertiary), 70 biological (secondary), and 8 pre-treatment (İSKİ, 2021). Currently treated wastewater is reused to water recreational areas, parks, and gardens of the city (Savun-Hekimoğlu et al., 2021). The amount of reused water also has increased throughout the years; in 2021, about 21 % of treated wastewater was reused, an increase from 17 % in 2013 (İSKİ, 2013-2021). The 1999 IMC report recommended developing dual water systems to increase water reuse, where greywater could be used for flushing, cleaning, municipal irrigation, fire-fighting, and industrial usages, though Savun-Hekimoğlu et al. (2021) note that the high cost for wastewater treatment and infrastructure retrofitting is a high barrier. In the water-exporting provinces, Tekirdağ, Kırklareli, and Düzce are also working to improve wastewater treatment and reuse to reduce pollution. Düzce and İSKİ have worked together to build biological water treatment plants to prevent untreated wastewater from entering the watershed, which has been identified as a major threat to the Melen rivers (İSKİ, 2022b).

Rainwater harvesting (RWH) is a recommended demand-side management option for Istanbul where the annual average precipitation is 690.5 mm (Turkish State Meteorological Service, 2021). Given that the majority of Istanbul's water supplies are surface water fed from precipitation and the long history of the use of rainwater-fed cisterns during the Byzantines, this is considered a viable option (Savun-Hekimoğlu et al., 2021). During periods of recorded drought during the Byzantine period, the response was not to increase abstraction from water resources but instead to construct cisterns to store rain water (Ward et al., 2020). Quantity and quality of a rainwater collection system relates to variables such as precipitation, runoff coefficient, rainfall duration, water catchment area, loss characteristics, as well as roof, piping, and water tank materials and environmental factors which impact potential chemical and microbial contaminant potential (Peker, 2023). Despite its heritage use during the Byzantine and Ottoman era, RWH has not become widespread in Istanbul, though recent policies are aiming to increase rainwater collection and use.

RWH-oriented policies were first mentioned in Turkey's Climate Change Adaptation Strategy and Action Plan (2011) which set targets for improving water management in cities through adaptation to climate change. The Plan recommends separating sewerage and rainwater collection systems in residential areas, however does not go into further details or plans for implementation (Peker, 2023). In 2017, the Ministry of Urbanization, Environment and Climate Change published the Regulation on Rainwater Collection, Storage and Discharge Systems which outlines the principles and procedures of all stages of rainwater collection, storage, and discharge systems (Peker, 2023). This regulation was further supported by the Development Regulation for Planned Areas (2021) amendment which requires new buildings built on land parcels larger than 2000 m^2 to install rainwater collection systems (İlhan, 2021b; Peker, 2023). Local authorities also have the ability to enforce this collection system regulation for smaller new builds at their discretion and municipal governments and many municipalities have adopted these regulations into their own policies and planning strategies (Peker, 2023).

The İBB 2021 Climate Change Action Plan includes the application of sustainable rainwater solutions including rainwater collection, storage, and re-use as one of their Mitigation Priority Action Strategies (İBB, 2021). İBB revised its Regulation on Istanbul's Urban Development to make the construction of cisterns for rainwater compulsory for new residential on parcels over 1,000 m^2 and public buildings, shopping centres, and other commercial buildings with a construction area over 5,000 m^2 (Peker, 2023). The cisterns will collect roof surface water and groundwater to be used for watering gardens, washing cars, and in toilet reservoirs. Under İBB, the production of RWH systems are under the authority of the district municipalities and as such must develop local urban development plans and planning codes/notes (Peker, 2023). Peker (2023) notes that local municipalities play a key role in implementation since development opportunities vary district by district. The District Municipality of Kadıköy recently initiated a new planning note that makes RWH compulsory for new buildings with construction parcels greater than 400 m^2 and greywater use is now compulsory in parcels over 2,000 m^2, meaning that from now on more than half of new constructions in the district will be using grey- and rainwater. In addition, İSKİ is currently working on their Water Master Plan which will include RWH methods under its adaptation policies. However, challenges to RWH adoption include planning and development, legislation and governance, financing, society, infrastructure, installation, and operation (Peker, 2023).

Finally, while not technically considered a demand-side water management solution, water resource protection can improve water quality locally, reducing the need for increased water supply. For the water basins surrounding Istanbul's water resources, İSKİ has developed Potable-Utility Water Basin Protection Plan studies. This includes Conservation Plan and Special Provision Determination studies for the water basins and recommendations to protect the basins, observe the balance between protection and use, and provide sustainable conservation of the basin for drinking water (İSKİ 2018-2020). As of 2021, plans have been developed for the Büyükçekmece Lake Basin, Melen Dam Basin, Elmalı 1-2 Basin, Ömerli Dam Basin, and Alibey Dam Basin and related conservation projects began in 2019 (İSKİ 2018-2021). İSKİ is also working on forestation activities in reservoir basins to improve habitat and water sequestration and has planted over 1 million trees since 2021 (İSKİ, 2016). There are 106 watersheds located within the urbanized area of Istanbul (IMC, 1999). Generally urbanized streams in the city followed the same pattern of degradation where sewage was let into the streams either through direct private connections or through overspill and surface flows from septic tanks, then were later developed into lined drainage canals or culverts to become combined collector sewers. In many instances, these canals or culverts were closed and roads were built above, meaning most of Istanbul's streams are now under roads (IMC, 1999), however İSKİ is working to protect local water resources. In 2021, İSKİ removed 1 million m^3 of sediment from streams to restore reclaimed streams and prevent floods (İSKİ, 2021). Rehabilitating streams is also one of İBB's target action for climate change and while the action is planned to reduce flooding hazards (İBB, 2021), it will also improve water quality of the streams still in existence within Istanbul, reducing pollution and increasing the potential for treatment and use of these sources in the future. İBB is also working on restoring habitat beside streams around the city to create "valleys of life" (*yaşam vadileri)* by planting trees and developing parks around streams and stormwater channels to reduce flooding and increase recreational areas and green space for the city, with the side benefit of reducing runoff into streams and the sea (Yeşil Istanbul, 2021).

2.5.4. Previous Research on Istanbul's Water Security

Due to concerns regarding Istanbul's water security in the context of urbanization and climate change, much research has been conducted on the water security of Istanbul from academic and municipal planning sources. The Istanbul Master Plan Consortium (IMC) is considered one of the most inclusive studies on Istanbul's water resources (Cüceloğlu et al., 2017) and was developed 28 years after the previous major master plan in 1971 (IMC, 1999). The Plan was developed to devise planning strategies to provide adequate water supply, wastewater, and stormwater services in an environmentally and financially sustainable manner until 2023. The Plan includes population and water demand projections, existing and future water supply sources, with water from the Melen River expected to provide roughly 50% of water needs (IMC, 1999). However it was written in 1999 many years before recent population increases and developmental activities and İSKİ is currently working on an update (Cüceloğlu et al., 2017). The Turkish Water Foundation on behalf of İSKİ conducted the "Climate Change Impacts on the Future of the Water Sources for Istanbul and Turkey Project" in 2010 and found that due to the predicted temperature changes between 2015 and 2040, the region is expected to face increasingly frequent and more intense precipitation, drought, and high temperature events (as translated and cited in Sivri et al., 2017). The report recommends measures to mitigate these impacts, including relying more on IBTs as well as water demand management and aquifer restoration. In addition to climate change, drought, and increased consumption threatening Istanbul's water resources, İSKİ's 2020 Annual Report identified additional pressures to water quality from industrialization, construction, and chemical product usage. The report states that to manage these stressors İSKİ must develop and improve existing water supplies while also finding new ground and underground water resources in addition to the Melen project (İSKİ, 2020, 45). In addition to extending capacity to increase withdrawals from the Melen River, İSKİ is planning on adding three additional reservoirs to its network, Karamandere on the European side of the city, and İsaköy and Sungurlu on the Asian side, each within the municipal borders (Daloğlu and Çetinkaya, 2022).

Academic research has also mainly focused on predictive models and assessment tools to understand water supply and demand of the city. van Leeuwen and Sjerps (2015) conducted an IWRM assessment of Istanbul, concluding that though İSKİ has developed adequate water supply currently, projected population increases, urbanization, and climate change will require finding new more sustainable solutions. Cüceloğlu et al. (2017) conducted a Soil and Water Assessment Tool (SWAT) analysis of current and potential water resources for the city. The authors found that 75 % of water potential occurs on the Asian side with the majority of these resources (except for Ömerli) not yet affected by heavy urbanization, therefore careful management of current and new resources could be beneficial in the case of population growth and climate change. In their study, Cüceloğlu et al. (2017) recommend more detailed analyses using different scenarios such as drought, climate, socio-economic, and land-use change scenarios should be conducted to provide more information and valuable knowledge for use by policy-makers, local administrators, and experts. However, a previous SWAT model study of the Melen Watershed concluded that an excessive withdrawal of water from the Melen River may lead to drought and threats to wildlife, in addition to threatening Istanbul's water security that relies on this river (Akiner and Akkoyunlu, 2012). Aktaş' (2014) research on the impact of climate change on Turkey's water resources echoed this sentiment, noting that while the Melen River is expected to face reduced water quantity and quality as a result of increasing river water temperature, the reduction in available surface water is more likely to be produced due to increases in water extraction and land use change.

More recently, as discussed above, Savun-Hekimoğlu et al. (2021) reviewed supply options for Istanbul's future water security, finding demand-side management solutions such as reuse of greywater and irrigation with reclaimed, treated water are the most sustainable options while supply-side options such as increased IBTs and desalination were the least attractive. Sözen et al. (2021) used remote sensing approach to analyze land use/land cover (LUCC) changes surrounding the two main water supply basins, Büyükçekmece and Ömerli between 1994 and 2019, showing a significant increase in artificial surfaces (i.e., buildings and roads) in the protection zone around the basins, leading to degradation of water quality and predicted water supply challenges due to increasing populations if water resources are not protected. Burak et al. (2021) assessed Istanbul's water supply scheme by modelling demand and supply as a network, resulting in predicted water scarcity by 2060. The authors argue that the cycle of increased water supply and subsequent increased demand due to in-migration and urbanization (supply-demand cycles and reservoir effect and coined by Di Baldassarre et al., 2018) means that water shortages cannot be resolved for the city unless it is accompanied by strong management policy measures.

Daloğlu Çetinkaya et al. (2022) assessed the impacts of climate change on water supply and demand in Istanbul using the Water Evaluation and Planning (WEAP) method, finding that increasing reliance on IBTs would not only decrease Istanbul's water security but also may impact the biodiversity and human and economic activities of neighbouring cities. Based on the model, climate change is expected to have a strong impact on Istanbul from 2030 onwards, with water supply resources showing sensitivities to extreme weather events related to climate change such as droughts and reduced precipitation (Daloğlu Çetinkaya et al., 2022). The authors' findings show that increased water demand under these scenarios will exacerbate the reliance on inter-regional water resources. Furthermore the interest in Istanbul's water security has driven research focusing on the city as a whole or specific watersheds. Less research has been made into the water security of both Istanbul and the towns that are located in donor watersheds, as well as the impacts of these inter-basin water transfers on socio-economic conditions outside of the city.

Beyond the more quantitative prediction and forecasting research on water security in the region, a few researchers have also sought to understand the governance and justice discourses of water supply in Istanbul. In their political ecology analysis of IBTs in Turkish water governance Işlar and Boda (2014), found that large-scale water supply projects such as the Melen Project are framed as the only solution to water scarcity concerns based on discourses of large urban centres as the drivers of necessary "modern" economic growth and development. İlhan (2021a and 2021b) also studied the justice aspects of supply-side water management policies in Istanbul, focusing on interviews with those affected in the Istrancalar and Melen watersheds to understand the impacts of IBTs. Işlar and Boda (2014) recommend further research to understand why large-scale supply-side water management projects continue to be promoted in Turkey and elsewhere over alternative demand-side management solutions. This research aims to combine a qualitative water security index with a water justice and political ecology approach to shed light on the region's current water security status and understand this reliance on large-scale water development projects.

This review of Istanbul's water supply demonstrates two important aspects of Istanbul's water security: that growing populations drives water governance and Istanbul's water security is greatly vulnerable to climate-driven hazards that could impact water supply, such as droughts. As a result, water supply and sanitation is of increasing importance to both the citizens of Istanbul and the surrounding regions due to pressures from both climate change and population and demographic change. In particular, İSKİ and decision makers emphasize large-scale, centralized, technical, and supply-oriented solutions which have consequences for the water security of Istanbul as well as the surrounding regions (Işlar and Boda, 2014). The water security of the city and the broader region is facing issues in water availability and quality to meet human and environmental needs, compounded by governance challenges in meeting increased demand and maintaining water access for all, not just those in the megacity. Although there has been media and non-governmental analyses of the impacts of IBTs in Turkey, more research is required to understand the impacts of IBTs to donor basins.

Given the ever-changing nature of climate change impacts to water security and Istanbul’s increasing populations, up to date analyses of Istanbul’s water supply and demand are recommended. Furthermore, few research into Istanbul’s water security has fully accounted for the impact of IBTs to the populations living in the donor basins and the consequences of these water transfers for the region. Thus the overall objectives of this current study are to analyze the impact of the IBTs to Istanbul and the water-exporting provinces of Kırklareli, Tekirdağ, and Düzce using a socio-hydrological approach which incorporates both a quantitative water security index and a qualitative analysis to review additional aspects of water security. This research will use an adapted version of Duan et al.’s (2022) Natural Efficiency and Stress Relief Indices to assess Istanbul and the surrounding region’s water security through measuring the efficiency and impact of IBTs to both the receiving and exporting regions. In accordance with recommendations from the current socio-hydrological field, the index component will be supplemented with qualitative document analysis to gain information on water security and impacts of the IBTs to the environment and socio-economic activities in the region. An in-depth analysis of the history of water governance in Istanbul and the governance structures provides a deeper look at understanding the persistence of supply-side water management in the region.

3. STUDY AREA

3.1. Water Resources and Water Management of Istanbul

3.1.1. Current Water Supply and Demand of Istanbul

Currently more than 99 % of Istanbul's domestic and industrial water demand is supplied from surface water resources in nine different watersheds (Figure 3.1; Güzel et al., 2022). The majority of water is supplied from 11 different sources (Table 3.1, Daloğlu Çetinkaya et al., 2022). Water and sewerage services of Istanbul are carried out by the Istanbul Water and Sewage Administration (*Istanbul Su ve Kanalizasyon İdaresi*, İSKİ), an independent subsidiary of the Istanbul Metropolitan Municipality. The 14th Regional Directorate of the State Hydraulic Works (*Devlet Su İşleri*, DSİ) was established mainly to supply water to the province of Istanbul and currently works with İSKİ on projects related to rivers. Until 1994, Istanbul's water supply resources were entirely within the city's administrative boundaries from the Ömerli, Darlık, Elmalı, Terkos, Alibeyköy, and Büyükçekmece dams, wells, and the Yeşilvadi Regulator. Following droughts and increasing demand during the 1980s-90s population increase, Istanbul's water supply increased from sources both within and outside the city boundaries (Table 3.1). The Istrancalar (1995-97), Kazandere (1997), and Pabuçdere (2000) Reservoirs, located in Tekirdağ and Kırklareli, about 150 km away from Istanbul, and the Melen River (2007 and 2014), located mostly in Düzce, 180 km from the city centre, were developed and included in the city's supply network (Daloğlu Çetinkaya et al., 2022)[3]. İSKİ also developed new internal sources, Sazlıdere Dam (1998) and Yeşilçay Regulator (2004), and increased capacity of the Büyükçekmece, Ömerli, and Terkos dams in 2002 (İSKİ, 2005). Due to the location of Istanbul's water resources, the service area of İSKİ and DSİ extends beyond the municipal borders and includes six provinces: Istanbul, Kırklareli, Tekirdağ, Kocaeli, Sakarya, and Düzce (İSKİ, 2021). In addition to anticipated increased supply from the Melen River, İSKİ plans to add three new reservoirs to its supply network, İsaköy and Sungurlu, on the Anatolian side of the city, and Karamandere, on the European side (Daloğlu Çetinkaya et al., 2022).

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[3] Three of the five Istranca streams are within Istanbul's borders (Kuzuludere, Büyükdere, and Düzdere) however this research considers the five Istranca streams as one IBT system, as recommended by İSKİ and previous research (Daloğlu Çetinkaya et al., 2022; Savun-Hekimoğlu et al., 2021; Burak et al., 2021)

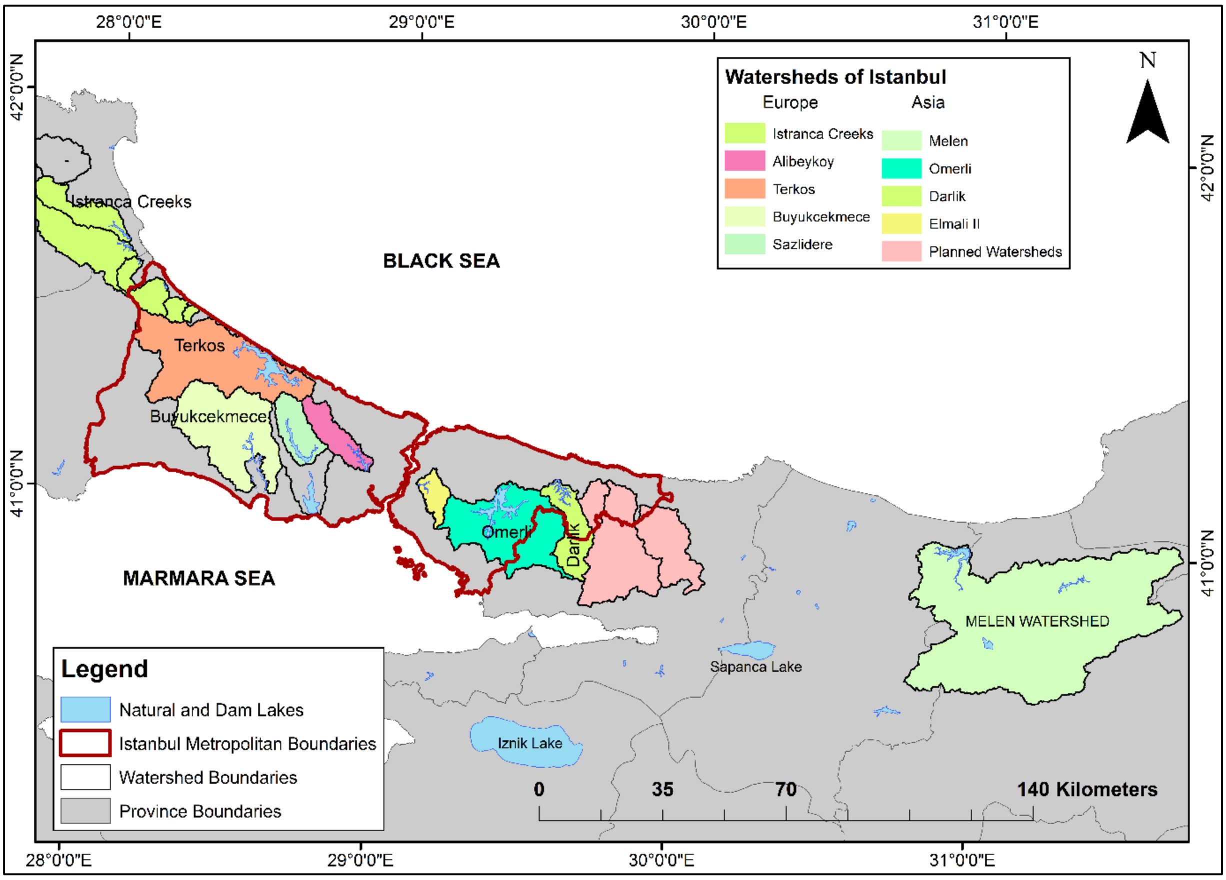

Figure 3.1. Watersheds that supply Istanbul with drinking water (Cüceloğlu et al., 2017, p. 5).

Table 3.1. Drinking water resources of Istanbul, adapted from İSKİ (2021).

Drinking Water Resource	**Location**	**Annual yield capacity (Million m^3)**	**Raw water abstracted in 2021 (Million m^3)**	**Opening Year**
Resources within Istanbul's borders				
Ömerli Dam	Çekmeköy, Istanbul	220	13.5	1972
Darlık Dam	Şile, Istanbul	97	91.2	1989
Elmalı 1 and 2 Dams	Beykoz, Istanbul	15	8.5	1893-1950
Terkos Dam	Arnavutköy, Istanbul	142	86.7	1883
Alibeyköy Dam	Sultangazi, Istanbul	36	31.3	1972
Büyükçekmece Dam	Büyükçekmece, Istanbul	100	55.8	1989
Sazlıdere Dam	Küçükçekmece, Istanbul	55	23.5	1998
Yeşilçay Regulator	Çekmeköy, Istanbul	145	144.5	2004
Yeşilvadi Regulator	Şile, Istanbul	10	5.3	1992
Wells	Multiple locations	30	11.8	Various
Inter-basin water transfers (IBTs)				
Istrancalar (considered as a whole IBT in Tekirdağ)		75	50.3	1995-1997
- Düzdere	Çatalca, Istanbul			
- Kuzuludere	Çatalca, Istanbul			
- Büyükdere	Çatalca, Istanbul			
- Elmalıdere	Tekirdağ			
- Sultanbahçedere	Tekirdağ			
Kazandere Dam	Kırklareli	100	43.1	1997
Pabuçdere Dam	Kırklareli	60	48.6	2000
Melen 1 and 2 Regulators	Düzce	575	480.5	2007 & 2014
Total		**1 Billion 660 Million m^3/ Year**	**1 Billion 94 Million m^3/Year**	

The total water supplied to the city in 2021 was 1,073,990,361 m^3 (İSKİ, 2021). The current capacity of Istanbul's water resources is 1 billion 625 million m^3/year. The resources with the largest capacities are the Ömerli Dam, located on the Asian side of the city (220 million m^3), and the Melen River, located in Düzce (480 million m^3) (İSKİ, 2021). In 2021, the largest sources of raw water were the Melen River (575 million m^3), Yeşilçay System (İsaköy and Sungurlu Regulator) (144 million m^3), Darlık Dam (91 million m^3), and Terkos Dam (86 million m^3). İSKİ distributes water to Istanbul's 39 local municipalities. In 2021, İSKİ served 15,840,900 people with an average daily water demand in the city at 2.942 million m^3 day^{-1} (~1 billion 73 million m^3/year) including domestic water use, industrial consumption, and non-reserve water or water losses (İSKİ, 2022a). In 2021, 32 % of the raw water supplied to Istanbul came from the European side, including the IBTs in Tekirdağ and Kırklareli, with the remaining 68 % coming from the Asian side and the Melen watershed east of Istanbul (İSKİ, 2021). 66 % of available water resources located within the city limits are on the Asian side of the city, while 60 % of the population lives on the European side (İSKİ, 2019; Istanbul Valiliği, 2020). To meet these geographic challenges, İSKİ manages an integrated system, with linked water reservoirs and underwater pipes to bring water under the Bosphorus to meet demand and provide operational flexibility (van Leeuwen and Sjerps, 2016). There are 16 main water treatment plants serving the city which have a combined capacity of 5,808,510 m^3/day (İSKİ, 2021).

