Toward equitable and sustainable food security in drylands under climate change: India and Israel compared

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Abstract

The agriculture-food-water nexus is one of the most critical challenges facing all countries, particularly for arid, and semi-arid dryland regions where the effects of climate change are becoming more pronounced. The increasing variability and intensity of rainfall in dryland regions threatens not only rural livelihoods, but broader food security and water security objectives identified in the Sustainable Development Goals (SDGs). This paper compares approaches to dryland agriculture and water management in the dryland regions of India and Israel, focusing on efforts to achieve both equitable and sustainable solutions. The paper presents the current knowledge on the connection between climate change, agriculture, and water management, including how these sectors relate to the SDGs. The connection between water resource management is assessed before turning the focus to water resource management and the agricultural sector of dryland regions in India and Israel. The assessments culminate in a series of solutions, innovations, and success stories from each country to highlight the unique approaches to sustainable and equitable dryland agriculture in the face of increasing climate change. The solutions are considered for their replicability, transferability, and/or scalability as an approach to dryland agriculture and water management more broadly. This paper concludes by arguing that there is no single approach to equitable dryland agriculture in the face of climate change, but that the solutions must be based on the needs and existing capacities of residents and institutions.

Keywords: drylands, equity, water resource management, India, Israel, climate change, food security

Introduction

The impacts of climate change on the global hydrological cycle are expected to alter the spatial and temporal distribution of rainfall (UN Water, 2010), and therefore affect the availability of water for agriculture (FAO, 2015). Rising temperatures will translate into increased crop water demand (UN Water, 2010). These changes will likely have an impact on crop productivity and food supply, heightening uncertainties throughout the food chain and posing a significant threat to global food security (FAO, 2015). The earliest and the most impacted are the drylands where there is already insufficient access to water (FAO, 2015). Increased warming and reduction in rainfall make the drylands more vulnerable to climate change, resulting in substantial loss in crop yields and reduced earnings (Shakoor et al., 2011). Various adaptation measures that deal with climate variability are built upon improved water management practices (UN Water, 2010) and have the potential to create resilience to climate change and enhance water and food security (FAO, 2015).

This paper utilizes an in-depth literature review of spatially relevant articles and available statistics to summarize the current knowledge of the anticipated impacts of climate change on water availability for agriculture in dryland regions. It further explores the impacts of climate change on food security in dryland regions through a comparison of agricultural practices between Israel and India to demonstrate, that while there are multiple approaches to water management, these approaches must prioritize equity to ensure successful and sustainable outcomes. This paper first introduces the connection between climate change, food security, and water resource management, and connects the related Sustainable Development Goals (SDG). The importance of equity in water resource management is then explored before evaluating water resource and agricultural challenges in India and Israel, including what failures, innovations, and success stories exist. Through this assessment the paper demonstrates, that although both countries strive to achieve similar outcomes in water efficiency, the approaches taken by each country differed based on their specific context in terms of needs, constraints, capacities, and institutional frameworks. These findings have wider implications for understanding how sustainable water resource management and innovations in dryland agriculture that are founded on the basis of equity and local context can become transferrable and scalable.

Climate Change, Water and Food Security

Climate change will considerably affect agriculture by raising water demand, diminishing agricultural productivity and by decreasing water availability in areas where irrigation is most necessary or advantageous (Turral et al., 2011). Rising temperatures caused by global warming are likely to intensify the hydrological cycle, increasing the rate of evaporation and precipitation (Arnell, 1999). However, the impacts of this change will be distributed unevenly such that the amount of rainfall will increase in the tropics and higher latitudes, while it will decrease in the already dry semi-arid to arid mid-latitudes and in the interior of large continents (Arnell, 1999). As a result, the already water-scarce regions around the world will be susceptible to becoming drier and hotter (Turral et al., 2011). Both rainfall and temperatures are predicted to become more variable due to climate change, with a consequent higher incidence of droughts and floods, sometimes in the same place (Turral et al., 2011). Altered rainfall pattern and increased rates of evaporation will in turn affect water resource availability (Turral et al., 2011).