3.2. Challenges to Istanbul's Water Security

Currently Istanbul is one of the 23 megacities in the world and is rapidly growing more than almost any other city in Europe (van Leeuwen and Sjerps, 2016). Megacities are defined by having a population of 10 million or more. In 2021 Istanbul had an official population of 15,840,900 (18.71 % of Turkey's population), an increase from the previous year by 378,448 (TUİK, 2021), although unofficial numbers are thought to be higher. The city generates 30.7 % of Turkey's economic activity-related GDP and employs one-fifth of Turkey's industrial workforce (İBB, 2021; İlhan. 2021b). In 2020 Istanbul accounted for 58 % of imports and 49 % of exports of Turkey's total trade (İBB, 2021). The annual population growth rate is projected to be 1.36 % based on projections between 2017 and 2023, larger than the rest of Turkey as a result of rural to urban in-migration (TUİK, 2018). By 2050, Istanbul's population is projected to rise to 21 million (Cüceloğlu et al., 2017). Research shows daily water consumption will increase alongside increasing populations as a result of lifestyle, income level, and eating habit changes (Table 3.2; IMC, 1999). There is also growing competition over water use between different regions and sectors that will only grow alongside these increases (Işlar and Boda, 2014). Despite the protection of the areas around the watersheds, unplanned settlements around water resources as a result of rapid urbanization also threaten the water quality of major water supply watersheds such as Ömerli, Elmalı, Büyükçekmece, and Alibeyköy (Bekiroğlu and Eker, 2010; Saatci, 2013). In addition to increasing population growth, urbanization, and pollution, challenges to Istanbul's water security include climate change, water-related hazards such as droughts and floods, and water losses from leakages within the distribution system (Li et al., 2015; Peker, 2020). Istanbul and the surrounding Marmara Region has a complex climate due its transitional location between the Mediterranean and Black Sea (İBB, 2021). The emerging issues for the Marmara Region include changes in temperature and precipitation patterns, increased drought and flood events, rising sea levels, and challenges related to the urban heat island effect and air quality (İBB, 2018).

Table 3.2. Istanbul's historical and projected population and water demand (Istanbul Valiliği, 2017).

Year	**Population (million)**	**Annual water requirement (hm^3/year)**	**Daily water demand (hm^3/year)**
1990	6.6	426	1.2
1995	8.4	525	1.4
2000	10.3	615	1.7
2007	12.6	714	1.9
2010	13.3	753	2.1
2015	14.8	967	2.7
2020	15.52	1,105	3.2
2030	16.6	1,229	4.0
2040	17.5	1,599	4.7

Globally, urban land-use change is driving habitat fragmentation, biodiversity loss, and appropriation of agricultural land (Seto and Shepherd, 2009; McDonald et al., 2020). In Istanbul between 1980 and 2017, agricultural lands in the city decreased by 27.3 %; residential, business, and industrial land use increased by 183.5 %; mining and construction sites increased by 279.6 %, and water surfaces, to meet increasing demands, increased by 124.3 % (Cengiz et al., 2019). The increase in urbanization and impermeable surfaces amplifies the urban heat island effect when coupled with increasing temperatures, leading to possible heat waves and loss of water resources from increased evaporation from reservoirs and surface water sources (İlhan, 2021b). The combination of droughts and heat waves which often occur together in Istanbul leads to increased water consumption, further impacting the water supply and demand balance (İlhan, 2021b). This is demonstrated by the highest recorded daily water demand for each year reaching 11-15 % more than the average daily demand during the hottest summer days (İSKİ, 2007-2021). The 1999 İSKİ Master Plan Consortium (IMC) reported that total abstractions from the two main water supply sources at the time, Ömerli and

Terkos, “significantly exceeded their safe yields during the period leading up to the 1990 drought” which contributed to severe water shortages during the subsequent drought year (IMC, 1999, p. 3-1).

This is further complicated by Istanbul’s temperate climate with a moderate soil water deficit in summer and strong seasonality in precipitation; when water demand is at its highest in summer, rainfall is at its lowest which creates seasonal water scarcity (Burak et al., 2021; He et al., 2021; ISKI, 2022a). The region’s hydrological cycle begins in October with reservoirs at their lowest early fall following seasonally low precipitation and high water demand during the summer months, meaning reduction in precipitation amounts in the winter could also lead to winter droughts (Burak et al., 2021). An interesting feature of Istanbul is that at least in the period before 2000, drought or low rainfall periods on the European and Asian sides of the city generally do not coincide, for example İSKİ reports that during the 1990-91 severe drought on the European side, the Asian side only experienced slightly below average rainfall (IMC, 1999). Since the late 1980s, Turkey generally has experienced droughts every four to seven years, with the most recent drought event lasting for almost two years (İlhan, 2021b). Droughts occurred in Turkey in 1971–1974, 1983–1984, 1989–1990, 1996–2001, and 2007–2008 (Kurnaz, 2014). Droughts occurred in the Thrace region in 1985, 2000, 2001, 2008 (Bağdatlı and Belliturk, 2016). The İBB reports additional Istanbul-specific droughts in 1994 and 2017 (İBB, 2021). The IPCC (2022) states that drought-related economic losses are high in Istanbul.

Total precipitation is projected to decrease slightly, short-term heavy rainfall events are expected to increase, which could lead to flash floods (İBB, 2018). There have been 1,209 floods between 1975 and 2015 in Turkey (Ekmekcioğlu et al., 2021). As of 2017, floods have cost an average of $100 million (USD) economic losses per year (Ekmekcioğlu et al., 2021). Regions in Turkey’s west and south experience more floods than the rest of the country (Tanir et al., 2022). As the most densely populated city in the country, Istanbul faces severe risks from flooding (Ekmekcioğlu et al., 2021; Tanir et al., 2022). Flood frequency/probability is currently at 1 in 30-50 years, however as the IPCC (2022) noted, floods are expected to increase in intensity and frequency as a result of climate change (İBB, 2021). In 2009, a flood event in the Marmara region led to 31 people losing their lives and serious economic losses, particularly in Istanbul (Ekmekcioğlu et al., 2021). The 2017 flood event led to adverse impacts on water and sewage systems, transportation disruptions, flooded highways and metro stations, and damage to homes, businesses, and vehicles, costing an estimated 200 million TL (İBB, 2021). The 2019 flood event led to floods in highly populated tourism and business areas in Fatih and Beyoğlu, transportation disruptions, and one death and multiple injuries (İBB, 2021).

Runoff and pollution entering water resources as a result of floods in highly urbanized Istanbul then further impacts water security of the city, increasing reliance on water sources outside of the city.

Furthermore, Istanbul is located in the Mediterranean region, an area which the IPCC (2022) Sixth Assessment Report designated as a "climate change hotspot" due to the projected increase in climate change-related hazards, highly vulnerable natural systems, and socioeconomic sectors. The region has experienced declining precipitation levels since 1960 with predicted extreme drought risks due to climate change in the future (IPCC, 2022). The IPCC reports observed increasing water scarcity, flood and storm-induced damages in coastal areas, damages to key economic sectors, and health impacts from heat stress. Availability of reservoirs and water levels in lakes are expected to decline by up to 45 % in 2100 (IPCC, 2022). These effects have already been observed in the eastern Mediterranean for the past 40 years (Williams et al., 2022). Istanbul's water sources are mostly collected in small lakes, ponds, and dams which means that periodic fluctuations in rainfall related to climate change can severely limit water resources (Sözen et al., 2021). Increased temperatures reduces water quality through reducing dissolved oxygen concentrations in surface waters (Aktaş, 2014). Dams and reservoirs themselves contribute to 4 % of anthropogenic carbon emissions worldwide, almost equivalent to the emissions from global aviation which may then exacerbate climate change-related challenges (İlhan, 2021b). Daloğlu Çetinkaya et al.'s (2022) WEAP assessment of the impacts of climate and socio-economic change in Istanbul found that the city will be strongly impacted by climate change 2030 onwards which will challenge Istanbul's water security, particularly after 2040. Burak et al. (2021)'s network modelling of Istanbul's projected water supply and demand found that the city would be faced with water scarcity by 2060.

Water quality and ecological health in the region is further at risk from current mega-projects (the third bridge and new Istanbul Airport) and the proposed Canal Istanbul Project (*KanalIstanbul*). The term "mega-project" refers to large-scale projects which involve high-cost development schemes and land-use transformation (Dogan and Stupar, 2017). Mega-projects signify power and wealth at both the national and international levels, and act as the main strategy for urban transformation (Dogan and Stupar, 2017). Construction of the third bridge and connected motorways, built close to the Black Sea, lead to deforestation. The main route passes through a portion of the Belgrade Conservation Forest on the European side of the city, while the majority of the route (~35 km) goes through the Bosphorus Key Biodiversity Area which includes habitats as varied "as sand dunes along the coastline, rocks, maquis [shrubland] communities, pasture lands, forests and lakes, as well as several vulnerable habitats with rare plant species, identified as Important Plant Areas (IPA)" (Dogan and Stupar, 2017, p. 286). The new Istanbul Airport also threatens ecologically protected and sensitive areas including water resources given its location is in the middle of the Terkos, Sazlıdere, and Alibeyköy watersheds. Deforestation as a result of these projects leads to decreased air quality, heat island effect, exacerbating the impact of rising temperatures and droughts, and makes the area more vulnerable to floods due to the increase in impervious surfaces (Dogan and Stupar, 2017). The construction of the new airport also is expected to lead to an increase in residential and business buildings in the region, increasing the population which puts further strain on water and environmental resources in the area (Ekmekcioglu et al., 2021).

The *KanalIstanbul* project proposes constructing a 40 km-long artificial straight in the west of the city between the Black and Marmara seas to increase vessel capacity and generate revenues from transit tolls which are forbidden on the Bosphorus due to the Montreux Convention (Williams et al., 2022; Remi and Lindenstrauss, 2020). If actualized, the project will invert the hydrological balance between the Black and Marmara Seas, destroy agricultural lands and forests that are important to the ecological resilience of the area, and decrease water availability (Dogan and Stupar, 2017; Governorship of Istanbul, 2019; İBB, 2020; Remi and Lindenstrauss, 2020). Istanbul will lose 2.8 % of its total water supply and the impact of the canal on the total water reserve is around 3 % (Governorship of Istanbul, 2019). Terkos Lake, Istanbul's fourth largest source of water, will have a reduced yield capacity of 2.7 million m^3/year and Sazlıdere Dam will have a reduced yield capacity of 30 million m^3/year, leading to a total reduction of 32.7 million m^3/year of water corresponding to 8% of water demand on the European side of the city (İBB, 2020). According to İBB (2020) studies, the Project will lead to a loss of 60 % of the Sazlıdere Dam catchment basin and damage the south-eastern drainage basin of Terkos Lake leading to a risk of salinization and reducing water availability for the 6 million people that rely on these sources. Groundwater will also be impacted through salt water intrusion and pollution from the canal (İBB, 2020). The Governorship of Istanbul (2019) also maintains that only an additional 500,000 people will be allowed to move to the new "city" to be established on the shores of the new canal, however any increase in Istanbul's population will further impact water supply and associated risks related to land use change and İBB estimates a total of 2 million people will be attracted to the proposed settlements (İBB, 2020). Given that high imbalance between supply and demand in the city and projected population increases, this is an extreme loss not only ecologically but for water security of the region, yet central government messaging sustains that this reduction will be supplemented by the Melen Project and future planned dams (Governorship of Istanbul, 2019). In contrast, İBB states that it will not be possible to provide more water for such an increase in demand when the city is already trying to use water from the Melen watershed (İBB, 2020). The İBB (2020) argues that the creation of the Project will also disperse pollution from the Black Sea and increase temperatures in the region, which further will impact water availability and quality.

Additionally, as in-migration and the tourism sector continue to grow, water demand will increase as well. Residential demand is the biggest driver in water demand for the city. Between 2016 and 2020, Istanbul's water use increased by 7.6 % while the population only increased by 4.4 %, signifying high water use activities such as tourism has a large impact on Istanbul's water security (İlhan, 2022). Tourists can use up to 15-20 times more water than a local person in the area that they are visiting. In 2021, Istanbul hosted 9 million tourists, demonstrating a significant demand (İlhan, 2022). The İBB reports an even higher number with 12.6 million visitors to the city each year (İBB, 2021). This is only expected to increase, with tourism reported as the largest employer in the city and the biggest contributor to Istanbul's GDP (İBB, 2021).

Finally, the water-exporting provinces have all increased their reliance on surface water over the past decade and plan on increasing their water supply from surface water sources in the future (Tekirdağ Valiliği, 2020; Düzce Valiliği, 2020). Düzce also reported goals to increase water usage in the agricultural sector by almost 20 % from 2018 to 2022, with expected increases in the future (Düzce Il Müdürlüğü, 2018). There is a chance that increasing demand from these provinces could challenge the status quo which allocates water sources for Istanbul's use, leading to potential political conflicts as a result of non-inclusive water governance structures (Yazar and York, 2021, as cited in Daloğlu Çetinkaya, 2022).

3.3. Water Resources Outside the City Limits of Istanbul

Due to increasing water demand and droughts, Istanbul built and began operating the Istranca system located in Tekirdağ (1995-97), Kazandere (1997) and Pabuçdere (2000) Dams in Kırklareli, and the Melen Regulators (2007 and 2014) in Düzce (Işlar and Boda, 2014; İSKİ, 2021). In 2021, 57 % of Istanbul's water needs came from four IBTs, (İSKİ, 2021). The share of raw water provided to the city from these IBTs has steadily increased in the last two decades: in 2017, 33 % of Istanbul's water came from water transfers, and in 2000 after the completion of the Istranca streams dams, it was only 12 % (Table 3.3; İSKİ, 2000-2021). In their assessment of Istanbul's IBTs, Burak et al. (2021) found that continuous urbanization and in-migration increased water demand over the years despite the numerous large scale water transfers built to help meet supply. Düzce's provincial boundaries cover the majority of the Melen Watershed, the largest source of water for Istanbul providing the city with 44 % of its water supply. The remaining portions of the Melen Watershed are located in Sakarya, Bolu, and Zonguldak. Tekirdağ and Kırklareli, located to the west of Istanbul, host the water sources of Istrancalar Streams, Kazandere Dam, and Pabuçdere Dam, together providing 12 % of the city's water needs. The capacity of these IBTs are a combined 49 % of the capacity of all of Istanbul's water resources (Burak et al., 2021).

Table 3.3. Annual raw water supply of each IBT supplying Istanbul, the proportion of the IBT to the water supply total, and total water supply for each year (İSKİ, 2000-2020).[4]

Water Source	**2020**		**2017**		**2006**		**2000**	
Raw water transfer	Million m^3/year	Percent of total	Million m^3/year	Percent of total	Million m^3/year	Percent of total	Million m^3/year	Percent of total
Melen	372.3	35	263.3	24	-	-	-	-
Istranca Streams	39.97	3	85.9	8	37.5	5	79.33	12
Total IBT supply	457.93	43	349.2	33	37.5	5	79.33	12
Total raw water supply	**1,074.1**	**100**	**1,018.6**	**100**	**757.8**	**100**	**647.3**	**100**

3.3.1. The Melen Project

The Melen Project is the second largest water transfer scheme after the *Güney Anadolu Project* in Turkey and the first time in Istanbul's history to use water from outside of the Marmara basin (Işlar and Boda, 2014). The Melen Watershed is approximately 180 km east of Istanbul with an area of 2,437 km^2, the majority of which is within the borders of Düzce, with the remaining portions falling under Sakarya, Bolu, and Zonguldak (Ozturk et al., 2013). Of all the watersheds surrounding Istanbul, the Melen Watershed is considered the most feasible and reliable source of water for the city with the highest water potential at 1.5 billion m^3/year and better water quality compared to other sources that were considered, such as water from the Sakarya basin (Cüceloğlu et al., 2017; Savun-Hekimoğlu et al., 2021; Agiralioglu and Danandeh Mehr, 2019). The Melen watershed has different hydrological

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[4] There is no data available prior to 2008 because the Melen Project began operation in 2008.

characteristics than other water supplies to Istanbul and its distant location coupled with meteorological records show the likelihood that the watershed will suffer a lesser drought than Istanbul in the chance of extraordinary droughts in the region (IMC, 1999). Transfers from the Büyük Melen River is considered the “fundamental remedial measure for supplying water to Istanbul in the medium and long term” (Ozturk et al., 2013, p. 1273) and a major solution for drought in Istanbul (Agiralioglu and Danandeh Mehr, 2019). Following Phase II of the project in 2014, Istanbul has received an average of 300 million m^3 of raw water per year from the river, though the number peaked in 2021 at 480 m^3/year, making it the largest source of raw water to the city (İSKİ, 2022).

A severe drought in 1989-90 revealed Istanbul’s vulnerable water supply and studies began to evaluate the feasibility of large-scale IBTs on the basis of potential water, resulting in the idea of bringing water from the Melen River to Istanbul being first proposed in 1990 (Agiralioglu and Danandeh Mehr, 2019). In 1999 the IMC stated that after the completion of the water transfers from the Istranca streams, no significant water resources were left on the European side to satisfy rising demands, and thus decided to focus on the Melen watershed (IMC, 1999). Water from the Büyük Melen system was first proposed by the DSİ as a long term solution for Istanbul’s water supplies, in addition to the Yesilcay project which takes water from the Göksu and Çanak rivers and was developed in 2004. The IMC also noted that since the Melen Project is such a large undertaking there was the high potential for delays, though Phase I of the project was originally planned for 2003 and subsequently was delayed as predicted. An additional severe drought in 2007 led to the project being expedited and the city began receiving drinking water supply from the Melen watershed in 2008 (Işlar and Boda, 2014; Ozturk et al., 2013; Sözen et al., 2021). The project is the largest investment in drinking water infrastructure in the Turkish Republic era (Agiralioglu and Danandeh Mehr, 2019). In 2010 the Mayor of Istanbul, Kadir Topbas, stated that the investments in water supply will ensure enough drinking water for the citizens of Istanbul until 2060 (İSKİ, 2010). However, in 2012, İSKİ reported that water from the Melen Basin will only be able to fulfil Istanbul’s water requirement until 2040, providing a short term solution while İSKİ explores alternative, more sustainable options (Patan, 2012, as cited in van Leuwen and Sjerps, 2016).

The Greater Melen water supply Project is divided into four stages (Table 3.4) with the aim to supply Istanbul with 1.077 billion m^3 of water per year upon completion. In Phase I of the project, approximately 235 km of pipeline was built with the capacity to bring 268 million m^3 of water annually via the Melen I Regulator constructed in 2007 (Işlar and Boda, 2014). After the first regulator was constructed, the Cumhuriyet Water Treatment Plant was built in 2012 to treat 720,000

m^3 of water per day and a second regulator was completed in 2014 to increase water supply (İSKİ, 2021). Following Phase II, the two Melen Regulators' capacity is currently at 575 million m^3 of water per year, making it Istanbul's largest source of water (İSKİ, 2021). Water is transported from the Melen I and II Pumping Stations to the Cumhuriyet Water Treatment Plant near the Ömerli Dam and then transferred to the European side of Istanbul through a tunnel inside the Bosphorus (Sözen et al., 2021). The remaining water from the Melen is transferred to the Ömerli Dam to be treated in either Ömerli or Kâğıthane water treatment plants. Phase III is still under construction and will consist of the Melen Dam, located 160 km east of the Bosphorus on the Büyük Melen River on the border between Düzce and Sakarya, and the 22 km Kâğıthane – Bahçelievler – Sefaköy tunnel under the Bosphorus Strait to distribute water to the European side of Istanbul (IMC, 1999; Işlar and Boda, 2014, İSKİ, 2021). This will be the longest drinking water tunnel in Istanbul (İSKİ, 2021). The Melen Dam is complete yet not operational due to cracks detected in the reservoir body, leading to an ongoing "body strengthening" project (Sözen et al., 2021). Construction of the tunnel is still ongoing as of 2021 with a planned completion date in 2024 (İSKİ, 2021). When the reservoir is completed, the Melen Regulators will have a capacity to provide ~1 billion 77 million m^3 per year in total from the Melen River (İSKİ, 2019).

Table 3.4. Istanbul Greater Melen water supply project[5]

Stage	Capacity (Mm^3/ year)	Average raw water supply 2008-2021 (Mm^3/year)	Water intake/ storage facility	Transmission main capacity (m^3/sec)	Pumping capacity (m^3/sec)	Water treatment plant capacity (m^3/day)
I	268	120	Regulator intake	8.5	8.5	720,000
II	307	140	Cumhuriyet Dam	15	10	800,000
III	307	-		15	10	800,000
IV	307	-		-	10	800,000
Total	**1,077**	**201**		**38.5**	**38.5**	**3,120,000**

3.3.1.1. Water resources and water management of Düzce. The majority of the 2,437 km2 Melen watershed, including the two largest rivers, the Büyük (Big) and Küçük (Little) Melen Rivers, falls under the administrative boundaries in Düzce, with the remaining areas falling into neighbouring provinces of Sakarya, Bolu, and Zonguldak, east of Istanbul (Ozturk et al., 2013). Düzce has a population of 400,976 with more than half of the population living in the Düzce city centre (TUİK,

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[5] There is less data available for Phases III and IV of the Project because they are currently under construction.

2020). The province has industrial zones and agricultural areas and produces mostly hazelnuts, maize, wheat, vegetables, fruits, and livestock feed such as silage maize, vetch, and paddy rice (Düzce Valiliği, 2015 and 2020).

Drinking and wastewater systems in Düzce are managed by the Water and Sewerage Directorate under the Düzce Municipality. Düzce is also under the 5th Regional Directorate of the DSİ which also includes Çankırı, Bolu, Çorum, and Kırıkkale provinces. The DSİ's role is to utilize all of the country's water resources (DSİ, 2022) and some DSİ directorates manage or co-manage irrigation facilities, flood control operations, drinking water facilities, and hydroelectric activities (DSİ 5. Bölge Müdürlüğü, n.d.). Düzce utilizes both surface and groundwater resources (Table 3.5; Figure 3.2). The province utilized mostly groundwater resources for drinking water until 1994 when water began to be taken from the Uğur Stream (Düzce Valiliği, 2016, p. 24). In 2020, 20 million m^3/year of water was abstracted for municipal use (TUİK, 2023). The province has a reported total water potential of 1,731 million m^3/year (Düzce Valiliği, 2020). As of 2014 the majority of drinking water comes from the Uğur Stream except during the summer during periods of drought, when the province also relies on well water (Düzce Valiliği, 2014-2021). In 2020 the Uğur Stream Regulator provided 12 million m^3/year of drinking water (Düzce Valiliği, 2020). The Akçakoca Dam also provides water to those living in Akçakoca, north of the province, and the Gumusova district also relies on water from three creeks that are tributaries of the Büyük Melen river. The Hasanlar Dam was built to provide irrigation for agriculture, energy, and flood control with side benefits from drinking water, tourism and water sports (Düzce Valiliği, 2016). The dam was built on the Büyük Melen River in 1992. The Dam's capacity has a 6.1 % drinking water potential and generates 40 Gwh per year and has an installed power of 9.4 Mw. There are a number of ponds and wells used for agricultural irrigation.

Table 3.5. Main drinking water resources in Düzce (Düzce Valiliği, 2020). Data is not available for every water resource, indicated by the hyphen.

Water resource	**Purpose**	**Operating year**	**Total storage capacity (hm^3)**	**Irrigation [gross] (hectares)**
Uğur Stream Regulator	Drinking	1994	-	-
Akçakoca Sarıyayla (Nazmi Çiloğlu) Dam	Drinking	2016	1.86	-
Wells	Drinking	-	-	-
Hasanlar Dam	Irrigation, hydroelectric, flood control	1992	55	11,000

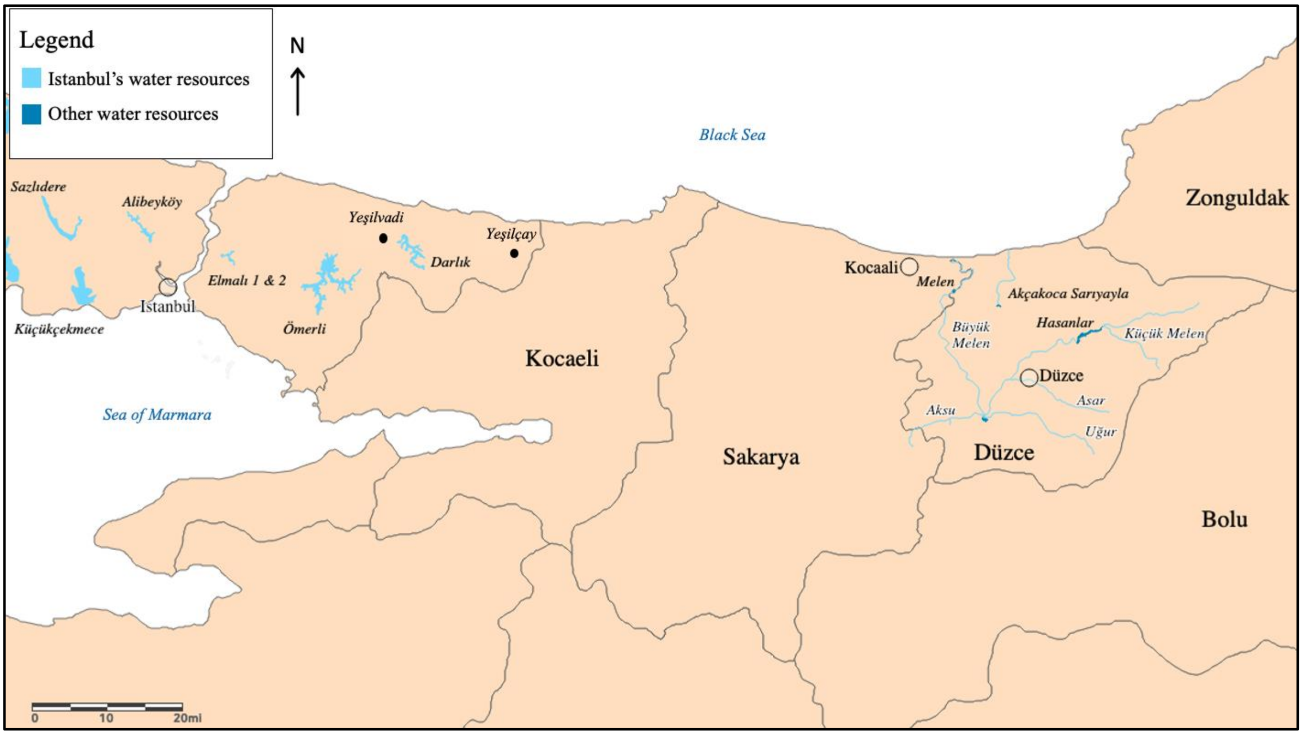

Figure 3.2. The water resources of Düzce and eastern Istanbul, including the Melen Dam which is under construction to supply Istanbul.

The Düzce Government predicts that the province will require 44.91 hm^3 of drinking water in 2045, more than double current supply rates. The Uğur Stream Regulator will be expanded to provide 32.73 hm^3/year and Hasanlar Dam to provide 12.18 hm^3/year (Düzce Valiliği, 2020, p. 47). Water from the Bicki Stream will also be brought to the Düzce Municipality via the Uğur Stream system which will provide an additional 9.3 hm^3/year and new wells will be opened to provide 1.9 hm^3/year. DSİ is also working on developing the Fındıklı Creek and Gucru Asar Stream for drinking water use.

3.3.2. Istranca Streams (Istrancalar, Kazandere, and Pabuçdere)

In addition to the Melen River which is the highest current and future supplier of water to Istanbul, the city also relies on three other sources from outside of the municipal boundaries located in the Yıldız (previously named Istranca) mountain region in Turkey's northwest Thracian region: the Istrancalar, Kazandere, and Pabuçdere streams (Karakaya et al., 2014). These water from these streams are the first modern IBT built to meet the water needs of Istanbul, which were increasing as mentioned as a result of rising populations during the 1980s and '90s and droughts in the early 1990s, although water from the Istranca region had previously supplied the city under Emperor Constantinus

I during the Roman period in the fourth century AD (İSKİ, 2021; Karakaya et al., 2014; Ozis et al., 2020). The idea to use the Istranca Streams was first developed in 1965, a Master Plan was written in 1988, and the project started in 1990 (İSKİ, 1994). DSİ first carried out investigations into the feasibility of the Istranca Streams and installed gauging stations to calculate flow (IMC, 1999). At the time, the project was originally planned to use the water partially for Istanbul, and partially for local irrigation and agricultural use though later the water was only available for Istanbul. Following DSİ's investigations, İSKİ commissioned studies on the Istranca Streams and Terkos Lake, developed the Istranca Master Plan in 1988, and began the project in 1990 (IMC, 1999; Table 3.6).

Table 3.6. The Istranca System 1 and 2 (IMC, 1999; İSKİ, 2021).

Project stage	**Stream source**	**Year completed**	**Capacity (hm^3/year)**
Istranca 1	Düzdere	1995	4.5
	Kuzuludere	1995	11.3
	Büyükdere	1995	28.4
Istranca 2	Elmalı	1997	11.6
	Sultanbahçe	1997	19.4
	Kazandere	1997	100
	Pabuçdere	2000	60

İSKİ manages five separate streams and their respective dams as one system, called the Istrancalar or Istranca Regulators located in Tekirdağ and northwest Istanbul: Düzdere, Kuzuludere, Büyükdere, Sultanbahçedere, and Elmalıdere (Figure 3.3). The Kazandere and Pabuçdere streams also have their own dams, located in Kıyıkoy, northern Kırklareli, and are connected by a 2.5 km long tunnel so that excess water from Kazandere can be transferred to the reserve volume in Pabuçdere (İSKİ, 2021; İSKİ, n.d.). The Istranca Streams transmission system runs parallel to the Black Sea coast in order to intercept the flows from the creeks (IMC, 1999). The first phase of the project included the development of three dams on three Istranca streams located in Istanbul (Düzdere, Kuzuludere, and Büyükdere (previously Cilingozdere) and water from these streams began to supply the city in 1995 and 1996 (İSKİ, 2021; IMC, 1999). The second phase included the Sultanbahçedere and Elmalıdere dams located in Tekirdağ (operating since 1997), completing the Istranca System project, and two new dams (operating as regulators) in Kırklareli: Kazandere (1997) and Pabuçdere (2000) Dams. The Istrancalar have a combined total annual capacity of 75 million m^3 (İSKİ, 2021). The Kazandere Dam has a capacity of 100 million m^3/year and the Pabuçdere Dam has a capacity of 60 m^3/year (İSKİ, 2021). From 2000 to 2021, the Istranca streams provided an average of 86 m^3/year of raw water to the city (İSKİ, 2000-2021). Phases 3 and 4 included building dams on additional streams in the region, however the development never began and İSKİ does not have any plans to continue based on available information.

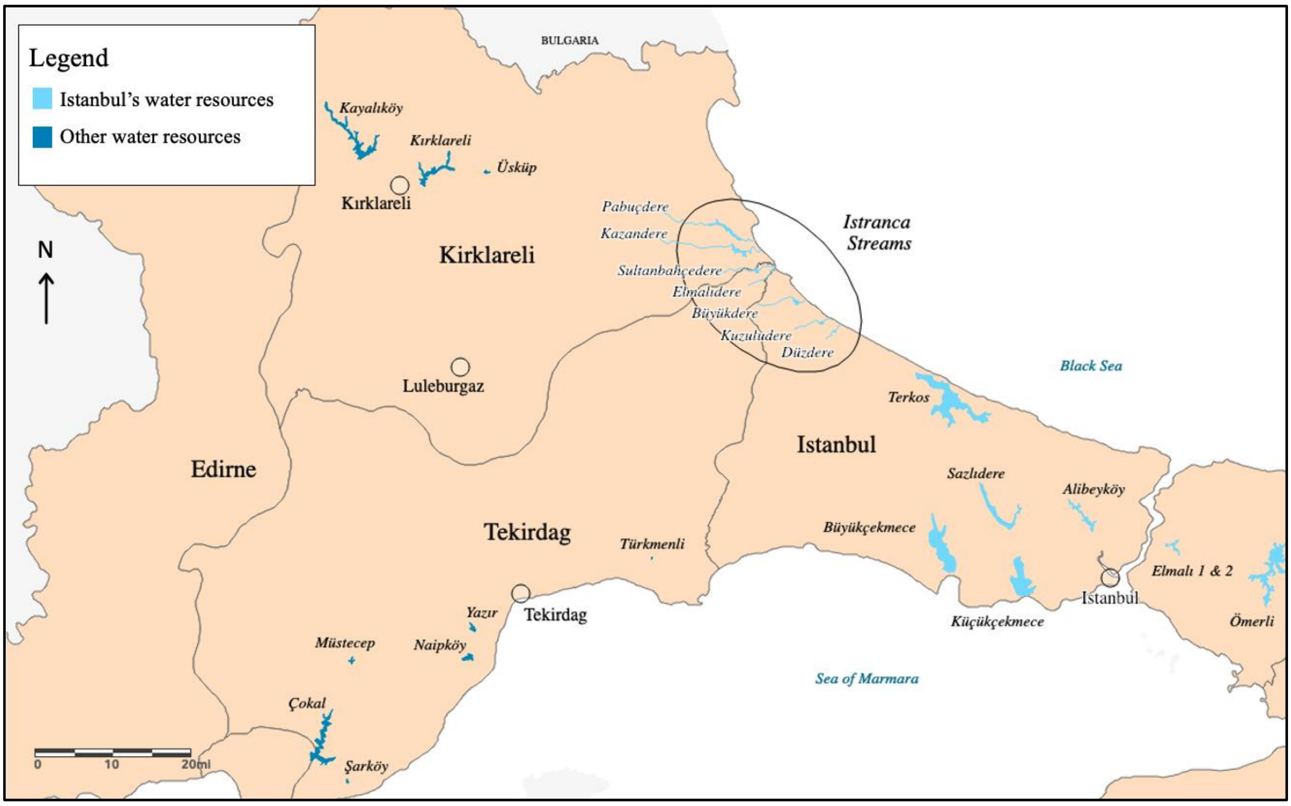

Figure 3.3. The water resources of Tekirdağ, Kırklareli, and western Istanbul.

<u>*3.3.2.1. Water resources and water management of Tekirdağ.*</u> Tekirdağ has a population of 1,113,400 with the most populous municipalities being Çorlu, Süleymanpaşa, Çerkezköy, and Kapaklı (TUİK, 2021). The Tekirdağ Water and Sewerage Administration (*Tekirdağ Su ve Kanalizasyon İdaresi*, TESKİ) manages the water and sewerage services for the entire province. The province is under the 11th Regional Directorate of the DSİ alongside Edirne and Kırklareli. In 2020, the total municipal water supplied to the province was 80,148,000 m^3 (TUİK, 2023). In 2021, 83 % of drinking and utility water came from groundwater sources, with the remaining coming from dams, lakes, and springs (Tekirdağ Valiliği, 2021). TESKİ operates 10 drinking water treatment plants with a capacity of 60,843 m^3/day and 19 wastewater treatment plants with a flow rate of 246,530 m^3/day (TESKİ, 2021). As of 2018, the province's total water potential is 885.9 million m3 per year (172 million m^3/year of groundwater and 713 million m^3/year of surface water potential) (Tekirdağ Valiliği, 2018).

The majority of surface drinking water comes from the Çokal Dam, southwest of the province on the border with Çanakkale (Figure 3.3; Table 3.7).

Table 3.7. Main drinking water resources in Tekirdağ (TESKİ, 2021, p. 143; Tekirdağ Valiliği, 2021). Data is not available for every water resource, indicated by the hyphen.

Water resources	**Purpose**	**Opening year**	**Total storage capacity (million m^3)**
Groundwater sources	Drinking, irrigation, industry	n/a	-
Şarköy Reservoir	Drinking	1981	1.2
Naipköy Reservoir	Drinking	2018	21.62
Çokal Dam	Drinking, irrigation, flood control	2016	204 (total volume) [16.8 for drinking water]
Türkmenli Reservoir	Drinking, irrigation	1994	15.29
Yazır Reservoir	Drinking	No date available	5.46
Mustecep Reservoir	Drinking	No date available	3.1
Spring catchments	Drinking	n/a	-

Threats to water security in the region include population increase, intensive industrial and agricultural consumption, and pollution from domestic, industrial, and agricultural sources, which led to a decrease in groundwater resources (Tekirdağ Valiliği, 2015). Uncontrolled well drilling as a result of increased water demand from industrial and irrigation activities led to a decrease in the groundwater table level from 10-30 m in the 1970s to 80-200 metres as of 2014 (Tekirdağ Valiliği, 2014). TESKİ has argued that due to this decrease, the province must transition to rely on surface water resources, as demonstrated by the construction and use of two new sources: the Çokal Dam which began operation in 2016 and the Naipköy Reservoir which began operation in 2018 (Tekirdağ Valiliği, 2015; TESKİ, 2016; TESKİ, 2018). An additional dam under construction, the Saray Ayacık, will provide an expected 5 million m^3/year more water to the province with a storage capacity of 11.21 million m^3 (TESKİ, 2021).

3.3.2.2. *Water resources and water management of Kırklareli.* Kırklareli has an area of 6,459 km^2 and a population of 366,363 with almost half of the population living in the Luleburgaz municipality and almost a third living in Kırklareli city centre (Kocer, 2019; Kırklareli Valiliği, 2020; TUİK, 2021). The Kırklareli Water and Sewerage Directorate (*Kırklareli Belediyesi Su ve Kanalizasyon*

Müdürlüğü) manages water in the province. In 2020, 23 million m^3 of water was abstracted for municipal use and 39,930 hectares (gross) were irrigated (TUİK, 2023; Kırklareli Valiliği, 2021). 95 % of the province's surface drinking water supply comes from the Kırklareli Dam with the remaining 5 % from fountains, wells, Kayalıköy Dam, and Merkez-Üsküp pond. Kırklareli total water potential is 476.1 million m^3/year (142 million m^3/year groundwater, 334.1 million m^3/year surface water) (Table 3.8; 11. DSİ Bölge Müdürlüğü, n.d.; Tekirdağ Valiliği, 2020; Kırklareli Valiliği, 2020; Cebi et al., 2019). The province has an annual available water potential at 345 million m^3/year (Tekirdağ and Edirne Valiliği, 2020; DSİ, 2023).

Table 3.8. Main drinking water resources in Kırklareli (Kırklareli Valiliği, 2022). Data is not available for every water resource, indicated by the hyphen.

Water resource	**Purpose**	**Operating year**	**Total storage capacity (hm^3)**	**Irrigation [gross] (hectares)**
Kırklareli Dam	Irrigation, drinking water, industrial use, flood control	2000-2002, 2004-2005	113.3	13,623
Kayalıköy Dam	Irrigation, drinking water, flood control	1986	149.9	15,957
Merkez-Üsküp Pond	Irrigation, drinking water	1990	1.24	166
Wells (138 in total)	Irrigation, drinking water	-	-	6,156

3.3.3. Challenges to Düzce, Tekirdağ, and Kırklareli provinces' water security

Threats to water quality in Düzce, Tekirdağ, and Kırklareli include industrialization, agricultural activities, and unplanned urbanization. The Melen Watershed Protection Action Plan identified human-induced pressures to the watershed: wastewater discharges, urban runoff, agricultural and rural runoff, highways and transportation, and air pollution/atmospheric deposition (Ozturk et al., 2013). The Sakarya Basin in which the Melen watershed is located has observed serious heavy metal contamination, particularly in the Büyük Melen River (Pehlivan and Yilmaz, 2005; Tokuslu, 2022). The river basin receives 50,000 m^3/day of treated wastewater from the Düzce Municipality which is located on the Asar Stream, leachate from an uncontrolled solid waste dump site, and wastewater discharge from multiple villages along the river (Düzce Belediyesi, 2021; Sözen et al., 2021). The Düzce Municipality claims the wastewater treatment plant prevents waste from entering the Melen River system (Düzce Belediyesi, 2021) however Sözen et al. (2021) argue that the collective discharges could lead to severe risk of microbial, viral, and chemical contamination untreatable by current facilities if not properly controlled.

Intensive industrialization is the largest source of pollutants to the Thrace region (Kırklareli Valiliği, 2022). Rapid industrialization in the Thrace region began in the 1980s and is a source of pollution for the region. Of the three provinces in the Thrace region, Tekirdağ hosts 75 % of all factories and manufacturing plants, Kırklareli has 17 %, followed by Edirne who hosts 8 % (Inan, 2017, p. 41). Pollutants from industrial activities often are discharged into water bodies which disrupts the ecological balance and creates a great threat to water sources that are used for irrigation. Additional threats to water in the three provinces include population growth, domestic untreated wastewater discharge, sewage system leaks, and excessive use of fertilizers and pesticides in agriculture (Ozturk et al., 2013; Kırklareli Valiliği, 2022; Cebi et al., 2019). Climate change is expected to exacerbate these challenges and increase drought and flooding events, reduce water quality, and reduce precipitation in the regions (Tokuslu, 2022).

4. METHODOLOGY

This study adopts a mixed-methods socio-hydrology case study approach combining a quantitative analysis using Duan et al.'s (2022) natural and social efficiency water security indices with a qualitative document analysis using available literature to understand the impacts of the IBTs to both Istanbul and the surrounding region's current water security (Figure 4.1). The results will be evaluated using theoretical approaches from political ecology, hydrosocial, and water justice studies. This approach aligns with Sivapalan et al. (2012) recommended avenues for socio-hydrology studies advancement which includes a historical assessment to understand the co-evolution of Istanbul's human-water systems, comparative socio-hydrology to understand different catchments and human-water interactions across socio-economic and climatic gradients, and process socio-hydrology to study a system in greater detail to understand causal relationships and feedback loops.

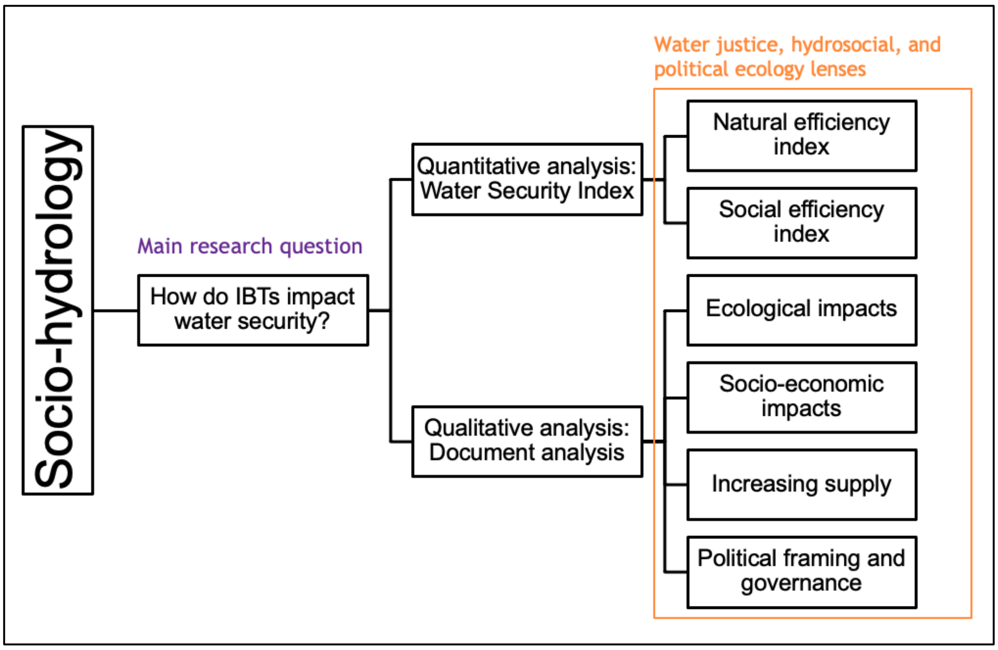

Figure 4.1. Methodological framework.

A case study approach is suitable for "process-tracing", which George and Bennet (2005) state attempts to understand the links between observed outcomes and their possible causes "trace the links between possible causes and observed outcomes" using historical records, archival documents, interviews, surveys, and other sources (p. 18). The qualitative document analysis will help understand the main themes that occur when studying Istanbul and the broader region's water security and the impacts of IBTs. This process also helps to understand complex issues, particularly useful given the competing interests and impacts of water security. Işlar and Boda (2014) note that a case study approach is appropriate when the chosen study area demonstrates importance in relation to the general problem, in this case the challenge of water security and managing water supply and demand in a large city with well-documented environmental and socio-economic implications as is the case with Istanbul.

Istanbul is a relevant case study to examine the global challenges of meeting water security for a megacity with a growing population due to in-migration, increasing economic activity, and pressures from climate change and water-related hazards. Furthermore, the city is comparatively under-researched, has a unique geography compared to other cities in the region due to its division across a straight and distance from large water resources, and is impacted by unprecedented megaprojects which requires further research (Güvenç, 2023). As discussed in the study area section, the city has long relied on IBTs and is a unique example given the multi-levels of governance surrounding water management. Işlar and Boda (2014) state that the Melen Project is one of the "most ambitious, large-scale, and potentially influential" projects in the region due to its size and planned water services supply to the country's largest urban metropolis making it a particularly important region to study (p. 3). Given that this project is still underway with much of the government focus and literature recommending the Melen River as the main solution improve water security for the city, this research is especially timely. As Istanbul is Turkey's largest city both in terms of population and development, İSKİ has the responsibility to act as a model "example institution to its counterparts within Turkey," showing that the study has implications for water management and water security policies across the country (İSKİ, 2014, p. 4; İlhan, 2021b).

4.1. Quantitative Analysis

This study relies on the water security indices developed by Duan et al. (2022) to measure the impact of IBTs to water security in the water-receiving and donating basins across the USA. Indices are a useful tool to quantify water security, measure change over time, and compare two study areas, which for the purposes of this study allows for the comparison of the two IBTs to Istanbul. A water security index generally should include information on water availability, consumption, population, water usage across different sectors, and environmental requirements (Veettil et al., 2022). With so many water security indices available, Duan et al.'s (2022) two indices were selected since they were purposefully designed to understand the impacts of IBTs on water security of both the water-exporting and water-receiving provinces, an important aspect since many research does not focus on quantifying the impact of IBTs to the water-exporting provinces. Furthermore, these indices were able to assess both the environmental and social impact of IBTs, an important requirement for both holistic understandings of water security and understanding human-water systems in socio-hydrology. Finally, publicly available data on the region is hard to access so an index which can use available data is especially relevant.

Duan et al. (2022) have developed two metrics to evaluate an IBT's efficiency or impact on water security in the study area, based on the assumption that IBTs impact water supply positively or negatively by transferring available water: a) Natural efficiency, and b) Social efficiency (Stress Relief Index). "Efficiency" is usually conceptualized by comparing the benefit to the cost (Colby, 1990, as cited in Duan et al., 2022). These indices allow for the impact of IBTs on water security to be assessed from both a water availability perspective (natural efficiency index) and include additional factors such as population, sectoral water demand, and ecological implications (social efficiency) which supports a more holistic approach to studying water security. This methodology also uses indicators that align with the Habitat Conservation Trust Fund's criteria for watershed indicators who argue that for strong studies of water security, indicator data should be available, understandable, credible, relevant, and integrative (see Section 2.2.3. Water Security Indices). All data was available from government sources (4.1.3. Data requirements). Natural efficiency looks at the impact of transfers to water availability in the donor and receiver basins, while social efficiency is calculated through the Stress Relief Index (SRI) which calculates the impact of IBTs on water stress of the two regions. The researchers used these indices in combination with a Dynamic water stress model which provided information on regional water availability and stress levels under various climate, water use, and water transfer contexts. The authors used a time scale of 1981-2010 in their study of 200 IBTs across the USA, including 150 receiving and 145 supplying watersheds.