Water management which includes irrigation, drainage, and water conservation and control, maintain soil conditions optimum for crop growth (Benkeblia, 2022). The agricultural system is not only highly dependent on water (Water in Agriculture, 2022), but the timing and reliability of supply of water is critical in crop production. Currently, rainfed agriculture account for more than 80% of global crop area and 60% of global food output, while (Benkeblia, 2022) irrigated agriculture contribute to 40% of the total food produced worldwide and represent 20% of the total cultivated land (Water in Agriculture, 2022). Rainfed farming being susceptible to the impacts of climate change and higher temperatures (Benkeblia, 2022), is deemed to become precarious in regions where rainfall is likely to decline (i.e., at the mid and low latitudes, particularly in the arid and semi-arid regions). This will result in an increased dependency on irrigation for food production, which is at least twice as productive per unit of land as rainfed agriculture, thereby allowing for more production intensification and crop diversification (Water in Agriculture, 2022). However, water supplies available for irrigation will become more variable and will decline in many parts of the world. Increased irrigation efficiency may ensure more water is available to crops (Douville et al., 2021). The corresponding reduction in runoff and subsurface recharge may exacerbate hydrologic drought, resulting in declining groundwater storage in some regions, and aggravating climate-induced changes of surface or subsurface water (Douville et al., 2021). Increased number of active storm systems will also impact agriculture, particularly in the tropics, where cyclone activity is predicted to worsen along with rising ocean temperatures (Turral et al., 2011). Hydroclimatic deficiencies manifested through low cumulative rainfall, meteorological droughts and dry spells will set the limits for potential yields (Falkenmark, & Rockström, 2004).

Global demand for food is increasing as the population continues to grow (Turner et al., 2004). Population growth adds further stress by taking land out of agriculture for urban development (Elliott et al., 2013). The Food and Agriculture Organization (FAO) defines food security as a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition comprises two key dimensions (Schmidhuber & Tubiello, 2007):

- Availability: Relates to the availability of sufficient food (i.e., to the overall ability of the agricultural system to meet food demand). Its subdimensions include the agro-climatic

fundamentals of crop production.
- Access: Relates to whether the food prices will remain within the purchasing power of consumers

Climate-related events can increase food insecurity, in terms of both availability and access, through a number of channels (FAO, IFAD, UNICEF, WFP, & WHO, 2017). A decline in agricultural production is already being observed, and this has escalated food inflation globally there is an acute shortage of food in many African and Asian countries, where the affordability of food is reduced, threatening food security (Misra, 2014). Climate change will further increase fluctuations in crop production and food supplies, particularly affecting food supplies and the incomes of poor people who are dependent on agriculture for their livelihoods, and increase vulnerability to food insecurity (Turner et al., 2004). New agricultural demands will be further tempered by the need to achieve better equity in access to reliable food supplies than in the past, complicating food security (Benkeblia, 2022).

Sustainable Development Goals

Agriculture being the largest consumer of freshwater resources (UNESCO, UN-Water, 2020) results in water and food being inextricably linked (Mitra et al., 2020). Additional pressure is exerted on the water-food nexus driven by an increasing world population, rapid urbanization, and a shift from starch-based diets to more water-intensive meat-based diets (UN-water, n.d.). Moreover, extreme weather events caused by climate change put additional stress on the availability and quality of water (European Commission, 2021). Higher incidences of water scarcity and water excess manifested through droughts and floods necessitate that the existing modes of production of the agricultural system undergo adaptation (Turral et al., 2011). This highlights the strong nexus between water, climate, and food, which needs to be acknowledged and understood to ensure sustainable management of water (SDG 6).

Sustainable food production systems and resilient agricultural practices (SDG 2.4) will not only help improve adaptation to climate change (SDG 13.1 and 13.3) (Tosun & Leininger, 2017) but will also improve water-related ecosystems (SDG 6.6), increase water-use efficiency (SDG 6.4), enhance water quality (SDG 6.3) through reduction of run-off pollutants (Tosun & Leininger, 2017). Maximizing synergies through strengthening cross-sectoral integration could facilitate greater climate change adaptation (Rasul & Sharma, 2016) which will lead to better resource management to enhance water and food security (Mitra et al., 2020).