4.1.1. Natural Efficiency Index

The "Natural efficiency" index developed by Duan et al. (2022) measures the difference between the transfer-in (TI) ratio and transfer-out (TO) ratio (DIO) of the amount of water transferred (T) compared to the freshwater availability in the water-receiving (TF(r)) and water-exporting (TF(e)) watersheds (Eq. 4.1). The transfer-in ratio (TI) is the ratio of the amount of water transferred (T) to the regional (i.e., local) renewable freshwater availability of the receiving region (TF(r)), which reflects the benefit for water supply in the region. Transfer-out ratio (TO) is the ratio of the amount of water transferred (T) to the regional renewable freshwater availability of the exporting region, reflecting the impact of water availability reduction and ecosystem disturbance in the donor region.

$$\mathrm{DIO} = \mathrm{TI} - \mathrm{TO} = \frac{\mathrm{T}}{\mathrm{TF(r)}} - \frac{\mathrm{T}}{\mathrm{TF(e)}} \tag{4.1}$$

4.1.2. Social Efficiency (Stress Relief Index)

The "Social efficiency" is calculated by the Stress Relief Index (SRI) used by Duan et al. (2022) (Eq. 4.2). The SRI indicates the "combined impacts of per unit transferred water on overall water stress" across the water-exporting or receiving watersheds and the areas downstream (Duan et al., 2022, p. 4). The impacts are measured by the IBT-induced increase or decrease in regional water stress multiplying the population impacted, as

$$SRI = \frac{\lambda_i \; x \; P_i \; x \; (-\Delta WS_i)}{T} \tag{4.2}$$

where T is the transfer amount of the IBT; P_i is the population and ΔWS_i is the IBT-induced change in water stress for the *i*th watershed, calculated below. λ_i is the weighing factor for the *i*th watershed, which Duan et al. (2022) suggest can be adjusted for different water management priorities; a higher λ_i could be implemented for regions where there is extreme water shortage, vulnerable ecosystems, and/or endangered aquatic species. Duan et al. (2022) set λ_i at a constant one to ensure consistency when comparing the impacts of climate change across the USA. ΔWS was adapted from Duan et al.'s (2022) research to work for the study area context (Eq. 4.3). For the receiving watershed, ΔWS is calculated as follows

$$\Delta WS = (WD_m + WD_a) \; x \; \left(\frac{1}{TF_{(r)}} - \frac{1}{TF_{(e)}}\right) \tag{4.3}$$

where WD is off-stream municipal (WD_m) and agricultural (WD_a) water consumption multiplied by the inverses of the water potential of the exporting and receiving watersheds.

Both indices measure efficiency of IBTs by assessing the positive impacts of an IBT on water supplies against the negative impacts. Duan et al. (2022) state that a larger DIO or SRI indicates a higher efficiency from an IBT in alleviating water scarcity. A negative value for the DIO or SRI suggests that the IBT may be inefficient in a specific hydrological and water-use context.

The study will look at the natural and social efficiency of IBTs for the period from the operation year of 2008 for the Melen System and from 2000 for the Istranca Streams until 2020. Though the first dams in the Istranca Project began operating in 1995, data was only available starting in 2000 which is when the final Istranca stream project began operating. Jensen and Wu (2018) recommend the administrative area of the municipality should set the system boundary since policy and governance shapes water security. Based on available data, the Istranca Streams (Istrancalar, Kazandere, and Pabuçdere) will be considered as one IBT with Tekirdağ and Kırklareli considered together as one region. Duan et al. (2022) included all regions upstream and downstream of the transfer in their study, however due to data constraints and given that the Istrancalar, Kazandere, and Pabuçdere sources drain into the Black Sea without crossing additional provincial borders, and that the majority of the Melen Watershed falls within Düzce's provincial borders, this study will only look at the receiving province (Istanbul) and water-exporting provinces' (Düzce, Tekirdağ, and Kırklareli) provincial administrative borders as the study boundaries. Although some of the Melen Watershed crosses into Sakarya, Bolu, and Zonguldak, a review of the provinces' water resources using their respective Provincial Environmental Status Reports[6] shows that these provinces rely on other water resources outside of the Melen Watershed and thus do not have to be considered for the purposes of this analysis since this study is looking at the impact of water transfers on water availability of each province that uses water directly from the water transfer's watershed.

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[6] https://ced.csb.gov.tr/il-cevre-durum-raporlari-i-82671

4.1.3. Data Requirements

Table 4.1. Data requirements.

Study Area	Istanbul, Düzce, Tekirdağ, Kırklareli
Study boundaries	Each province's provincial boundaries (Tekirdağ and Kırklareli as one region)
Inter-basin water transfers (IBTs)	- Melen Watershed (Düzce) - Istranca Streams [Istrancalar, Kazandere, and Pabuçdere] (Tekirdağ and Kırklareli)
Timeline	Melen: 2008-2020 Istranca Streams: 2000-2020
Timestep	2 years
Data sources	Regional Environmental Status Reports (*Yılı Çevre Durum Raporları*), İSKİ Annual Reports, TUİK Regional Statistics (*Bölgesel İstatistikler*), DSİ, TESKİ

Data needed	**Symbol**	**Source (2000-2020)**
Natural efficiency		
Transfer magnitude for each IBT	T	İSKİ
Freshwater availability for each province (ground and surface water)	TF(r) for receiving TF(e) for exporting	Regional Environmental Status Reports, DSİ
Social efficiency (Stress Relief Index)		
Transfer magnitude for each IBTs	T	İSKİ
Population of each region	P	TUİK
Weighing factor based on water management priorities	λ	Duan et al. (2022)
Change in water stress due to IBT	ΔWS	İSKİ, TESKİ, Regional Environmental Status Reports
Municipal water use (residential, industrial, commercial)	WD_m	TUİK Regional statistics
Agricultural water use	WD_a	Regional Environmental Status Reports, DSİ

4.2. Qualitative Document Analysis

Qualitative data were collected through examining previous academic research on the region, government and non-governmental organization (NGO) reports and planning documents published by the Istanbul Metropolitan Municipality (İBB), Istanbul Water and Sewerage Administration (İSKİ), State Hydraulic Works (DSİ), provincial governments, Istanbul Master Plan Consortium

(IMC), and World Wildlife Fund Turkey (WWF). This study employs document analysis, the reviewing of documents to “elicit meaning, gain understanding, and develop empirical knowledge” from government and non-governmental reports, and news articles in addition to reviewing academic articles (Bowen, 2009, p. 27). A document analysis aims to identify the “underlying themes in the materials being analyzed” which is useful to distil such a broad concept such as water security and understand the main impacts from IBTs to water security as analyzed in the literature (Bryman, 2004, p. 392, as cited in Islar and Boda, 2014). A document analysis is also useful for a qualitative case study analysis because it helps to identify important details surrounding the topic (Yin, 2009, as cited in Islar and Boda, 2014). This aligns with the proposed process socio-hydrology approach which recommends studying a system in detail to understand causal relationships (Sivapalan et al., 2012).

Document analysis in tandem with the quantitative natural and social efficiency indices approach will provide a more holistic understanding of Istanbul and the broader region’s water security and gain insights into governance and justice issues that arise as a result of the reliance on IBTs. Reports and articles were selected for their research into Istanbul’s water security, policies and governance, and/or the impacts of IBTs. The document analysis of available research on Istanbul’s water security and the impacts of IBTs in Table 4.2 uncovered four main themes that the literature focuses on: ecological and socio-economic impacts from the IBTs, the impacts of increasing supply leading to increased growth for Istanbul’s, otherwise known as the supply-demand cycle as defined by Di Baldassarre et al. (2018), and the political framing and resulting governance challenges that come from prioritizing supply-side management solutions such as IBTs for Istanbul’s water supply instead of demand-side management. Given Istanbul’s importance as a global city and Turkey’s largest city in terms of population and economic contribution, the majority of the research focused on Istanbul and how increasing water resources allows for continued expansion of the city, leading to governance challenges. A limited amount of research concentrated on the actual ecological and/or socio-economic impacts of the IBTs to the water-exporting provinces, signifying the importance of this study to expand the literature.

Table 4.2. Document analysis of research on Istanbul and the surrounding regions’ water security and identified main themes.

Research	**Purpose, methodology, and/or research aim**	**Main theme(s) explored**			
		Ecological	Socio-economic	Increasing supply	Governance challenges
Government and NGO reports					
ISKI (1994-2021) *Annual reports*	History of Istanbul’s water supply, current resources, current actions Istanbul is taking to conserve water			✓	✓
IBB (2018, 2021) *Climate action plans*	Background on current climate change risks and future plans and policies			✓	
IBB (2020) *Canal Istanbul workshop*	Report from workshops with experts on the impacts of the proposed Canal Istanbul project	✓		✓	
Istanbul, Kırklareli, Tekirdağ, and Düzce Valiliği (2012-2020) *Regional environmental status reports.*	Information on water availability, water consumption, water quality, land use change etc.	✓		✓	
IMC (1999) *Istanbul water supply, sewerage and drainage, sewage treatment and disposal master plan.*	Information on Istanbul’s water supply, environmental assessment reports etc.	✓	✓	✓	
WWF (2012) *Mega dreams, empty hopes. Report on IBTs.*	Information on the impacts of IBTs across Turkey	✓	✓		
Academic research					
Acara (2019) *Sequestering a river: The political ecology of the “dead” Ergene River and neoliberal urbanization in today’s Turkey.*	Political ecology study on the transformation of Turkey’s water sector since 2000, particularly in the Thrace region		✓		✓
Aktas (2014) *Impacts of climate change on water resources in Turkey.*	Desktop study on the impacts of climate change and water use on water resource availability	✓		✓	
Bakirci (2016) *The effects of dams on the spatial reorganization: The case of Melen Dam.*	Assessment of the impacts of the Melen dam to both geographical and social characteristics	✓	✓		
Bekiroğlu and Eker (2010) *The importance of forests in sustainable supply of drinking water: Istanbul example.*	Qualitative analysis to study Istanbul’s forestry management and its impact to water resources			✓	
Burak et al. (2021) *Assessment and simulation of water transfer for the megacity Istanbul.*	Network analysis to model Istanbul’s water supply and demand (1995-2100)			✓	✓

Research	**Purpose, methodology, and/or research aim**	**Main theme(s) explored**			
		Ecological	Socio-economic	Increasing supply	Governance challenges
Cengiz et al. (2019) *The impact of economic growth oriented development policies on landscape changes in Istanbul Province.*	Study to assess the impact of urban policies affect green areas in Istanbul, using satellite images and DEM data			✓	✓
Cinar (2009) *Privatisation of urban water and sewerage services.*	History of water and sewerage management in Turkey				✓
Daloğlu Çetinkaya et al. (2022) *Urban climate resilience and water insecurity: Future scenarios of water supply and demand in Istanbul.*	WEAP analysis to study Istanbul’s water security under climate change and socio-economic scenarios			✓	
Güneralp et al. (2013) *Local assessment of Istanbul: Biodiversity and ecosystem services.*	Assessment of the main challenges Istanbul faces in biodiversity conservation and ecosystem services	✓	✓	✓	✓
İlhan (2021a) *Political ecology of Istanbul’s two-thousand-year-old water paradigm, explorations along the peripheries.*	Political ecology and environmental justice study of Istanbul’s water management	✓	✓	✓	✓
Ilhan (2022) *Istanbul’un suyu, Istanbul’un gelecegi.*	Background of Istanbul’s water security and challenges	✓	✓	✓	✓
Işlar (2012) *Struggles for recognition: Privatisation of water use rights of Turkish rivers.*	Assessment of water usage rights privatization for energy production in Turkey				✓
Işlar and Boda (2014) *Political ecology of inter-basin water transfers in Turkish water governance.*	Political ecology and hydrosocial approach to study IBTs to Istanbul and Ankara	✓	✓	✓	✓
Harris and Işlar (2013) *Neoliberalism, Nature, and Changing Modalities of Environmental Governance in Contemporary Turkey.*	Analysis of changing water governance policies in Turkey from the Ottoman era to the present				✓
Karakaya et al. (2014) *Interbasin water transfer practices in Turkey.*	IBT environmental and socio-economic impacts study	✓	✓	✓	✓
Saatci (2013) *Solving water problems of a metropolis.*	Background of Istanbul’s water security and challenges			✓	
Savun-Hekimoğlu et al. (2021) *Evaluation of water supply alternatives for Istanbul using forecasting and multi-criteria decision making methods.*	Multi-criteria decision making (MCDM) analysis combined with demand forecasting and interviews with experts to assess demand-side water management options			✓	✓
Sözen et al. (2021) *Water management for Istanbul: Collapse or survival.*	Remote sensing to analyze land use/cover change around Büyükçekmece and Ömerli watersheds			✓	✓
Van Leeuwen and Sjerps (2016) *Istanbul: the challenges of integrated water resources management in Europa’s megacity.*	A IWRM assessment of Istanbul’s water resources and management			✓	✓

5. RESULTS

5.1. Quantitative Analysis

Duan et al.'s (2022) analysis of American IBTs found that larger natural and social efficiency values show a higher efficiency of an IBT in remedying water scarcity. Negative values suggest that the IBT is inefficient in certain hydrological and water use contexts. Conflicting results between natural efficiency and SRI (calculated by DIO x SRI < 0) reflects different perspectives on the purpose of IBTs (Duan et al., 2022). DIO (natural efficiency) shows the ratios of the amount of water transferred to available water in the exporting and receiving basins, while SRI (social efficiency) varies with population levels and the amount of water abstracted from resources, reflecting the hydrological response to climate and water use changes. Thus the length of analysis matters: over a short period of time, SRI variation is mostly based on temporal variability of water availability since socioeconomic change is relatively stable. The transfer amount also plays a role in efficiency, the higher the transfer amount, the lower the efficiency for both the natural and social efficiency indices since it means a higher removal in water from the water-exporting region, which could impact the region ecologically and socio-economically. The transfer amounts over time are shown in Figure 5.1. The full data set for these indices is available in Appendix A.

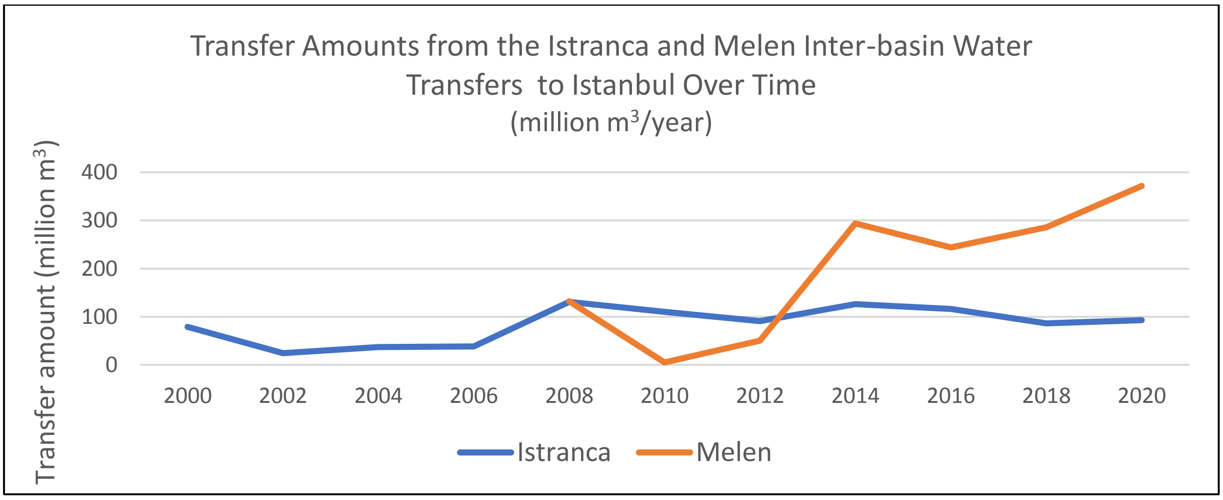

Figure 5.1. The transfer amounts from the Istranca and Melen IBTs to Istanbul. The Melen IBT (in orange) did not begin operating until 2008.

The first index looks at natural efficiency to understand if the water transfer amount is going from a region of higher water availability to lower or vice versa. If the transfer is going from an area of lower water potential to an area of higher, it can be considered inefficient and may cause environmental impacts. For Istanbul, the Istranca, Kazandere, and Pabuçdere water transfers are shown as slightly less naturally efficient than the Melen IBT, due to the larger water potential in Düzce province (Table 5.1). However the natural efficiency for both transfers are close to zero, denoting a more “neutral” efficiency that is neither positive nor negative. Duan et al. (2022) use these indices to show the efficiency of an IBT in remedying water scarcity for the receiving region so based on this index, natural efficiency increases for Istanbul with higher amounts of water transfers, as demonstrated by the difference for the Melen transfer between 2012 and 2014 after the operation of the second Melen Regulator (Phase II) increased transfer amounts (Figure 5.1). For the Melen transfer, Düzce’s water potential is higher than Istanbul’s, meaning that there will never be a negative value for the natural efficiency, corroborated with test analyses using larger transfer amounts. Similarly, since Istanbul has a higher water potential than Tekirdağ and Kırklareli, the transfer-in value will always be higher than transfer-out, leading to a negative result even for very low transfer amounts. Following the construction of the second Melen Regulator, 8 % to 28 % of water from Düzce’s available water was transferred to Istanbul each year. For the Istranca streams, 1% to 11% was removed from the water availability of Tekirdağ and Kırklareli each year.

Table 5.1. Results of the water security indices for Istanbul’s water transfers.

Istranca Streams (Istrancalar, Kazandere, and Pabuçdere) - Tekirdağ and Kırklareli

	2020	**2018**	**2016**	**2014**	**2012**	**2010**	**2008**	**2006**	**2004**	**2002**	**2000**
Transfer amount (million m^3/year)											
Istranca	93	86	116	126	91	110	131	38	37	24	79
Natural efficiency (transfer-in – transfer-out)											
Istranca	-0.016	-0.003	-0.003	-0.005	-0.003	-0.002	-0.002	-0.003	-0.001	-0.001	-0.001
Social efficiency (SRI)											
Ist.	-30.4	-7.1	-5.1	-2.3	-3	-2.3	-1.4	-6	-4.9	-6.7	-2
Tek. and Kirk.	-0.77	-0.17	-0.12	-0.05	-0.07	-0.06	-0.05	-0.16	-0.15	-0.22	-0.06

Melen Regulators - Düzce

	2020	**2018**	**2016**	**2014**	**2012**	**2010**	**2008**
Transfer amount (million m^3/year)							
Melen	372	286	244	294	50	5	132
Natural efficiency (transfer-in – transfer-out)							
Melen	0.024	0.054	0.046	0.056	0.007	0.001	0.020
Social efficiency (SRI)							
Istanbul	2.854	10.293	11.56	5.586	39.161	309.841	9.773
Düzce	0.003	0.011	0.011	0.006	0.042	0.363	0.016

For social efficiency which takes population and water demand into account, the Istranca, Kazandere, and Pabuçdere transfers show a negative value for Istanbul and Tekirdağ and Kırklareli, showing an inefficiency for Istanbul in alleviating water scarcity given the city’s higher population and water demand (about a third higher than Tekirdağ and Kırklareli’s combined water demand) (Table 5.1; Figure 5.2). This is due to Istanbul’s water availability being larger than Tekirdağ and Kırklareli, and as such is not considered efficient for either region. The larger negative value for 2020 is a result of Istanbul’s water potential increasing significantly between 2018 and 2020 which reduced water stress in the province, thereby leading to a larger difference between the two provinces’ water availability. For the exporting provinces of the Istranca transfer, the social efficiency is negative but still close to zero, signifying that though there is a negative impact given the fact that the two provinces have a smaller water potential than Istanbul, the smaller water demand and populations means that this impact is not extreme. The combined residential, agricultural, and industrial water demand for Tekirdağ and Kırklareli is about ¼ to ⅓ of Istanbul's water demand and the two provinces have similar water potential, with Istanbul's water potential slightly larger.

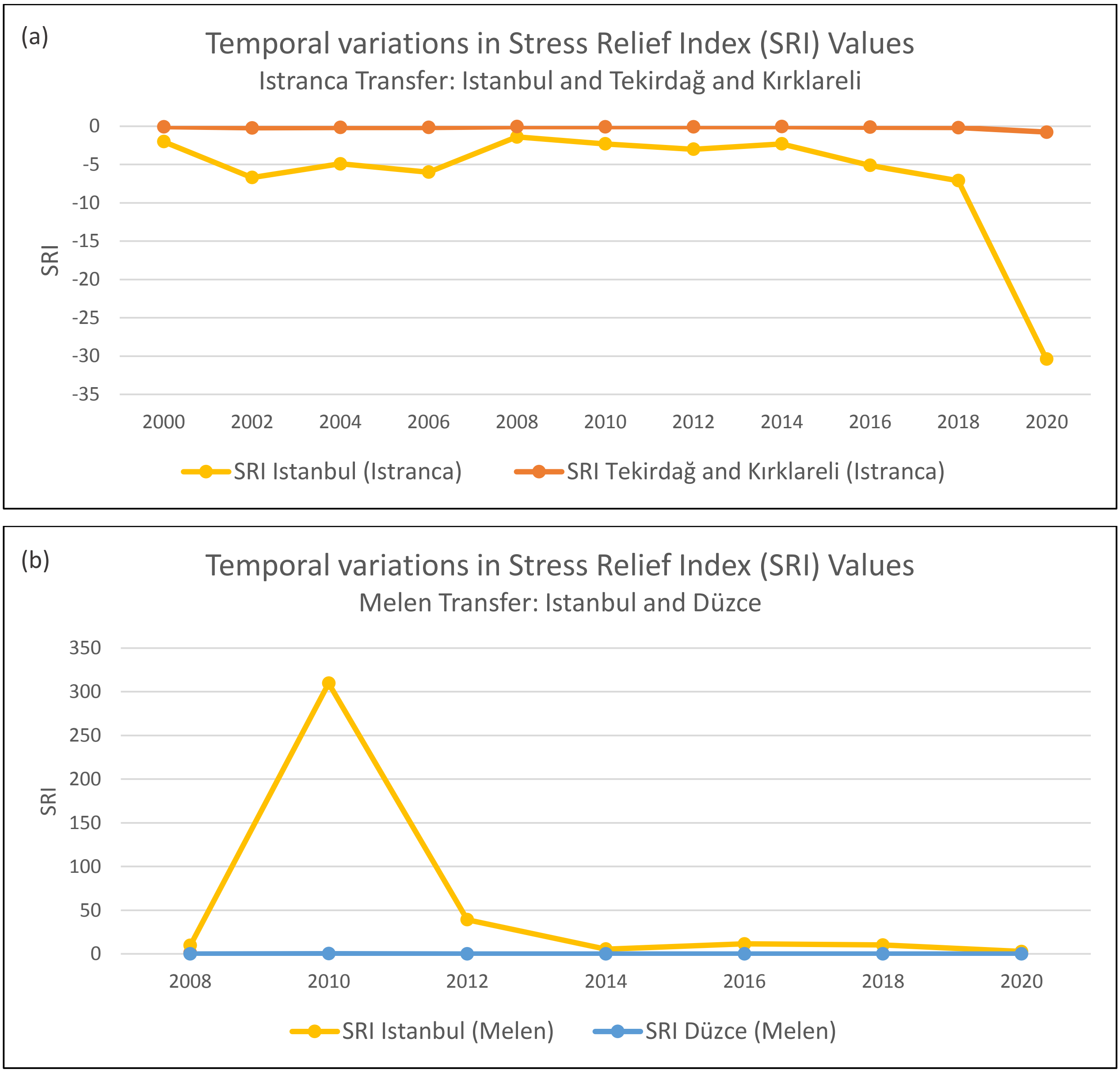

Figure 5.2. Temporal variations in Stress Relief Index (SRI) values for (a) the Istranca transfer: Istanbul, Tekirdağ and Kırklareli, and (b) the Melen transfer: Istanbul and Düzce.

Similarly, the IBT from the Melen watershed in Düzce leaves a positive impact for Istanbul given the increase in water availability for the megacity. The efficiency of the transfers do decrease in size as the transfer volume increases, which aligns with Duan et al.'s (2022) results that show smaller transfers are more efficient under the SRI analysis since they benefit receiving populations without removing too much water from the exporting region. The higher SRI values for 2010 and 2012 are due to lower transfer amounts for those years (Figure 5.1 and Figure 5.2). While these years experienced drought conditions that lead to lower amounts of water being transferred, lower transfer amounts actually mean a more positive result in improving water scarcity for the receiving basin and less negative effects for the exporting region since there is less water being removed and therefore a more sustainable solution. In other words, Istanbul then is not relying too much on one water source for the majority of its water supply, while the SRI decreases in efficiency as the transfer amount increases as Istanbul's reliance on the transfer grows. For Düzce, there is a slight negative effect due to the water transfer which increases as the transfers increase in volume. Düzce has a much higher water potential than Istanbul, with a much smaller population than Tekirdağ and Kırklareli which explains why the results are not that dissimilar between the two exporting regions despite the higher transfer amounts from Düzce.

5.2. Qualitative Analysis

While the quantitative analysis provides an overview of the impact of IBTs on water security for Istanbul, Düzce, Tekirdağ, and Kırklareli, the indices do not go into much detail beyond whether or not the water transfers have a positive of negative impact on the water exporting and receiving provinces. Sivapalan et al. (2012) recommend that to better understand human-water systems and water security, a socio-hydrology approach should be taken to couple the quantitative analysis with more holistic descriptions of systems and their process interactions. The following document analysis supports the indices by diving deeper into aspects of water security that cannot be elaborated on in a quantitative analysis.

The four themes identified in the document analysis are the current ecological and socio-economic impacts of IBTs, the future concerns that may arise as a result from the reliance on IBTs regarding Istanbul's increased growth and water demand which will impact water security in the future, and governance challenges. The review of previous research conducted on the region, government and NGO reports, and some news articles found that IBTs impact the water security of Istanbul and the surrounding watersheds both ecologically and socio-economically with the majority of research assessing future threats to water security as a result of increasing supply and increasing reliance on water transfers, focusing on water availability as a result of climate and socio-economic changes. Academic research in particular also assessed the governance challenges of relying on IBTs and the political framing that is used for their justification (e.g., Islar and Boda, 2014; Ilhan, 2021a). Another major theme is the governance challenges as Istanbul continues to expand beyond available water resource capacity; as the city continues to grow, due, in part, to increased water supply, demand also increases leading to the need for more water resources. As many future prediction and climate change forecasting studies found, Istanbul will face increased water scarcity beginning in 2030 with more severe challenges by 2040 and 2050 (Daloğlu Cetinkaya et al., 2022; Burak et al., 2021). This leads to governance challenges as the city becomes more and more reliant on water resources outside of the city borders over time. This analysis expands on these themes and takes a more in depth look at water security in the region to assess the ecological and socio-economic impacts to the region from IBTs currently and in the future, as well as governance challenges in the region. The themes revealed in the document analysis also aligns with critiques of socio-hydrology, who argue that models alone are not enough to address institutional capacity, governance challenges, and/or historical and cultural drivers of coupled human-water systems (Wesselink et al., 2016; Carr et al., 2022).

5.2.1. Ecological Impacts

Large dams and water transfers interrupt, modify, and often damage river water cycles and flow regimes irreversibly (McDonald et al., 2014). Modifications to landscape soil and vegetation coverage and slopes and elevations surrounding water resources and urban environments also impact the way rainfall is captured, stored, and released in hydrological systems (McGrane, 2016). Between 1995 and 2002, there was a "linear trend of a 16 % decrease in surface water flow rates" in Turkey's 25 hydrological basins and a linearly increasing trend in river water temperature with a mean annual rate of ~0.2 degrees Celsius, which impacts water quality and quantity (Aktaş, 2014, pp. 884-5). Aktaş (2014) notes that these reductions in surface water availability are not only as a result of climate change, but that they are more likely to be caused by increasing water extraction and land use change. For example, overexploitation from Istanbul's local water resources is attributed to subsequent low yields and increased vulnerability from droughts (IMC, 1999).

Many researchers have noted concerns with the removal of large amounts of water from resources such as the Melen in reducing flow rates (IMC, 1999; Islar and Boda, 2014; Ilhan, 2022). Neither transfers have exceeded the safe yields as delineated in the İSKİ Master Plan; 181 million m^3/year for the Istranca Streams and 1,190 million m^3/year from the Büyük Melen River, which have been factored down to account for seasonal variations (IMC, 1999), however the safe yields could change in the future with climate change impacts. If the water abstraction from the Melen System increases to the planned 1,077 million m^3/year, using Duan et al.'s (2022) index, the natural efficiency would be still a similar value at 0.068, however this high amount would remove 62 % of Düzce's available freshwater leading to potential serious consequences for the province showing the need for further analysis. In their environmental assessment, the IMC (1999) reported that the Istranca streams project will have significant ecological impacts to the area from reduced water flows downstream of the regulators and dams. During dry years, reduced flow rates as a result of the regulators and dams will severely impact downstream wetland habitats and marsh areas that rely on regular flooding from the Istranca valley streams, which further exacerbates drought effects if such systems are not flooded during the winter months (IMC, 1999). As Figure 5.1 showed in the 5.1. Quantitative Analysis section, transfer abstraction from both the Melen and Istranca systems have increased over the last few decades. Continued increases in transfer amounts may lead to environmental challenges in the future given Düzce and Tekirdağ's investments to expand water use from surface water sources as a result of population increases and groundwater pollution and over-abstraction.

In addition to disruptions to flow regimes, there is often a disproportionate impact of IBTs on the flora and fauna in the donor basins (Gupta and van der Zaag, 2008). World Wildlife Fund Turkey (WWF, 2012) noted that there are many environmental effects as a result of the construction of dam projects. In the Melen Dam reservoir area there are 11 endemic plant species impacted by dam construction and operation (WWF, 2012). One species, the *Cyclamen coum* (Eastern Sowbread or Persian Violet) is a strictly protected flora species under the Bern Convention. The Istranca scheme has flooded the habitat of diverse submerged and riparian plant species upstream of the regulators and dams, while areas downstream are affected by reduced flows (IMC, 1999). The Istranca projects also threaten the Iğneada Longos (alluvial or floodplain) forest, an internationally significant wetland located in Kırklareli province (Karakaya et al., 2014). The area is ecologically significant due to its diverse range of ecosystems including the longos forest, calcareous peat bog, wetlands, fresh- and saltwater lakes, and sand dunes and is home to endemic and rare species. The region hosts 46 mammal species, 194 bird species, 17 reptile species, 28 fish species, 18 tree species, and 544 plant species, six of which are listed in Annex I of the Bern Convention (*Centaurea arenaria, Aurinia uechtritziana, Salvinia natans, Silene sangaria, Trapa natans*, and *Verbascum degenii*) (Karakaya et al., 2014).

5.2.2. Socio-economic Impacts

Economically, IBTs tend to have more benefits for the receiving region and lead to improvements at the country level such as increased GDP, while communities in the water-exporting regions often lose land, homes, and economic opportunities locally (Faundez et al., 2022). This trend is seen in the IBTs to Istanbul where communities in the Istranca and Melen projects regions lost land

and livelihoods as a result of the transfers. For the Melen Project, 16 villages in Düzce and Sakarya were resettled due to construction and operation of the transfer (Islar and Boda, 2014). Of this, four settlements (one town and three villages) in the Kocaali district of Sakarya will be fully submerged for the creation of the Melen dam (Bakirci, 2016). As of 2014, some people in the region still did not receive compensation for the loss of land expropriated for construction of the project, and others waited almost seven years for their compensation (Islar and Boda, 2014). Some community members who relocated to cities expressed their unhappiness with the relocation and face less economic opportunities (Ilhan, 2021a). The 2009 Greater Melen Project Environmental Impact Assessment Report (Ozturk, 2009, as cited in Işlar and Boda, 2014) stated the project's protracted planning period has hampered long-term investments in the region as a result of the associated uncertainty. This led to rural to urban migration even before the project started (Işlar and Boda, 2014). In Işlar and Boda's (2014) in-depth interviews with government officials, project designers, and local residents, the head engineer of the Melen project admitted that the region's textile dyeing activities were constrained to prevent pollution of the Melen water. Similarly to the economic impacts of the Melen Project, the Istranca streams dams, built following the 1993 drought, expropriated agricultural land, leading to a loss of income and reliance on the more precarious livelihoods of fisheries and seasonal tourism and increased rural to urban migration in search of jobs (İlhan, 2021a). Excessive withdrawals from the Pabuçdere and Kazandere reservoirs reduced the profits of fisheries in Vize and Kırklareli regions (Acara, 2019). Those living in the area of the planned İsaköy, Karamandere, and Sungurlu reservoirs are also vocalising their opposition at the loss of their land and agro-economies as a result from the planned dam construction (Guvemli, 2017, as cited in Daloğlu Çetinkaya et al., 2022).

Though information regarding the ecological and socio-economic impacts of the IBTs to the region was limited, this analysis shows that Istanbul's IBTs create challenges to water justice. Negative impacts from the projects are unjustly distributed to the water-exporting regions, while those in Istanbul continues to benefit. As Bakirci (2016) writes, though the Melen dam is considered a solution to Istanbul's water problems, the local communities face emotional damage as a result of losing their homes and communities, in addition to issues in the expropriation processes and relocation-related uncertainties. The loss of land, homes, and local economies in smaller towns and rural areas also contribute to Turkey's rural-urban migration challenge as people are forced to move and look for work elsewhere. This cements the path dependency challenge where Istanbul will continue to concentrate in-migration and industrial development, creating a need for more water resources, resulting in loss of land and investment in donor regions, leading to a continued supply-demand and resource effect cycle.

5.2.3. Impacts of Increasing Supply from IBTs to Istanbul

The majority of research conducted on Istanbul’s IBTs focused on future threats to the region’s water security as a result of IBTs. The document analysis found that one of the main themes in studying Istanbul’s water security was noting Istanbul’s continued expansion beyond its available water resources. As Istanbul continues to increase its available water resources, including from IBTs, the city then continues to grow and demand more water resources as a result. This is known as the supply-demand effect as coined in Di Baldassarre et al.’s (2018) study of IBTs who found that global trends show increasing water supplies only leads to increased demand in the future. Istanbul is Turkey’s largest city, and while the annual growth rate has slowed in recent years, its accelerated growth coupled with droughts in the late 1980s, early-to-mid-1990s, and mid-2000s were what justified the two IBTs, in addition to developing local resources such as the Büyükçekmece (1989), Darlık (1989), and Sazlıdere (1998) Dams and the Yeşilvadi (1992) and Yeşilçay (2004) Regulators (ISKI, 2021). A study of ISKI’s annual reports from 1994-2021 shows that the city had to continually find and exploit new water resources both within the municipal boundaries and beyond to meet rising demand (Figure 5.3). Studies from IBB (2018, 2021) and researchers such as Daloğlu Cetinkaya et al. (2022), Burak et al., (2021), and Savun-Hekimoğlu et al. (2021) assessed future water availability to note water scarcity concerns in the future as a result of continued population growth from in-migration and effects from climate change. The literature found that the impact of IBTs to Istanbul’s own water security led to the city’s continued expansion, threatening its own water resource quality and quantity, leading to the need for the city to continue to rely on water resources outside of the city boundaries.

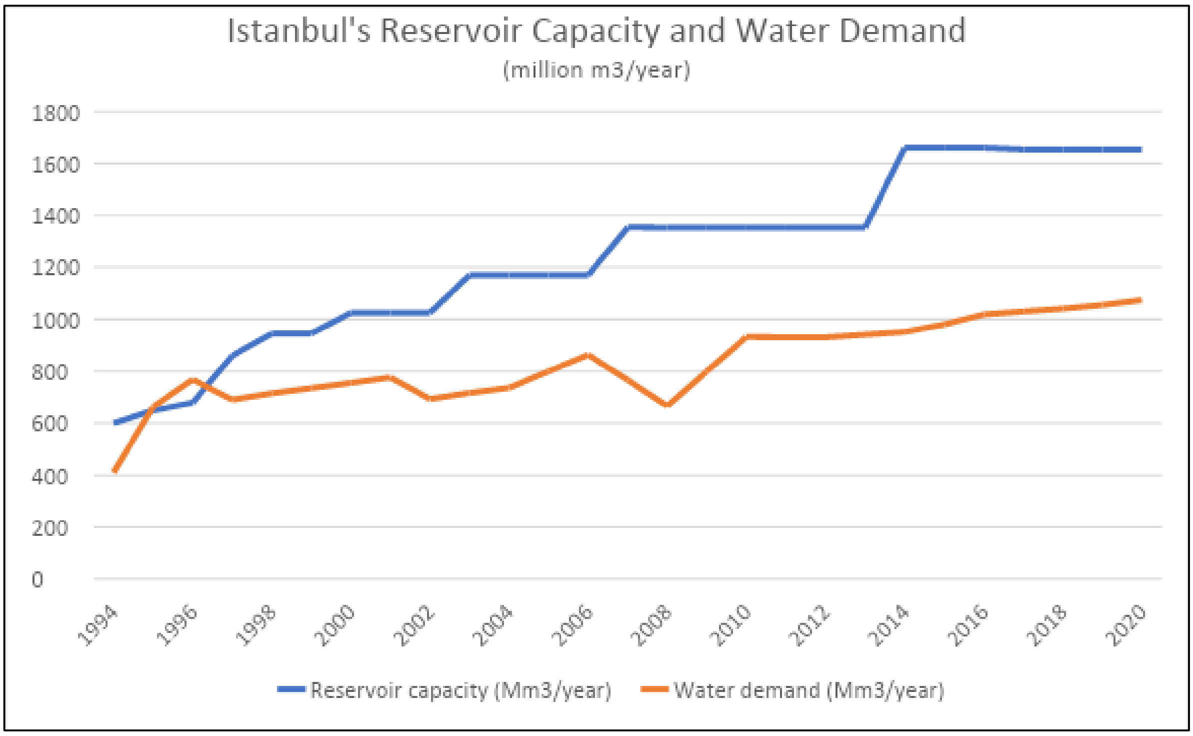

Figure 5.3. Istanbul’s reservoir capacity and water demand (million m^3/year). This depicts supply-demand dynamics where demand continues to grow while supply capacity stagnates (İSKİ Annual Reports 1994-2020; TUİK, 2023).

Urbanization and land use change impacts both the water quality and quantity of the region, while unimpeded growth in Istanbul leads to further impacts from the IBTs in the water-exporting provinces as outlined in the previous sections. Istanbul’s land cover and land use change has changed dramatically in the last few decades (Table 5.2). Between 1980 and 2017, built-up areas increased in Istanbul by 183.5 % and transportation networks increased by 117.4 %. In 1984, 56.1 % of Istanbul was covered in forests and woodlands, but this value decreased to 49.6 % in 2017 (Cengiz et al., 2019). Increased urbanization and reduction of natural areas significantly impacts Istanbul’s water availability and water quality. While settlements in the past were driven by a shortage of housing unable to meet the demand during major demographic shifts beginning in the late 1950s, more recent developments are now speculative in nature, meaning the chance for increased profits and as a result, increased development within watersheds (Güneralp et al., 2013). Güneralp et al. (2013) argue that continued expansion degrades the water-provisioning capacity of Istanbul’s current water resources, while also reducing habitat that supports local biodiversity. Ilhan (2022) continues this argument, stating that Istanbul continues to pollute its own waters and then looks towards water resources beyond the city borders as a remedy, creating not only a water justice challenge but also creating the supply-demand feedback loop that will increase water demand in the future as the city continues to expand.

Table 5.2. Change rate of land use and land cover change from 1984-2017 (Cengiz et al., 2019, p. 7).

Class name	**1984 area (km^2)**	**1984 rate (percent)**	**2000 area (km^2)**	**2000 rate (percent)**	**2017 area (km^2)**	**2017 rate (percent)**
Agricultural land	1,728.14	31.76	1,480.44	27.2	1,255.67	23.07
Barren land	100.95	1.86	22.86	0.42	26.14	0.48
Built-up areas	261.99	4.81	588.68	10.82	742.62	13.65
Forested land	3,052.80	56.1	2,840.88	52.2	2,700.16	49.61
Mining and construction areas	50.71	0.93	123.71	2.27	192.51	3.53
Transportation network	68.32	1.26	116.48	2.14	148.57	2.73
Urban green and residential gardens	104.75	1.92	151.02	2.77	209.8	3.85
Water bodies	74.15	1.36	117.75	2.16	166.32	3.05

Globally, urban land-use change is driving habitat fragmentation, biodiversity loss, and appropriation of agricultural land (Seto and Shepherd, 2009; McDonald et al., 2020). Urban hydrologists have increasingly focused on the impacts of expanding urbanization on water quality (McGrane, 2016). The urban landscape impacts meteorological and hydrological dynamics. Increased impervious surface material use and the expansion of artificial drainage networks greatly impacts the magnitude, flow paths, and timing of runoff. Urban runoff carries contaminants such as heavy metals, nutrients, garbage, and rubber residue from roads, while urban wastewater if not properly treated can discharge microbial contaminants, synthetic chemicals, and pharmaceuticals into water bodies (McGrane, 2016). Forests and natural environments can store water and delay its flow, playing an important role in reducing flood hazards from run-off during severe precipitation events and reducing erosion and sedimentation of waterways and water pollution (Bekiroğlu and Eker, 2010). Drinking water resources often overlap with forests and important biodiversity areas, as is the case in Istanbul (Bekiroğlu and Eker, 2010). Almost half of the city’s land area is covered in forests; however recent years have seen encroachment of urban settlements within forested areas (İBB, 2021).

Reservoirs within Istanbul are impacted not just by urbanization and increasing water demand, but also by unplanned settlements built without permission surrounding water reservoirs and related inadequate sewage facilities (İBB, 2021). These settlements are developed due to Istanbul’s increased population from in-migration and speculative real estate investments (Güneralp et al., 2013). In Istanbul, while sewage infrastructure is separate from storm water drains which reduces water pollution, there are still illegal sewer cross-connections that link to the storm water network, leading to pollution of watersheds, drinking water supply reservoirs, and the sea (Burak et al., 2021). Roadways and the increase in impermeable surfaces near water bodies also reduce water quality due to runoff. Roadways also increase people's' access to water resources, thereby threatening water quality with litter and increased human activities, while pollutants from cars such as mineral oils, heavy metals, polycyclic aromatic hydrocarbons, and other contaminants can enter water bodies with severe environmental and human health risks (İlhan, 2022).

Unplanned and unmonitored settlements around the Ömerli reservoir have led to water quality concerns from wastewater discharge, reducing ecological health in the watershed and increased energy required for treatment at the Pasakoy Wastewater Treatment Plant (Bekiroğlu and Eker, 2011; Saatci, 2013). The Ömerli Dam has one of the highest capacities of all of Istanbul's water resources (220 million m^3/year) and the lake is one of the largest water resources within the city limits (İSKİ, 2021). There has been significant land use and land cover change in the Ömerli watershed between 1987 and 2006 decades after the Ömerli Dam was completed in 1972: natural areas (mainly heathlands and woodlands) decreased from 46,000 ha to 41, 000 ha, agricultural areas decreased by 82 %, and urbanized areas increased by 169 % (Güneralp et al., 2013). Urban land in the Sultanbeyli District expanded within the long-distance protection zone around the reservoir and now has an area over 3,000 ha with a population of about 350,000 as of 2021 (TUİK, 2022). This unplanned urbanization damages the area ecology and the Ömerli reservoir is polluted by sewage, industrial wastewater, and soil run-off, leading to toxic blue-green algae in the late summer and mid-fall months (Güneralp et al., 2013). Raw water from the Ömerli Lake has significantly decreased in the last four years: in 2017 it provided 187 million m^3/year of raw water; in 2018, 164 million m^3; in 2019, 210 million m^3; in 2020, 161 million m^3; yet, in 2021, only 13 million m^3/year was provided (ISKI 2017-2021). The reduction in local water resource quality and quantity then leads Istanbul to further rely on water resources outside of the city, which also face severe groundwater and surface water pollution from agriculture, residential, and industrial sources which impacts human health and agricultural activities (Kırklareli Valiliği, 2022; Inan, 2017; Sözen et al., 2021) (See Section 3.3.3. Challenges to Düzce, Tekirdağ, and Kırklareli provinces' water security).

Turkey has the richest flora of all European, Middle Eastern, and North African countries with 8,600 total species, 2,700 of which are endemic to the country (IMC, 1999). Istanbul has six Important Bird Areas (IBAs) and seven Important Plant Areas (IPAs) and is home to 2,500 native vascular plants (IMC, 1999; BirdLife International, 2022). Despite the many areas with high biodiversity, many have not received protected status, and those who are protected still face threats from urban expansion and climate hazards, including large portions of the IPAs and IBAs (İBB, 2021). Important ecological areas and water resources go hand in hand; three of Istanbul's IBAs coincide with water supply resource basins (Büyükçekmece, Sazlıdere, Terkos) and one of the IPAs is in the Ömerli Watershed which is also significant for bird abundance (Güneralp et al., 2013; BirdLife International, 2022). The Ömerli watershed has a diversity of habitat including wetlands, heathlands, natural and planned coniferous forests, deciduous forests, meadows, peatlands, and agricultural lands which provide habitat to valuable biological diversity of rare plant, bird, insect, reptile, and amphibian species, all of which is severely impacted by unapproved urban expansion (Güneralp et al., 2013). Given that the city's historical creeks have mostly either dried up or become covered by residential developments, remaining water resources are particularly important for the ecology of the region as well as for supplying water (Sözen et al., 2021).

Government measures have attempted to reduce the impact of urban sprawl and development on water resources and the environment in Istanbul to mixed results. In 1984, İSKİ enacted Drinking Water Basin Regulations to prohibit "all industrial and urban activities with polluting potential in the protection zones defined around surface water resources" in order to maintain and protect potable water quality (Sözen et al., 2021). These regulations prohibit settlements, agriculture, mining, industrial, etc. activities at levels of intensity at various distances from the water source, however these regulations are not always successful (Saatci, 2013; IMC, 1999). For example, Küçükçekmece Lake (11 km^2) on the European side of the city was once an important water source but it is now unusable as a result of excessive pollution caused by increased urban and industrial developments as well as seawater salt intrusion (IMC, 1999; Sözen et al., 2021, İBB, 2021). Instead, Sazlıdere was developed as an alternative to Küçükçekmece (IMC, 1999). Similarly, there was a significant reliance on groundwater in the city with widespread wellfields in operation in the past, however these wells were polluted due to uncontrolled residential development and as such only wells in less urbanized settings are used, providing about 11 million m^3 of water in 2021, around 1 % of total water needs (IMC, 1999; İSKİ, 2021). However, there is precedent and demonstrated capacity for the remediation of polluted water bodies. Following the drought in Istanbul during 1993-94 the previously polluted and abandoned Elmalı reservoir was treated and put back into service, increasing water supply yield capacity by 15 million m^3 per year though the water resource still faces pollution challenges (Saatci, 2013; İSKİ, 2021; Güneralp et al., 2013). As of 2021, İSKİ continues to review and enforce the protection regulations, expropriating buildings surrounding reservoirs that threaten water quality and continuing to restore streams and remove accumulated sediment in streams around the region (İSKİ, 2021).

5.2.4. Political Framing and Governance Challenges

In addition to ecological and socio-economic impacts of the IBTs and the impacts of increasing water supply to Istanbul's own water security, the fourth theme identified in the document analysis is the political framing that is used to justify IBT development and the resulting governance challenges such as overlapping jurisdictions and the privatization of water resources. Islar and Boda (2014) note that it is important to understand that the "process of problem framing can be highly political," with the IBTs to Istanbul framed as a solution to problems related to "natural drought conditions and general water scarcity, rather than increasing water demands or historical urbanization patterns" (p. 5), which have been outlined in the previous section. The 1994 drought led to the renewal of existing water lines and construction of new dams, particularly the Sazlıdere and dams in the Istranca region (İBB, 2021; IMC, 1999). As mentioned earlier, the motivation for the Melen Project was also related to droughts in the 1990s and Phase I of the project was expedited following the 2007 drought (Işlar and Boda, 2014). The justification of the IBTs used to solve drought challenges continues; in 2012, regarding the Melen transfer, the Turkish Minister of Forestry and Water said that the "Melen project is the insurance of Istanbulites drinking water. As Melen is another river basin and situated in a different climatic zone, it can provide water even if there is a drought in Istanbul" (Haber 7, 2012, as cited in Işlar and Boda, 2014, p. 5). Similarly, the language surrounding the Istranca streams also emphasized prioritizing the city; the 1994 İSKİ Annual Report argued that while Istanbul was without water, the Istranca streams were "flowing into the Black Sea uselessly"[7] and thus were seen as a solution to Istanbul's water supply challenges (p. 33). Furthermore, with plans to increase abstraction from the Büyük Melen River to 1,077 million m^3 upon completion of the dam, the Melen IBT continues to be used as a solution to Istanbul's water challenges and as a justification for the city to continue to grow. Regarding the KanalIstanbul project which may lead to an increase in population between 500,000 to 2 million and a decrease in total water availability by 3 %, the Governorship of Istanbul says these challenges will be ameliorated by the increase in water abstraction from the Melen system (Governorship of Istanbul, 2019; IBB, 2020).

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[7] Translated from "*Istanbul susuzdu, Istranca Dereleri Karadeniz'e yine boşuna akıyordu ve bu dereleri Istanbul'a kavuşturacak güç o tarihlerde İSKİ'de kalmamıştı.*" (İSKİ Annual Report, 1994, p. 33).

While IBTs can improve the reliability and responsiveness of water systems in the case of water-related hazards such as droughts, often extreme weather events impact the whole region, including both the receiving and donor basins (Karakaya et al., 2014; Rollason et al., 2021). Political positioning of the Melen Project as an “insurance” against drought for Istanbul then is unfounded, recalling that the 2014 drought affected the entire Marmara region, with the Melen River flow decreasing by 50% and the Istranca Streams also experiencing low flows (İlhan, 2021a). Furthermore, as Daloğlu Çetinkaya et al.’s (2022) research shows, Istanbul is expected to face water challenges in the 2030s under the RCP 4.5 scenario and after 2050 under the RCP 8.5. While increasing water withdrawals from the Melen would resolve water-scarcity challenges through 2100, Daloğlu Çetinkaya et al. (2022) note that increased withdrawals has environmental consequences such as reducing river flow, water quality, and biodiversity, reducing the available water that can be safely provided in the future. The 2017 drought led to the occupancy rate of 10 dams in Istanbul to fall to 65 % and agricultural production in the region also decreased (IBB, 2021). In March 2023, Istanbul’s dams’ occupancy rate hovered around 35-37 %, their lowest occupancy rate in ten years since the 2014 drought (İSKİ, 2023a), while Düzce’s important water source, the Hasanlar Dam built on the Küçük Melen river in the Melen watershed is also experiencing low volumes as a result of low rainfall in the region (Ürer, 2023). The government position that the Melen project and other IBTs will “solve” water-related hazards such as droughts is clearly a water justice issue since Istanbul is prioritized at the expense of rural areas and smaller cities and leads to Istanbul becoming more vulnerable as it continues to expand. While the Istrancalar and Melen IBTs were built following droughts, the related environmental and social impacts and continued urban growth becomes a supply-demand cycle feedback loop; once the gap between water supply and demand was closed through IBTs, continuous in-migration and urbanization lead to increased water demand (Işlar and Boda, 2014; Burak et al., 2021).

Cook and Bakker (2012) argue that one of the main reasons to assess water security from a broad and more integrative framing which includes water availability, climate change, water-related hazards environmental and human health, and socio-economic aspects is because it brings governance issues to the forefront. Good governance is necessary to successfully manage multiple stressors that impact water security, as listed above. The authors state that water security sets goals for improved governance, while good governance is required to make water security operational (Cook and Bakker, 2012). However water security and governance in the region is complicated due to overlapping jurisdictions, a multiplicity of users and user needs, and impacts from global trends moving towards increased commodification of water.

5.2.4.1. Overlapping jurisdictions. The regulatory framework which governs Istanbul's water supply and management is complex. İSKİ's responsibilities overlap with the İBB and DSİ, while İSKİ and the 14th Regional Directorate of the DSİ also took over the governance of water resources in Düzce, Tekirdağ, and Kırklareli used to supply Istanbul beginning in the 1990s that under different circumstances would be under the 5th and 11th DSİ directorates and the provinces' respective water management authorities. Further challenges occur within Istanbul's local jurisdiction that impact local water security. Water conservation and resource protection zones surrounding water resources to prevent pollution are introduced by the Environment Law and the Public Health Law, under which İSKİ has its own regulations enacted in 1984, based on the 1976 Protocol on the Conservation of Water Sources, and later revised in 1998 (IMC, 1999). These regulations include the four water protection zones surrounding water resources which were designed for İSKİ to exercise strict control over land-use planning within water catchments that supply the city with water. However, recent rapid urbanization and population in-migration has led to unplanned, illegal housing and industrial development in water protection zones (IMC, 1999). Without proper enforcement and prevention which falls under the İBB's responsibility under the Municipalities Law, existing houses can only be removed through expropriation where İSKİ will effectively 'buy' the building and then demolish it. Similarly, while İSKİ is in charge of regulating discharges to sewers, direct discharges to water bodies are regulated by the Provincial Government (Istanbul Valiliği) and discharges to fish-producing waters fall under the Ministry of Agriculture. The overlapping jurisdictions within Istanbul challenge local water quality while the extended mandates of İSKİ and the 14th DSİ Regional Directorate also further complicate water governance in the water-exporting provinces of Tekirdağ, Kırklareli, and Düzce.

5.2.4.2. Privatization of water resources. In line with global trends, the 1980s saw the beginning of a period of neoliberalization and commodification of natural resources across the country. Turgut Özal, as a minister in the Demirel government prior to the military coup in 1980, developed an economic program to promote free trade, decentralization and deregulation of governance, and implement the structural adjustment packages of the International Monetary Fund (IMF) and World Bank (Işlar and Harris, 2013). After the coup, these reforms were fully implemented, paving the way for major industrialization and modernization projects with the commodification of natural resources and private companies playing a larger role. Two important laws, Law No. 3096 (1984) and Law No. 3291 (1986) supported private sector involvement in the governance of natural resources through the construction, operation, and management of water infrastructure and electricity production and the privatization of the State Economic Enterprises which controlled industry sectors such as manufacturing (Işlar and Harris, 2013).

This period led to a shift in how DSİ and İSKİ operate as well. While the state is considered the "owner of rivers", DSİ gained the authority to regulate, control, and approve proposed projects related to rivers (Işlar, 2012, p. 321). Harris and Işlar (2013) argue that this transformed DSİ's role to provide better institutional support for market interactions and private entities, in line with theoretical discussions related to neoliberalism. Previously, large scale hydroelectric development projects such as the Keban and the Atatürk Dams on the Euphrates rivers were funded by the national budget (Conker, 2016). However, under Law No. 4628 Electricity Market Law of 2001, DSİ became the main body in "in charge of implementing the initial steps for the privatization" of water (Işlar, 2012, p. 320), which Harris and Işlar (2013) refer to as the "privatization of Turkey's rivers" (p. 4). Işlar (2012) cites Swyngedouw's (2005) definition of privatization, where resources that "had not been formally privately owned, managed or organised, are taken away from whoever or whatever owned them before and transferred to a new property configuration that is based on some form of 'private' ownership or control" (p. 82). An additional structural reform occurred in 2007 when DSİ moved under the Ministry of Environment and Forests, which is seen as a contentious move since the Ministry's mandate is to protect natural resources, while DSİ has the responsibility to plan, manage, develop, and operate all water resources in the country (Harris and Işlar, 2013; DSİ, 2022). Işlar (2012) argues that this move weakens the control mechanisms of the Ministry of Environment and Forests with DSİ's priorities of developing water resources for hydropower and irrigation.

In cities, municipalities were given more financial independency and were encouraged to seek financial support from private sources, with the share of foreign credits used for sewage infrastructure (mostly from the World Bank, the European Investment Bank and the German Bank for Reconstruction) increased from 19 % to 48 % between 1990 and 1996 (Cinar, 2006, as cited in Harris and Işlar, 2013, p. 236). Cinar (2009) argues that İSKİ's establishment was aimed to "enable a public utility to operate under a commercial regime which facilitates the mobilization of financial resources via foreign loans" (p. 351). İSKİ is able to set drinking and wastewater tariffs to allow for a minimum profit rate of 10 % of all expenditures, thus pricing water as an economic good rather than a basic necessity (Cinar, 2009). Thus the role of the state gradually transformed from "being the provider of public utilities and services, such as electricity, gas, telecommunications, and water, to being the regulator of a business friendly environment, assisting private companies to provide these services (Işlar, 2012, p. 319). However not all aspects of urban water were privatized; attempts to increase water tariffs in Istanbul, Izmir, Antalya, and Izmit failed as a result of local resistance (Harris and Işlar, 2013), and, as mentioned. İSKİ is still taking strong steps to improve Istanbul’s water security by protecting Istanbul’s water resources and manage demand in a more sustainable manner.

6. DISCUSSION

Conducting both a quantitative study using the water security indices to assess the impacts of IBTs to the water security of the region helps to uncover more details that the index may not be able to evaluate in detail. Socio-hydrology argues that there is a need to understand how human decision making impacts water resource, with humans themselves playing a role in water scarcity, as discussed in Section 5. Results. Given that it is difficult for models to account for the many uses and values of water and address historical or cultural drivers, the document analysis was utilized to address some of these critiques in socio-hydrology studies. While the indices results show there are inefficiencies with Istanbul's water transfers, the document analysis was able to assess the actual impacts of relying on IBTs for water supply, and the role of governance actions that drives the need for the city to continuously utilize water resources beyond the city boundaries. This section discusses some limitations of the quantitative analysis indices study and then analyses the results of the research using lenses from water justice, hydrosocial, and political ecology studies as recommended by Haeffner et al. (2021).

6.1. Quantitative Analysis

To quantify the impact of the IBTs to Istanbul and the water-exporting provinces' water security, two indices were used from Duan et al.'s (2022) analyses. The natural efficiency calculates the difference between the transfer-in and transfer-out water amounts compared to the receiving and exporting provinces, showing that since Tekirdağ and Kırklareli have a smaller water potential than Istanbul, the Istranca Streams transfer is less efficient compared to the Melen transfer which comes from a more water-rich province of Düzce. The social efficiency seeks to understand the efficiency of the transfers in relation to water demand, population, and water availability. Similarly the Istranca streams water transfer is seen as less efficient than the Melen transfer due to the lower water potential of the two Thracian provinces and the higher population compared to Düzce.

Duan et al.'s (2022) indices are the first study to use these formulas so comparisons across was not possible, however the results for Istanbul align with the researchers findings that positive and higher values for the natural and social efficiency signify a more efficient transfer. Here, since Düzce has a higher water potential and much smaller population and water demand than Istanbul, the values were positive for both results, while the lower water potential for Tekirdağ and Kırklareli led to negative values. In addition to water potential and transfers driving the formula, population and water demand also plays a large role. Increasing Istanbul’s water demand or population for the Melen transfers showed an increase in social efficiency for Istanbul given that more of the population would benefit from the transfer, while an increase in Istanbul’s water demand decreased social efficiency further for the Istranca Streams given it would be a larger impact on an area with already less water potential than the city. Concurrently, an increase in population in the exporting provinces reduces efficiency for their watersheds since more people will then be negatively impacted by the reduced water availability.

Limitations to the study include data availability challenges particularly for the Thracian provinces. For agricultural water demand for Tekirdağ there was only one year with both surface water and groundwater hectares and water use available, so this value was used for all years. For Kırklareli, only hectares of irrigated agricultural land was available, so the amount of water used was calculated based on Tekirdağ’s water use per hectare value since both provinces grow similar crops. Kırklareli’s water potential was not available from DSİ so the value was found by using the available water potential data for the 11th DSİ Regional Directorate which includes Edirne, Tekirdağ, and Kırklareli and then subtracting Edirne and Tekirdağ’s water potential to find the value for Kırklareli. Additionally, water potential for each province was not always provided for each year. Given that water potential does not change much within short time periods, previous years’ data were used to fill in gaps.

Further limitations on the methodology include the large impact that water potential has on the positive or negative values of the results of the indices. As mentioned, since Tekirdağ and Kırklareli have less water potential than Istanbul, their results were always negative, while Düzce, with its larger water potential always showed positive values. This challenges sensitivity analyses; for the Istranca streams transfer, tests with larger transfer amounts actually improved Istanbul’s social-efficiency while for Düzce, larger transfer amounts reduced it, which is more in-line with Duan et al.’s (2022) hypotheses. Furthermore, these indices do not allow us to understand interactions between population or water demand changes between the provinces. For example, though an increase in population or water demand in the exporting province would decrease the social efficiency related water security for that province, as long as the transfer magnitude does not change, Istanbul’s SRI would not be affected. For this reason, the following qualitative analysis attempts to assess the impacts of the IBTs on other aspects of water security, including water availability, water-related hazards such as droughts and climate change effects, sustainability and the environment, socio-economic impacts, and governance challenges.

While these results provide a comparative method to understand the efficiency of the IBT using some social variables, ultimately, as argued by socio-hydrology, quantitative methods are not always able to account for all aspects of human-water relationships. This leads to a further discussion in the water security and governance literature regarding the difficulties in capturing human-water interactions and feedback due to the plurality of water uses, human values of water, and management and governance impacts on water availability. Wesselink et al. (2016) has argued that conceptual mathematical models such as indices may not be able to account for heterogeneous water uses and needs and capture these interactions. The developers of the concept of socio-hydrology, Sivapalan et al. (2012) acknowledge that hydrology requires a shift towards more holistic descriptions of human-water relations. For this reason, a deeper study of the region's water scarcity using hydrosocial, water justice, and political ecology approaches were undertaken to fully understand the IBTs impacts and why there is a continued reliance on supply-side water management projects in the following section.

6.2. Qualitative Analysis

Recalling the main aspects of water security (water availability, productivity and economic activity, hazards, human and environmental health, and governance), the qualitative document analysis of the impacts of IBTs shows that beyond the question of efficiency, Istanbul's increasing reliance on water transfers has impacts for the city and the exporting provinces. The majority of the research analyzed in Table 4.2 focused on the impact of increasing supply on Istanbul's water security, and how its expansion may impact the broader region. Less research was available on the ecological and socio-economic impacts to the water-exporting provinces, however the indices were able to uncover some impacts such as how water availability in the exporting provinces has decreased as a result of the transfers to Istanbul, which has consequences on flow rates and exacerbates the effects of drought events. Though there are enough current and planned water resources for the populations of Tekirdağ, Kırklareli, and Düzce, as illuminated by the relatively neutral social efficiency Stress Relief Index values for these provinces (Table 5.1, Figure 5.2), this will become more complicated in the future. The development of Phase III and IV of the Melen Project will increase abstraction up to 62 % of available water from the province, coupled with additional challenges from increased population and agricultural and industrial demand in the three water-exporting provinces. As Turkey is in a climate change hotspot, future projections have shown that climate change will reduce water security in the region and Istanbul may face water challenges as early as the 2030s (Daloğlu Çetinkaya et al., 2022). Furthermore, the supply-demand cycle, where increased supply has allowed Istanbul to continue to grow and demand more water, led to increased urbanization and encroachment into forested, agricultural, meadow, and watershed areas around the city, creating water quality issues across the region, without reducing water demand. Istanbul’s IBTs also impacted the ecological health of habitats in the areas around the Istranca streams and Melen watershed.

Finally, an aspect of water security that is more difficult to quantify is the impact of IBTs on socio-economic and governance issues and vice versa. As Srinavasapan et al. (2012) championed, hydrological science studies must be expanded to include studying human-water interactions and their impacts on hydrology and water availability. For Istanbul, unchecked population growth has driven the city’s water demand, particularly after increased in-migration in the 1980s and 1990s, while recent surges in tourism will also increase water use (Ilhan, 2022). Assessing the reservoir effect and supply-demand cycles shows that despite the increase in Istanbul’s water supply and reservoir capacity, demand is increasing at a greater rate while storage capacity has plateaued the last 9 years (Figure 5.3). Additionally, as mentioned the continued reliance on large-scale water transfer infrastructure may be rendered meaningless if current trends in low flows and changing precipitation patterns and increases in evapotranspiration due to climate change continue (Daloğlu Çetinkaya et al., 2022). With 57 % of Istanbul’s water needs met by water transfers from outside of the city borders, and 43 % of water met by the Melen alone, Istanbul itself is also becoming increasingly vulnerable to climate change impacts as well as potential hazards such as infrastructural failure in the water supply system by having the majority of its water come from one resource (İSKİ, 2021). As the social efficiency Stress Relief Index results showed, it is more efficient for Istanbul to use smaller water transfers (Figure 5.2), however the transfer magnitude continues to grow and government policies continue to frame the Melen transfer as a solution to all water scarcity challenges in the future. Using a hydrosocial, water justice, and political ecology approaches to study these human-water interactions help make sense of the water security of the region and coupled human-water interactions that drive water supply management policies.

The history of Istanbul’s water supply systems and IBT development follows the three steps identified in Hommes and Boelens’ (2017) hydrosocial approach to studying water transfers. Many hydrosocial studies analyze “how power dynamics in social and political processes are fused into the physical and managerial aspects of water governance" (Işlar and Boda, 2014, p. 2). Firstly, IBTs reconfigure ownership arrangements over water and its regulation and secondly, these arrangements become institutionalized, thereby de-territorializing these water resources and obscuring the effect of the transfers (Hommes and Boelens, 2017). Given Istanbul's economic and political power as the region with the largest share of Turkey's GDP, İSKİ and the 14th DSİ Regional Directorate's mandate was expanded beyond Istanbul to include Kırklareli, Tekirdağ, Kocaeli, Sakarya, and Düzce in order to secure water resources for the city. Despite the recognition that the Istranca streams and Büyük Melen River waters were used by local communities in environmental assessments (IMC, 1999), the waters were easily appropriated for use of the city and the expense of rural communities. Thirdly, Hommes and Boelens (2017) argue that in order to justify these water regulation changes, decision makers rely on discourses of water scarcity of the receiving area and economic or political power to argue that water is put to better use in the receiving area. As mentioned, the document analysis found that discourses surrounding Istanbul's water transfers rely on the city's importance while obscuring local uses in the exporting regions. The Istranca Streams were "flowing into the Black Sea uselessly" while Istanbul was "thirsty" (İSKİ, 1994, p. 33) and the Melen Project, particularly following Phase III and IV which will greatly increase abstraction, is seen as "insurance" against drought for the city and a solution to all water scarcity challenges (İlhan, 2021a; Işlar and Boda, 2014). Here, residential Istanbul water use is prioritized despite local economies' reliance on the Melen River and Istranca Streams for agriculture, fisheries, forestry, textile industry, and tourism activities. Even when megaprojects like the proposed Canal Istanbul (KanalIstanbul) will reduce Istanbul's local water resources by at least 3 % by constructing an artificial waterway connecting the Black Sea and Sea of Marmara west of the city, the planned increase in extraction from the Melen River is again seen as a cover-all solution since the city's economy must come first.

Water transfers then become a justice issue where the impacts of the IBTs are disproportionately felt by those living in the water exporting watersheds. Environmental and water justice includes three principles: distributive justice, (the spatial and temporal "allocation of burdens and benefits among individuals, nations and generations), procedural justice ("who decides and participates in decision-making"), and recognition, "which entails basic respect and robust engagement with and fair consideration of diverse cultures and perspectives" (IPCC, 2022, p. 7). In terms of distributive justice, both water-exporting regions bear the brunt of the negative externalities from the transfers, through disruptions in the local ecology, loss of jobs and economic opportunities, and, in the case of the Melen Project, the loss of homes and land in 16 villages (Işlar and Boda, 2014). Even with compensation, an aspect that aims to reduce these negative impacts, people in the Melen watershed faced delays in receiving the appropriate compensation and some had not received any seven years after the project had begun (Işlar and Boda, 2014). Though there are regulations to reduce water pollution within the city, poorly planned urbanization, industrial development, individual polluters, and regulation enforcement challenges lead to pollution and overexploitation of Istanbul's water sources while they continue to take water from other watersheds and explore additional sources, signifying a distributional and recognition justice issue as well (İlhan, 2022).

With the mandate regions of İSKİ and the 14th DSİ Regional Directorate expanded to include the waters of six provinces, procedural justice options are also limited as local governments and communities have less power to participate in decision making compared to the larger governance bodies. As the *muhtar* (local authority) of Aksicim village in Kırklareli related to İlhan (2021a) regarding the water transfers, "Istanbul is a big fish, our villages are small fish, what can we do against a big fish?" Finally, an additional aspect of water justice includes the concept of recognition to understand who is valued or respected. Istanbul as the largest share of Turkey's GDP is given the most value, even if the majority of water demand is for residential use, while more sustainable local economic activities in the water-exporting provinces were deemed unimportant. Işlar (2012) argued that Turkey relies on a "politics of exclusion, through redefinition of productive use, access, and rights – as well as through legal and social discursive practices that marginalize and undermine alternative framings of nature" (p. 319). Recalling concepts of water justice, state ownership of rivers can lead to procedural injustices where those most impacted by water resource development have less of a voice in decision-making, coupled with a lack of recognition of less powerful groups' interests in water resources for the benefit of larger state interests and the needs of megacities such as Istanbul.

The centralization of power and capital creates a distance between those making decisions surrounding water resource development, management, and distribution, and those who are impacted by these decisions (Johnston, 2003). This leads to tense, "conflictual relationships between geographical imaginations of modernization and urbanization, and the actual social, economic and ecological costs generated by modernity imaginations" (Hommes and Boelens, 2017, 74). In political ecology, environmental problems are seen not as a result of "natural" forces, but instead are often a result of political and economic forces (Işlar and Boda, 2014). Işlar and Boda (2014) argue that "large-scale hydro-political projects" such as IBTs can be viewed as "political symbols that help state actors to gain legitimacy and political and economic support from other state institutions and/or their voting constituency" (p. 2). This trend has occurred across the eastern Mediterranean, particularly after the 1950s, for governments to justify their development through discourses of progress, development, modernization, and nationalism (Mason, 2020). Though their impact is felt at the local scale, IBTs are usually controlled by national governments supported by powerful collectives of engineering, financial, and political groups which leads to water justice challenges since there usually is a lack of engagement or assessment of other alternatives as previously discussed (Rollason et al., 2021). Both the Istranca Streams and Melen Projects were co-developed with İSKİ and DSİ. The Melen Project's size in particular is seen as a sign of prestige and attracts many investors including Turkish construction and engineering companies and business elites which further increases support for similar projects and obscures more sustainable alternative water management options (Işlar and Boda, 2014).

Trends show that "developing" and "managing" water resources through a centralized and commodified approach changes power relations over water value, access, use, and control from those living near the water resource to external power structures (Johnston, 2003). The commodification of water shifts the meaning and prioritization of local uses towards the national, and sometimes global economy, (Johnston, 2003) as is the case for Istanbul's water supply which invisibilizes rural communities' rights to water. In Turkey, with neoliberal structural changes to DSİ, the privatization process leads to the redefinition of productive use, access, and rights to water which then marginalize less powerful voices and "alternative framings of nature" or water use (Işlar, 2012, p. 319). Though İSKİ and sometimes the national government has developed demand-side water management solutions such as reducing water leaks from the system, encouraging residential water conservation, planting trees and developing protection zones for watersheds, and designing regulations for rainwater harvesting and reuse, there is still a reliance on increasing water supply both from the Melen and from new sources like the Karamandere, İsaköy, and Sungurlu. This is also further complicated by megaprojects such as the new Istanbul Airport, built close to Terkos Lake which threatens local water quality, and the proposed KanalIstanbul Project. KanalIstanbul also shows an inter-jurisdictional challenge when it comes to water security. İBB is vocally against KanalIstanbul, which is led by the central government, and states that the project, "if undertaken, will cause irreversible environmental damage and deepen the effects of climate crisis with the urban heat island that it will create" (İBB, 2020, p. 4). İBB's messaging counters the central government and Istanbul Valiliği, stating that with the destruction of the Sazlıdere Dam and damage to Terkos Lake caused by the Project and increased demand due to new housing projects around the Canal, "it will not be possible to provide for such a demand in a city that is already trying to supply water from Melen River" (p. 12). This creates governance challenges where different government bodies' goals and views on water security come into conflict, often at the expense of the less powerful groups. Furthermore, water-exporting provinces of Tekirdağ and Düzce are planning to increase their surface water supply as demand grows and groundwater faces increased pollution, which could create potential conflict between the provinces in the future.

Ultimately the continued reliance on large-scale water transfers as a solution to Istanbul's water scarcity neglects the fact that water scarcity is a result of water demand and as a result cements a path dependency towards continued expansion of water resources to meet increased demand due to the supply-demand cycle and reservoir effects. As water supply increases, so too will demand through increased economic activity and investments in the region, creating a never-ending supply-demand cycle feedback loop. Similar patterns occur around the world, where, soon after the development of an IBT, water scarcity reappears due to continued development and in-migration that is fuelled by a false perception of water security and government programs (Burak et al., 2021). This leads to increased vulnerability not only for the donor provinces but also for Istanbul as the city relies further on water from hundreds of kilometres away. Expected impacts from climate change such as changes in precipitation patterns and reduction in water availability will impact Istanbul immensely (İBB, 2021). Williams et al. (2022) argue that climate justice components are intrinsic to the structural factors that impact climate change-related vulnerability in cities, and these impacts will most likely be faced by marginalized groups. Unequal distribution of risks from climate change-exacerbated hazards such as droughts and flooding often relate to an unequal distribution of urban infrastructure and certain communities facing more difficulty in accessing the formal economy. Informal and later-formalized settlements are often home to marginalized and displaced communities who have moved to neighbourhoods that are more at risk due to lower costs of housing in these areas (Williams et al., 2022). This review shows that water transfers impact both the water-importing and -exporting provinces beyond water availability and shows that water security across the whole region can be affected both environmentally and socio-economically.

7. CONCLUSION

This study attempted to understand the water security of Istanbul and the provinces that provide the city with water and uncover the impacts of the reliance of the city on IBTs. Based on recommendations from the literature, a socio-hydrology approach was conducted to combine a quantitative study using indices to study the impacts of IBTs of the region with a document analysis case study approach to better understand the human-water relationships that drive water security in the region. Quantitative analyses are not always detailed enough to consider all aspects of water security, particularly in such an extreme case such as Istanbul with its high population and share of the country's GDP in an area with limited local water resources. Indices that study water security and water scarcity are limited in their ability to represent complex human-water interactions, spatial and temporal variations in water availability, and uncertain effects of climate change and socio-economic changes (Jaeger et al., 2013). Therefore, as recommended by socio-hydrology studies, the IBT efficiency water security index is supplemented with document analysis to uncover the impacts of water transfers to both Istanbul and the water-exporting provinces of Tekirdağ, Kırklareli, and Düzce. The main themes in the literature are the ecological and socio-econoic impacts of the IBTs to the water-exporting provinces, the impacts of increasing water supply and reliance on IBTs towards Istanbul's own expanded growth and water security, and the political framing and governance challenges that come from relying on IBTs. These results also aligned with aspects of water security such as water availability, climate change, water-related hazards, environmental health, socioeconomic impacts, and governance which are all affected by the IBTs . In this way, the three recommended avenues for socio-hydrological studies were analyzed. Firstly the indices used a comparative socio-hydrology analysis to understand the impact of the IBTs on the receiving and exporting provinces which was elaborated on further with a historical and process socio-hydrology study to understand the impacts of the IBTs on water security in the region and uncover the political and governance reasonings for the continued reliance on supply-side water management in the region. Water security was assessed using research from the fields of political ecology, hydrosocial studies, and water justice to better understand all aspects of water security that might be hidden by conducting a quantitative analysis on its own.

As discussed, power plays a large role in IBTs and water security of Istanbul, where the city consolidates economic and political power and is prioritized at the expense of the surrounding regions. Water security is framed through supply-side management to increase water supply in the face of climate change rather than demand-side management which would conserve current available resources. Political ecology can help to uncover the power relationships in water-human relationships at all levels of governance. As the literature argues, when considering Istanbul’s water supply infrastructure at the local scale, it may appear to be needed to solve local water scarcity challenges, however when considering the impacts to the water exporting provinces and the broader region, the impacts become more complex. Given that the reliance on IBTs can be argued as false solutions to drought events and climate change, their disproportionate socio-economic impact to donor basin communities, and climate-related water scarcity concerns, IBTs become a water justice issue not just a question of water security. İlhan (2021a) notes that true environmental and climate justice can be found at the intersection of distributive, procedural, and recognition justice. In this intersection, the benefits and costs of IBTs would be more equally distributed, all stakeholders would have meaningful power in the decision-making process, and differing values of water would be considered (İlhan, 2021a).

Therefore, a socio-hydrological approach combining a quantitative indices through political ecology, hydrosocial, and water justice studies lens to studying Istanbul’s water security uncovers the past and current impacts of relying on large-scale IBTs to combat water scarcity, and illuminates potential challenges for the future. Istanbul’s economic and political power is used to justify these large-scale water transfers while donor basins face displacement, loss of livelihood, and loss of the ability to take part in the decision making process or benefit from development investments. However, in the future as Istanbul’s population and urbanization increases, alongside risks of drought and changing temperatures, both rural and urban areas will face water stress and negative health and economic impacts if water is not properly managed.

Although path dependency of urban infrastructure is locked in with the reliance on current IBTs, there are still opportunities to manage water for the good of the environment and to mitigate climate change impacts. İSKİ, as well as the national and local governments, have demonstrated a greater interest in improving demand-side water management options such as through rainwater harvesting, encouraging reduced consumption, and reducing losses and leaks from the system. Lessons can be learned from historical water management where Byzantine and Ottoman water supply systems utilized more sustainable water resources such as rainwater and managed population in-migration to reduce demand. Governments must seek out demand-side management solutions to properly conserve water and reduce negative impacts to the environment and local livelihoods, while involving all stakeholders in the decision-making process including defining what water justice may look like.

More research is recommended to explore the impacts of water transfers to the water security of water-exporting provinces in the future under different climate change and socio-economic change.

8. FUTURE RESEARCH

More research is needed on the impacts of the water transfers to the water-exporting provinces' water security from a socio-hydrological lens that seeks to understand hydrological, ecological, socio-economic, and governance changes. While this study focused on Istanbul as the driving force in challenges to water security in the region, research from these provinces were severely limited compared to the literature on Istanbul and should be explored further. Examples could include studying historical water gauge data from DSİ on rivers in the water-exporting provinces to assess changes in flow and monitoring and forecasting water loss from evapotranspiration from dams to better understand the impacts of the reliance on reservoirs as the main water storage methods for the region. From a governance perspective, future research could include interviews with local governments and communities in the water-exporting provinces to better understand the impacts of the IBTs and the possible participatory justice challenges involved. For example, information was not available on how exactly the DSİ and İSKİ were able to expand their mandated areas to include additional provinces, how were local communities and governments involved in decision making, and are there concerns for the future water security of Tekirdağ, Kırklareli, and Düzce considering these provinces recent push to rely more on surface water sources rather than groundwater? Additional research is required to understand the relationship between ISKI and DSİ and if there are any conflicts in water management due to differing mandates. Finally, though many Turkish-language resources were used, the author's limited Turkish meant that some sources may not have been discovered so future studies should ensure to include all resources available in both English and Turkish.

Duan et al. (2022) extend their indices into future projections under different population, climate change, and water infrastructure development scenarios. Istanbul has been studied under different future projection scenarios (WEAP by Daloğlu Çetinkaya et al., 2022; network modelling by Burak et al., 2021; etc.). In order to understand supply-demand dynamics of IBTs, the three provinces, Tekirdağ, Kırklareli, and Düzce, as well as additional provinces impacted by Istanbul's water transfers that were beyond the scope of this analysis (Kocaeli and Sakarya), should also be studied under different climate change and socio-economic scenarios to understand potential future impacts of the water transfers. This research should also be expanded to regions down- and upstream of the IBT projects for a more comprehensive look on the impact of the water transfers to the region. Similar to Duan et al. (2022) who studied the entire continental USA, a comparative study of all of Turkey's

IBTs using these indices would also help to understand water security across the country, especially considering the rise in IBTs to supply residential and agricultural water and building of new dams in the last few decades.

REFERENCES

Acara, E. (2019). Sequestering a river: The political ecology of the “dead” Ergene River and neoliberal urbanization in today’s Turkey. *Annals of the American Association of Geographers, 109*(2), 422-433. https://doi.org/10.1080/24694452.2018.1494537

Aktaş, O. (2014). Impacts of climate change on water resources in Turkey. *Environmental Engineering and Management Journal, 13*(4), 881-889. https://doi.org/10.30638/eemj.2014.092

Ağıralioğlu, N., & Danandeh Mehr, A. (2019, April 20-22). P*rinciples of planning and realization of Greater Melen Water Supply Project* [Conference paper]. International Conference on Civil and Environmental Geology and Mining Engineering, Trabzon, Turkey. Retrieved from http://acikerisim.antalya.edu.tr/handle/20.500.12566/75?locale-attribute=en

Avila, L., Silveira, R., Campos, A., Rogiski, N., Gocalves, K., Scortegagna, A., Freita, C., Aver, C., & Fan, F. (2022). Comparative evaluation of five hydrological models in a large-scale and tropical river basin. *Water, 13,* 3013. https://doi.org/10.3390/w14193013

Agyeman, J., Schlosberg, D., Craven, L., & Matthews, C. (2016). Trends and directions in environmental justice: From inequity to everyday life, community, and just sustainabilities. *Annual Review in Environmental Resources, 41,* 321-40. https://doi.org/10.1146/annurev-environ-110615-090052

Babel, M., and Shinde, V. R. (2018). A framework for water security assessment at basin scale. *APN Science Bulletin, 8*(1), 27-32. https://doi.org/10.30852/sb.2018.342

Bağdatlı, M.C., & Belliturk, K. (2016). Negative Effects of Climate Change in Turkey. *Advances in Plants & Agriculture Research, 3*(2), 44-46. https://doi.org/10.15406/apar.2016.03.00091

Bakirci, M. (2016). The effects of dams on the spatial reorganization: The case of Melen Dam. *Marmara Cografya Dergisi, 33,* 439-464. https://dergipark.org.tr/tr/pub/marucog/issue/28299/300675

Bakker, K., & Allen, D. (2015). *Canadian water security assessment framework*. Canadian Water Network. https://cwn-rce.ca/report/canadian-water-security-assessment-framework-tools-for-assessing-watershed-security-and-improving-watershed-governance/

Beal, C. D., Ram Gurung, T., & Stewart, R. A. (2016). Demand-side management for supply-side efficiency: Modeling tailored strategies for reducing peak residential water demand. *Sustainable Production and Consumption, 6*, 1-11. https://agris.fao.org/agris-search/search.do?recordID=US201900192141

Bekiroğlu, S., & Eker, O. (2011). The importance of forests in sustainable supply of drinking water: Istanbul example. *African Journal of Agricultural Research, 6*(7), 1794-1801. https://doi.org/10.5897/AJAR10.690

BirdLife International. (2022). *Country profile: Turkey*. Retrieved December 13, 2022, from http://datazone.birdlife.org/country/turkey

Biswas, A. (2004). Integrated water resources management: A reassessment: A water forum contribution. *Water International, 29*(2), 248-256. https://doi.org/10.1080/02508060408691775

Biswas, A. K. (2008). Integrated water resources management: Is it working? *Water Resources Development, 24*(1), 5–22. https://doi.org/10.1080/07900620701871718

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal, 9*(2), 27-40. https://doi.org/10.3316/QRJ0902027

Burak, S., Hunmeyra Bilge, A., & Ilker, D. (2021). Assessment and simulation of water transfer for the megacity Istanbul. *Physical Geography*. https://doi.org/10.1080/02723646.2021.1904698

Carr, G., Barendrecht, M. H., Balana, B. B., & Debevec, L. (2022). Exploring water quality management with a socio-hydrological model: a case study from Burkina Faso. *Hydrological Sciences Journal*, *67*(6), 831-846. https://doi.org/10.1080/02626667.2021.2020276

Cebi, U., Ozer, S., Ozturk, O., Ozcan, C., Tok, E., Sengorur, B., & Ahi, Y. (2019). Edirne ili barajlarının bazı fiziko-kimyasal özellikleri ve sulama suyu kalite sınıfları. *Toprak Su Dergisi, 8*(2), 96-106. https://doi.org/10.21657/topraksu.555554

Cengiz, S., Atmis, E., & Gormus, S. (2019). The impact of economic growth oriented development policies on landscape changes in Istanbul Province in Turkey. *Land Use Policy, 87*. https://doi.org/10.1016/j.landusepol.2019.104086

Chaves, H. M. L., & Alipaz, S. (2007). An integrated indicator based on basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index. *Water Resources Management, 21,* 883-895. https://doi.org/10.1007/s11269-006-9107-2

Cinar, T. (2009). Privatisation of urban water and sewerage services in Turkey: Some trends. *Development in Practice, 19*(3), 350-364. https://www.jstor.org/stable/27752063

Clement, F., Suhardiman, D., & Bharati, L. (2017). IWRM discourses, institutional holy grail and water justice in Nepal. *Water Alternatives, 10*(3), 870-887. http://www.water-alternatives.org/index.php/alldoc/articles/vol10/v10issue3/386-a10-3-12/file

Cook, C., & Bakker, C. (2012). Water security: Debating an emerging paradigm. *Global Environmental Change, 22*(1), 94–102. https://doi.org/10.1016/j.gloenvcha.2011.10.011

Cüceloğlu, G., Abbaspour, K. C., Ozturk, I., 2017. Assessing the water-resources potential of Istanbul by using a soil and water assessment tool (SWAT) hydrological model. Water, 9,10, 1-18. https://www.mdpi.com/2073-4441/9/10/814

Devlet Su Isleri (DSİ). (2022). *Hakkimizda*. Retrieved March 4, 2023, from https://www.DSİ.gov.tr/Sayfa/Detay/692

Devlet Su Isleri (DSİ). (2023). *Toprak ve su kaynakları*. Retrieved March 4, 2023, from https://bolge14.DSİ.gov.tr/Sayfa/Detay/1185

Devlet Su Isleri (DSİ) 5. Bölge Müdürlüğü. (n.d.). *Toprak ve su kaynakları*. Retrieved March 4, 2023, from https://bolge05.dsi.gov.tr/Sayfa/Detay/978

Devlet Su Isleri (DSİ) 11. Bölge Müdürlüğü. (n.d.). *Toprak ve su kaynakları.* Retrieved March 4, 2023, from https://bolge11.dsi.gov.tr/Sayfa/Detay/1081

Daloğlu Çetinkaya, I., Yazar, M., Kilinc, S., & Guven, B. (2022). Urban climate resilience and water insecurity: future scenarios of water supply and demand in Istanbul. *Urban Water Journal*. https://doi.org/10.1080/1573062X.2022.2066548

Di Baldassarre, G., Wanders, N., AghaKouchak, A., Kuil, L., Rangecroft, S., Veldkamp, T. I. E., Garcia, M., van Oel, P. R., Breinl, K., & Van Loon, A. F. (2018). Water shortages worsened by reservoir effects. *Nature Sustainability, 1*, 617-622. https://doi.org/10.1038/s41893-018-0159-0

Dinçkal, N. (2008). Reluctant modernization: The cultural dynamics of water supply in Istanbul, 1885-1950. *Technology and Culture, 49*(3), 675-700. https://doi.org/10.1353/tech.0.0079

Dogan, E. & Stupar, A. (2017). The limits of growth: A case study of three mega-projects in Istanbul. *Cities, 60*(A), 281-288. https://doi.org/10.1016/j.cities.2016.09.013

Doğruel, A. S., & Doğruel., F. (2018). Two phases of deindustrialization policies in Istanbul. *Journal of Research in Economics, 2*(2), 186-201. https://doi.org/10.24954/JORE.2018.24

Duan, K., Caldwell, P. V., Sun, G., McNulty, S. G., Qin, Y., Chen, X., & Liu, N. (2022). Climate change challenges efficiency of inter-basin water transfers in alleviating water stress. *Environmental Research Letters, 17*, 1-13. https://doi.org/10.1088/1748-9326/ac5e68

Düzce Il Mudurlugu – T.C. Gida Tarim ve Hayvancilik Bakanligi. (2018). *Düzce Tarimsal Kuraklik Eylem Plani (2018-2022)*. Düzce Il Mudurlugu – T.C. Gida Tarim ve Hayvancilik Bakanligi. https://www.Düzce.tarimorman.gov.tr/Belgeler/_Kuraklik_Eylem_Plani.pdf

Düzce Municipality (Düzce Belediyesi). (2021). *2021 Yili Faaliyet Raporu. T. C. Düzce Belediye Baskanligi Mali Hizmetler Mudurlugu*. Düzce Belediyesi. https://Düzce.bel.tr/8873-faaliyet-raporu

Düzce Valiliği. (2012-2020). *Il çevre durum raporu.* T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. https://ced.csb.gov.tr/il-cevre-durum-raporlari-i-82671

Ekmekcioğlu, Ö., Koc, K., Özger, M. (2021). District based flood risk assessment in Istanbul using fuzzy analytical hierarchy process. *Stochastic Environmental Research and Risk Assessment, 35,* 617-637. https://doi.org/10.1007/s00477-020-01924-8(0123456789().,-volV)(0123456789,-().volV)

Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum, 13*(4), 258–267. https://doi.org/10.1111/j.1477-8947.1989.tb00348

FAO Land Division Water Development. (2000). *New Dimensions in Water Security: Water, Society and Ecosystem Services in the 21st Century*. Food and Agriculture Organization of the United Nations. https://www.fao.org/documents/card/es/c/f99b86cd-de54-4eea-b241-dbe6e3e2b6f2/

Faundez, M., Alcayaga, H., Walters, J., Pizarro, A., & Soto-Alarez, M. (2022). Sustainability of water transfer projects: A systematic review. *Science of the Total Environment, 860.* https://doi.org/10.1016/j.scitotenv.2022.160500

Fielding, K. S., Spinks, A., Russell, S., McCrea, R., Steward, R., & Gardner, J. (2013). An experimental test of voluntary strategies to promote urban water demand management. *Journal of Environmental Management, 114,* 343-351. https://doi.org/10.1016/j.jenvman.2012.10.027

Frota, R., L., de Assis Souza Filho, F., Barros, L. S., Silva, S. M. O., Porto, V. C., & Rocha, R. V. (2021). “Network” sociohydrology: A case study of causal factors that shape the Jaguaribe River Basin, Ceará-Brazil. *Hydrological Sciences Journal, 66*(6), 935-950. https://doi.org/10.1080/02626667.2021.1913282

Global Water Partnership (GWP). (2000). *Towards water security: A framework for action.* Global Water Partnership. https://www.ircwash.org/resources/towards-water-security-framework-action

George, A. L., & A. Bennett. (2005). *Case studies and theory development in the social sciences*. Cambridge, Massachusetts, USA: MIT Press.

Ghoreishi, M., Elshorbagy, A., Razavi, S., Blöschl, G., Sivapalan, M., & Abdelkader, A. (2023). *Cooperation in a transboundary river basin: a large-scale socio-hydrological model of the Eastern*

Nile. Hydrology and Earth System Sciences, 27(5), 1201-1219. https://doi.org/10.5194/hess-27-1201-2023.

Governorship of Istanbul. (2019). *Kanal Istanbul: Project of the Century*. Retrieved December 13, 2022, from http://en.Istanbul.gov.tr/kanal-Istanbul-project-of-the-century

Grey, D., & Sadoff, C.W. (2007). Sink or Swim? Water security for growth and development. *Water Policy, 9*, 545-571. https://doi.org/10.2166/wp.2007.021

Güneralp, B., Tezer, A., & Albayrak, I. (2013). Local assessment of Istanbul: Biodiversity and ecosystem services. In T., Elmqvist et al. (Ed.). *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment* (1st ed., pp. 291-311). Springer Nature. https://doi.org/10.1007/978-94-007-7088-1_16

Gupta, J. & van der Zaag, P. (2008). Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. *Physics and Chemistry of the Earth, 33*(1-2), 28-40. https://doi.org/10.1016/j.pce.2007.04.003

Güvenç, M. (2023, March 14). *Istanbul, a Thirsty City: the Curse of Geography?* [Conference presentation]. Water in Istanbul and Beyond: Past, Present, Future, Istanbul, Turkey. https://biaa.ac.uk/events/water-in-Istanbul-and-turkey-past-present-future/

Güzel, B., Canli, O., & Aslan, E. (2022). Spatial distribution, source identification and ecological risk assessment of POPs and heavy metals in lake sediments of Istanbul, Turkey. *Marine Pollution Bulletin, 125*, 1-14. https://doi.org/10.1016/j.marpolbul.2021.113172

Haeffner, M., Hellman, D., Cantor, A., Ajibade, I., Oyanedel-Craver, V., Kelly, M., Schifman, L., & Weasel, L. (2021). Representation justice as a research agenda for socio-hydrology and water governance. *Hydrological Sciences Journal, 66*(11), 1611-1624. https://doi.org/10.1080/02626667.2021.1945609

Hall, D. & Lobina., E. (2009). *The Private Sector in water in 2009*. Public Services International Research Unit. https://www.academia.edu/83514320/The_private_sector_in_water_in_2009

Harris, L. M., & Işlar, M. (2013). Neoliberalism, Nature, and Changing Modalities of Environmental Governance in Contemporary Turkey. In Y., Atasoy (Ed.). *Global Economic Crisis and the Politics of Diversity: Trans/Regional Variations, Mixed Responses, New Tensions* (52-78). London: Palgrave Macmillan.

Harris, L. M., McKenzie, S., Rodina, L., Shah, S. H., & Wilson, N. J. (2017). Water justice: Key concepts, debates and research agendas. In R., Holifield, J., Chakraborty, & G., Walker (Eds.). *The Routledge Handbook of Environmental Justice* (338-349). London: Routledge.

He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A. (2021). Future global urban water scarcity and potential solutions. Nature Communications, 12, 1-11. https://doi.org/10.1038/s41467-021-25026-3

Hommes, L., & Boelens, R. (2017). Urbanizing rural waters: Rural-urban water transfers and the reconfiguration of hydrosocial territories in Lima. *Political Geography, 57,* 71-80. http://dx.doi.org/10.1016/j.polgeo.2016.12.002

İBB. (2018). *Istanbul climate change action plan summary report*. İBB. https://cevre.İBB.Istanbul/brosurler/

İBB. (2020). *Canal Istanbul workshop.* İstanbul Büyükşehir Belediye and Istanbul Planning Agency. https://ipa.Istanbul/wp-content/uploads/2021/08/canal-Istanbul-workshop.pdf

İBB. (2021). *Istanbul climate change action plan*. İstanbul Büyükşehir Belediye. https://cevre.İBB.Istanbul/wp-content/uploads/2022/06/Istanbul_climate_change_action_plan_v03.pdf

İlhan, A. (2021a, April 9). *Political Ecology of Istanbul's Two-Thousand-Year-Old Water Paradigm, Explorations along the Peripheries of Contemporary Istanbul* [Conference presentation]. Istanbul Unbound Conference, Istanbul, Turkey. https://en.iae.org.tr/content/Istanbul-unbound/188

İlhan, A. (2021b, September 15). *Supply, demand or prayer.* Eurozine. https://www.eurozine.com/supply-demand-or-prayer/

İlhan, A. (2022). Istanbul’un suyu, Istanbul’un gelecegi. In M. Genc (Ed.). *Istanbul Su Kulturu* (pp. 387-414). Istanbul, Turkey, İstanbul Büyükşehir Belediye.

IMC (Istanbul Master Plan Consortium). (1999). *Istanbul water supply, sewerage and drainage, sewage treatment and disposal master plan*. Istanbul, Turkey: İSKİ, Istanbul Metropolitan Municipality, and General Directorate of Istanbul.

Inan, I. H. (2017). Environmental problems of Thrace region in Turkey. *Proceedings of the 2nd International Balkan Agriculture Congress, Tekirdağ, 16-18 May 2017, Turkey* (pp. 26-31). https://agribalkan.net/en/sayfa/988/previous-congress

IPCC. (2014). Summary for policymakers. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, L.L. White (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, U.S.A: Cambridge University Press.

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. In H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.). *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA: Cambridge University Press. https://doi.org/10.1017/9781009325844.

İSKİ. (2000-2021). *Annual Reports 2000-2021*. ISKI. Retrieved January 5, 2023, from https://www.İSKİ.Istanbul/web/en-US/kurumsal/İSKİ-hakkinda/annual-reports1

İSKİ. (2022a). *Istanbul monthly water consumption data* [Data set]. IMM Open Data Portal. https://data.İBB.gov.tr/en/dataset/Istanbul-aylik-su-tuketimi-verileri

İSKİ. (2022b, January 18). *Melen Havzasına İleri Biyolojik Arıtma Geliyor!* https://İSKİ.gov.tr/web/tr-TR/haberler1/haberler-detay/melen-havzasina-ileri-biyolojik-aritma-geliyor1

İSKİ. (2022c). *Melen ve Yesilcay Regulatorlerinden alinan su miktarlari* [Data set]. IMM Open Data Portal. https://data.İBB.gov.tr/dataset/melen-ve-yesilcay-regulatorlerinden-alinan-su-miktarlari

İSKİ. (2023). *Baraj doluluk orani.* Retrieved March 31, 2023, from https://www.İSKİ.Istanbul/web/tr-TR/baraj-doluluk

İSKİ. (2023b, January 23). *Saving water in 21 ways*. https://www.İSKİ.Istanbul/web/en-US/kurumsal/haberler/haberler-detay/saving-water-in-21-ways1

Işlar, M. (2012). Struggles for recognition: Privatisation of water use rights of Turkish rivers. *Local Environment, 17*(3), 317-329. http://dx.doi.org/10.1080/13549839.2012.665858

Işlar, M., & Boda, C. (2014). Political ecology of inter-basin water transfers in Turkish water governance. *Ecology and Society, 19*(4), 1-8. http://dx.doi.org/10.5751/ES-06885-190415

Istanbul Valiliği. (2012-2020). *İl çevre durum raporu*. T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. https://ced.csb.gov.tr/il-cevre-durum-raporlari-i-82671

Jaeger, W. K., Plantinga, A.J., Chang, H., Dello, K., Grant, G., Hulse, D., McDonnell, J.J., Lancaster, S., Moradkhani, H., Morzillo, A. T., Mote, P., Nolin, A., Santelmann, M., & Wu, J. (2013). Toward a formal definition of water scarcity in natural-human systems. *Water Resources Resources, 49,* 4506–4517. https://doi.org/10.1002/wrcr.20249

Jensen, O. and Wu, H. (2018). Urban water security indicators: Development and pilot. *Environmental Science and Policy, 83,* 33-45. https://doi.org/10.1016/j.envsci.2018.02.003

Johnston, B. R. (2003). The political ecology of water: An introduction. *Capitalism, Nature, Socialism, 14*(3), 73-90. https://doi.org/10.1080/10455750308565535

Karakaya, N., Evrendilek, F., & Gonenc, E. (2014). Interbasin water transfer practices in Turkey. *Ecosystem & Ecography, 4*(2), 1-5. http://dx.doi.org/10.4172/2157-7625.1000149

Kibaroglu, A. (2022). Turkiye’s water security policy: Energy, agriculture, and transboundary issues. *Insight Turkey, 24*(2), 69-88. https://doi.org/10.25253/99.2022242.5

Kırklareli Valiliği. (2012-2020). *İl çevre durum raporu*. T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. https://ced.csb.gov.tr/il-cevre-durum-raporlari-i-82671

Komakech, H.C., van der Zaag, P., & van Koppen, B. (2012). The last will be first: Water transfers from agriculture to cities in the Pangani river basin, Tanzania. *Water Alternatives, 5*(3), 700-720. https://hdl.handle.net/10568/40234

Kurnaz, L. (2014). *Drought in Turkey*. Istanbul Policy Center. https://ipc.sabanciuniv.edu/Content/Images/CKeditorImages/20200323-16034498.pdf

Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., Xu, Z., Chung M. G., Sun, J., & Li S. (2018). Nexus approaches to global sustainable development. *Nature Sustainability, 1*(9), 466-476. https://www.sei.org/publications/nexus-global-sustainable-development/

Mason, M. (2020). Hydraulic patronage: A political ecology of the Turkish-Northern Cyprus water pipeline. *Political Geography, 76*. https://doi.org/10.1016/j.polgeo.2019.102086

Mason, N., & Calow, R. (2012). *Water security: From abstract concept to meaningful metrics*. ODI. https://odi.org/en/publications/water-security-from-abstract-concept-to-meaningful-metrics/

McDonald, R. I., Weber, K., & Padowski, J. (2014). Water on an urban planet: Urbanization and the reach of urban water infrastructure. *Global Environmental Change, 27*(1), 96-105. https://doi.org/10.1016/j.gloenvcha.2014.04.022

McDonald, R. I., et al., 2020. Research gaps in knowledge of the impact of urban growth on biodiversity. *Nature Sustainability, 3*(1), 16-24. https://doi.org/10.1038/s41893-019-0436-6

McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: A review. *Hydrological Sciences Journal, 61*(13). https://doi.org/10.1080/02626667.2015.1128084

McMillan, H., Montanari, A., Cudennec, C., Savenije, H., Kreibich, H., Krueger, T., Liu, J., Mejia, A., Van Loon, A., Aksoy, H., & Di Baldassarre, G. (2016). Panta Rhei 2013-2015: Global perspectives on hydrology, society and change. *Hydrological Sciences Journal, 61*(7), 1174-1191. https://doi.org/10.1080/02626667.2016.1159308

Mendoza, A. R. (2019). *The aqueduct between us – inserting and asserting an Indigenous California Indian perspective about Los Angeles water* (ProQuest ID: Mendoza_ucla_0031N_18091) [Master's thesis, University of California]. UCLA e-Scholarship. https://escholarship.org/uc/item/9nn7v9z8

Mirchi, A., Madani, K., Watkins, D., & Ahmad, S. (2012). Synthesis of system dynamics tools for holistic conceptualization of water resources problems. *Water Resources Management, 26,* 2421-2442. https://doi.org/10.1007/s11269-012-0024-2

Mostert, E. (2018). An alternative approach for socio–hydrology: case study research. *Hydrology and Earth System Sciences*, *22*(1), 317-329. https://doi.org/10.5194/hess-22-317-2018, 2018

Neal, M., Lukasiewicz, A., & Syme, G. J. (2014). Why justice matters in water governance: Some ideas for a 'water justice framework'. *Water Policy, 16*(2), 1-18. https://doi.org/10.2166/wp.2014.109

Norman, E. S., Dunn, G., Bakker, K., Allen, D. M., & Cavalcanti de Albuquerque, R. (2013). Water security assessment: Integrating governance and freshwater indicators. *Water Resources Management, 27,* 535-551. https://doi.org/10.1007/s11269-012-0200-4

Owens, K., Carmody, E., Grafton, Q., O'Donnell, E., Wheeler, S., Godden, L., Allen, R., Lyster, R., Steduto, P., Jiang, Q., Kingsford, R., & Quiggin, J. (2022). Delivering global water security: Embedding water justice as a response to increased irrigation efficiency. *Wiley Interdisciplinary Reviews-Water*, *9*(6). https://doi.org/10.1002/wat2.1608

Ozis, U., Alkan, A., & Ozdemir, Y. (2020). Water works of ancient civilizations. In N. B. Harmancioglu & D. Altinbilek (Eds.). *Water Resources of Turkey* (pp. 11-59). https://doi.org/10.1007/978-3-030-11729-0_2

Ozturk, I., Erturk, A., Ekdal, A., Gurel, M. (2013). Integrated watershed management efforts: Case study from Melen Watershed experiencing interbasin water transfer. *Water Science &Technology Water Supply, 13*(5), 1272-1280. https://doi.org/10.2166/ws.2013.139

Pahl-Wostl, C., Holtz, G., Kastens, B., & Knieper, C. (2010). Analyzing complex water governance regimes: the management and transition framework. *Environmental Science & Policy, 13*(7), 571–581. https://doi.org/10.1016/j.envsci.2010.08.006

Pahl-Wostl, C., Palmer, M., Richards, K. (2013). Enhancing water security for the benefits of humans and nature—the role of governance. *Current Opinion in Environmental Sustainability, 5*(6), 676-684. https://doi.org/10.1016/j.cosust.2013.10.018

Pande, S., & Sivapalan, M. (2017). Progress in socio-hydrology: A meta-analysis of challenges and opportunities. *WIREs Water, 4*(1193), 1-18. https://doi.org/10.1002/wat2.1193

Pehlivan, R. & Yilmaz, O. (2005). Water quality and hydrogeochemical characteristics of the River Buyukmelen, Düzce, Turkey. *Hydrological Processes, 19,* 3947-3971. https://doi.org/10.1002/hyp.5859

Peker, E. (2020). Urban water management in Istanbul: exploring the challenges in the face of climate change. *Heritage Turkey, 10*, 29. https://doi.org/10.18866/biaa2020.14

Peker, E. (2023). Enabling widespread use of rainwater harvesting (RWH) systems: Challenges and needs in twenty-first-century Istanbul. *European Planning Studies, 31*(1), 103-122. https://doi.org/10.1080/09654313.2022.2125794

Petz, S. (2021, September 15). *After 24 years of water advisories, Shoal Lake 40 First Nation can drink from the tap.* CBC News. https://www.cbc.ca/news/canada/manitoba/shoal-lake-40-first-nation-drinking-water-advisory-1.6176167

Philip, E. (2021). Coupling Sustainable Development Goal 11.3.1 with current planning tools: city of Hamilton, Canada. *Hydrological Sciences Journal, 66*(7), 1124-1131. https://doi.org/10.1080/02626667.2021.1918340

Raskin, P., Gleick, P., Kirshen, P., Pontius, G., & Strzepek, K. (1997). *Comprehensive Assessment of the Freshwater Resources of the World. Water Futures: Assessment of Long-range Patterns and Problems.* WMO. https://www.sei.org/publications/water-futures-assessment-long-range-patterns-problems-2/

Reddy, V. R., & Syme, G. J. (2014). Editorial: Social sciences and hydrology: An introduction. *Journal of Hydrology, 550*, 441-452. https://doi.org/10.1016/j.jhydrol.2017.05.008

Remi, D.& Lindenstrauss, G. (2020). The Istanbul canal: Erdogan's "crazy project" raises concerns. *Institute for National Security Studies, 1269*, 1-5. https://www.jstor.org/stable/resrep23523

Rollason, E., Sinha, P., & Bracken, L. J. (2021). Interbasin water transfer in a changing world: A new conceptual model. *Progress in Physical Geography, 0*(0), 1-27. https://doi.org/10.1177/03091333211065004

Saatci, A. M., 2013. Solving water problems of a metropolis. *Journal of Water Resource and Protection, 5,* 7-10. http://dx.doi.org/10.4236/jwarp.2013.54A002

Sanchis-Ibor, C., Molla, M. G., Torregrosa, T., Ortega-Reig, M., and Jimenez, M. S. (2019). Water transfers between agricultural and urban users in the region of Valencia (Spain). A case of weak governance? *Water Security,7*, 1-17. https://doi.org/10.1016/j.wasec.2019.100030

Savun-Hekimoğlu, B., Erbay, B., Hekimoğlu, M., & Burak, S. (2021). Evaluation of water supply alternatives for Istanbul using forecasting and multi-criteria decision making methods. *Journal of Cleaner Production, 287*, 1-14. https://doi.org/10.1016/j.jclepro.2020.125080

Schlosberg, D. (2007). D*efining Environmental Justice: Theories, Movements, and Nature.* Oxford, England: Oxford Academic. https://doi.org/10.1093/acprof:oso/9780199286294.001.0001

Seto, K., & Shepherd, J. (2009). Global urban land-use trends and climate impacts. *Current Opinion in Environmental Sustainability, 1*(1), 89-95. https://doi.org/10.1016/j.cosust.2009.07.012

Sivapalan, M., Savenije, H. H. G., & Blöschl, G. (2012). Socio-hydrology: A new science of people and water. *Hydrological Processes, 26*, 1270-1276. https://doi.org/10.1002/hyp.8426

Sivri, N., Cilingirturk, A. M., Seker, D. Z., Imamoglu, Z., & Ucan, O. N. (2017). Prediction of water consumption in Istanbul by means of statistical forecasting models and Geographical Information Systems (GIS). *Fresenius Environmental Bulletin, 26*(1), 375-382. https://www.researchgate.net/publication/357956944_WATER_CONSUMPTION_OF_ISTANBUL_BY_MEANS_OF_STATISTICAL_FORECASTING_MODEL_GIS

Soued, C., Harrison, J. A., Mercier-Blais, S., & Prairie, Y. T. (2022). Reservoir CO_2 and CH_4 emissions and their climate impact over the period 1900–2060. *Nature Geoscience, 15*, 700-705. https://doi.org/10.1038/s41561-022-01004-2

Sözen, S., Yuzer, E., Duba, S., & Gokcekus, H. (2021). Water management for Istanbul: Collapse or survival. *Environmental Earth Sciences, 80*(7), 289. https://doi.org/10.1007/s12665-021-09563-0

Srinivasan, V., Konar, M., & Sivapalan, M. (2017). A dynamic framework for water security. *Water Security, 1*, 12-20. https://doi.org/10.1016/j.wasec.2017.03.001

Sullivan, C. (2002). Calculating a water poverty index. *World Development, 30*(7), 1195-1210. https://doi.org/10.1016/S0305-750X(02)00035-9

Tanir, T., Findik, S. B., Girayhan, T. F., & Yorulmaz, O. (2022). Flood social vulnerability assessment: A case study of Turkey. *Turkish Journal of Water Science and Management, 6*(2), 237-259. https://dergipark.org.tr/tr/pub/tjwsm/issue/70496/1089403

Taylor, D.E. (2000). The rise of the environmental justice paradigm: injustice framing and the social construction of environmental discourses. *American Behavioural Scientist, 43*(4), 508–580. https://doi.org/10.1177/0002764200043004003

Tekirdağ Valiliği. (2012-2020). *İl çevre durum raporu*. T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. https://ced.csb.gov.tr/il-cevre-durum-raporlari-i-82671

TESKİ. (2014-2021). *Annual Report*. TESKİ. https://www.TESKİ.gov.tr/icerik/detay.aspx?Id=344

Tokuslu, A. (2022). Assessing the impact of climate change on Turkish basins. *International Journal of Environment and Geoinformatics (IJEGEO),* *9*(4), 102-112. https://doi.org/10.30897/ijegeo.1066840

Torio, P. C., Harris, L. M., and Angeles, L. C. (2019). The rural-urban equity nexus of Metro Manila’s water system. *Water International, 44*(2), 115-128. https://doi.org/10.1080/02508060.2019.1560559

TUİK. (2018). *Nüfus Projeksiyonları, 2018-2080* [Data set]. TUİK. https://data.TUİK.gov.tr/Bulten/Index?p=Nufus-Projeksiyonlari-2018-2080-30567

TUİK. (2022). *Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları, 2021* [Data set]. TUİK. https://data.TUİK.gov.tr/Bulten/Index?p=45500

TUİK. (2023). *Regional Statistics (1998-2020)* [Data set]. TUİK. https://biruni.TUİK.gov.tr/bolgeselistatistik/anaSayfa.do?dil=en

UNDP. (n.d.). *The SDGs in action*. Retrieved May 10, 2023, from https://www.undp.org/sustainable-developmentgoals?gclid=CjwKCAjw__ihBhADEiwAXEazJo14jjlZspWvFTpOUeDiY6_kyfk9t1FU77RHJeQMYMzhllW8Zmsg8hoCUFMQAvD_BwE

UNESCO-IHE. (2009). *Research themes: Water security*. Retrieved December 15, 2022, from http://www.unesco-ihe.org/ Research/Research-Themes/Water-security

UNICEF. (n.d.). *What is Climate Justice? And what can we do achieve it?* Retrieved January 28, 2023, from https://www.unicef.org/globalinsight/what-climate-justice-and-what-can-we-do-achieve-it

Ürer, O. (2023, January 6). *Yağış azlığı Hasanlar Barajı'nda su seviyesini düşürdü*. Anadolu Ajansi. https://www.aa.com.tr/tr/gundem/yagis-azligi-hasanlar-barajinda-su-seviyesini-dusurdu/2781162

Van Leeuwen, K. & Sjerps, R. (2016). Istanbul: The challenges of Integrated Water Resources Management in Europe’s megacity. *Environment, Development and Sustainability, 18,* 1-17. https://doi.org/10.1007/s10668-015-9636-z

Veettil, A. V., Mishra, A. K., & Green, T. R. (2022). Explaining water security indicators using hydrologic and agricultural systems models. *Journal of Hydrology, 607*, 1-15. https://doi.org/10.1016/j.jhydrol.2022.127463

Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, Sullivan, S. E.., Sullivan, C. A., Reidy Liermann, C., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature, 467*, 555-561. https://doi.org/10.1038/nature09440

Walker, G. (2012). *Environmental justice: Concepts, evidence and politics*. London, Routledge. https://doi.org/10.4324/9780203610671

Ward, K., Smith, S. D., & Crapper, M. (2020). Using the Byzantine water supply of Constantinople to examine modern concepts of sustainability. In S., Charlesworth, C. A., Booth, & K., Adeyeye, (Eds.). *Sustainable Water Engineering* (pp. 13-30). https://doi.org/10.1016/C2017-0-04301-X

WEAP21. (n.d.). *Welcome to WEAP!* Retrieved July 2, 2021, from https://www.weap21.org/

Wesselink, A., Kooy, M., & Warner, J. (2016). Socio-hydrology and hydrosocial analysis: Toward dialogues across disciplines. *Wiley Interdisciplinary Reviews-Water, 4*(2). https://doi.org/10.1002/wat2.1196

Winz, I., Brierley, G., & Trowsdale, S. (2009). The use of system dynamics simulation in water resource management. *Water Resources Management, 23*, 1301-1323. https://doi.org/10.1007/s11269-008-9328-7

WWF Turkey. (2012). *Mega dreams, empty hopes. Report on IBTs. (Cilgin ruyalar, bos umutlar. Havzalararasi su transferi).* World Wildlife Fund Turkey. https://docplayer.biz.tr/1567217-Cilgin-ruyalar-bos-umutlar-havzalar-arasi-su-transferi.html

Xu, L., Gober, P., Wheater, H., S., & Kajikawa, Y. (2018). Reframing socio-hydrological research to include a social science perspective. *Journal of Hydrology, 563*, 76-83. https://doi.org/10.1016/j.jhydrol.2018.05.061

Yates, D., Sieber, J., Purkey, D., & Huber-Lee, A. (2005). WEAP21 – A demand-, priority, and preference-driven water planning model. *Water International, 30*(4), 487-500. https://doi.org/10.1080/02508060508691893

Yeşil Istanbul. (2021). *15 yeni yasam vadisi.* Retrieved April 6, 2023, from https://yesil.Istanbul/haber_15-yeni-yasam-vadisi

APPENDIX A: DATA FOR THE INDICES

Table A.1. Data for the indices. Data for the Melen Project is available following its development from 2008 onwards.

	2020	**2018**	**2016**	**2014**	**2012**	**2010**	**2008**	**2006**	**2004**	**2002**	**2000**
Istanbul											
Water potential (hm^3/year)	1,558.44	1,558.44	1,336.21	1,336.21	1,401.79	1,401.79	1,401.79	1,401.79	1,401.79	1,401.79	1,401.79
Water demand (hm^3/year)	1,074.13	1,040.97	1,018.6	951.49	930.83	931.89	666	862.98	736.15	693.56	750.84
Population (thousand)	15,462	15,068	14,804	14,377	13,855	12,783	12,697	12,208	11,478	10,748	10,018
Istranca Streams transfer - Tekirdağ and Kırklareli											
Transfer magnitude (hm^3/year)	300.96	93.29	86.87	116.09	126.15	90.92	110.45	131.16	37.53	36.9	23.67
Water potential (hm^3/year)	1230.9	1269.6	1269.6	1269.6	1361	1361	1361	1361	1361	1361	1361
Water demand (hm^3/year)	293	274	266	243	254	254	260	270	249	245	239
Population (thousand)	1,442	1,390	1,324	1,250	1,193	1,130	1,107	1,041	1,011	981	952
Melen Watershed transfer - Düzce											
Transfer magnitude (hm^3/year)	372.31	286.72	244.44	294.04	50.43	5.89	132.51	-	-	-	-
Water potential (hm^3/year)	1731	1785	1785	1785	1785	1785	1785	-	-	-	-
Water demand (hm^3/year)	40	36	31	32	31	33	34	-	-	-	-
Population (thousand)	396	388	370	356	346	338	329	-	-	-	-