Water Resource Management and Equity

Water is a primary medium through which the impacts of climate change are manifested, therefore Water Resource Management is crucial in adapting to climate change challenges (Cap-Net UNDP, 2018). Agricultural water management must internalize ecology, equity, and democracy (Mollinga, 2007). To ensure that all people have access to water of adequate quantity and quality, equity needs to be a central element of water resource management, and this can only be achieved by enabling the participation of all stakeholders in water management (Placht, 2007). Fair, open, and transparent decision-making processes in which all individuals and groups impacted by water decisions have an opportunity to participate are necessary for achieving equity (Ingram et al., 2008). Local community involvement increases system ownership and confidence, and input from the community offers a valuable repository of knowledge and concepts that can result in workable and long-lasting solutions (Placht, 2007).

The stakeholders in water management are many, and single-factor solutions are alluring to multilateral investors, bilateral funders, and politicians, as they can be easily communicated, and progress can be monitored with a few simple indicators (Mollinga, 2007). However, in contrast to the investment made, these institutional change attempts in the irrigation industry have had only modest success (Mollinga, 2007). Water Resource Management necessitates an interdisciplinary strategy that encourages cross-sectoral collaboration and partnerships between stakeholders and governmental agencies encompassing different sectors, disciplines, and institutions to ensure equity (Placht, 2007).

Case Studies

India

India in Context

The Republic of India, a democratic country and member state in the Commonwealth of Nations, is bounded by the Indian Ocean, the Arabian Sea, and the Bay of Bengal. At 3.2 million square kilometers, India is the seventh largest country by land and is home to approximately 1.4 billion people (United Nations, 2022). Owing to rapid urbanization, increasingly unchecked development, and a competition for available water resources amongst agriculture, domestic, and industrial uses, India has experienced both overexploitation of groundwater resources, as well as surface and groundwater contamination (Ramachandra et al., 2018).

India experiences approximately four billion cubic meters of average annual precipitation, of which approximately three billion cubic meters fall during the monsoon season from June to September (known as the *kharif* season). In India's dryland regions, annual rainfall ranges from 375 millimeters to 1,125 millimeters, which is compounded by limited irrigation facilities (Vijayan, 2016). India's dryland region includes the northwestern desert regions of Rajasthan, the plateau region of central India, the alluvial plains of Ganga Yamuna river basin, the central highlands of Gujarat, Maharashtra and Madhya Pradesh, the rain shadow regions of Deccan in Maharashtra, the Deccan Plateau of Andhra Pradesh, and the Tamil Nadu highlands (Figure 1; Singh et al., 2011). These regions are characterized by an uneven distribution of rainfall, extensive soil degradation, and a prevalence of monocropping, all of which contributes to the common occurrence of drought (Chary et al., 2022). Despite these challenges, dryland regions in India are responsible for 44% of total food production in India and 68% of the cultivated area in the country is in drylands (Vijayan, 2016). Therefore, solving water resource issues in India's drylands remains critical to ensuring food security for all of India.

Figure 1. Dryland regions in India (Singh et al., 2011).

Climate Change Impacts

Climate change is considered the greatest threat to India's economy (Krishnan & Beniwal, 2015), affecting environmental, biophysical, and socio-economic components of India's agricultural sector (Figure 2). However, India's dryland agriculture is even more sensitive to climate change than other economic activities due to the prevalence of small or marginal land holdings, subsistence farming, and the low water holding capabilities and nutrient deficiencies of soils in these regions (Aggarwal et al., 2004; Vijayan, 2016). Projected climate change scenarios over the Indian subcontinent include an increase in winter crop season (*rabi* season) temperatures leading to decreased snowpack availability and resulting snowmelt (Mall et al., 2006). This is particularly troubling for regions near the Ganges because as much as 70% of the summer discharge of the Ganges comes from melting glaciers (Barnett et al., 2005). Moreover, climate change will lead to an increase in the incidence of extreme weather conditions such as floods, droughts, and heat waves (Mall et al., 2006; Birthal et al., 2014) as the result of increasing rainfall and temperatures (Figure 3), leading to an increase in evapotranspiration and more difficult growing seasons (Moors et al., 2011). Increased evapotranspiration will also reduce infiltration rates and groundwater recharge (Shah, 2009), which may lead to lagging effects on the agricultural sector due to an increased demand for groundwater.

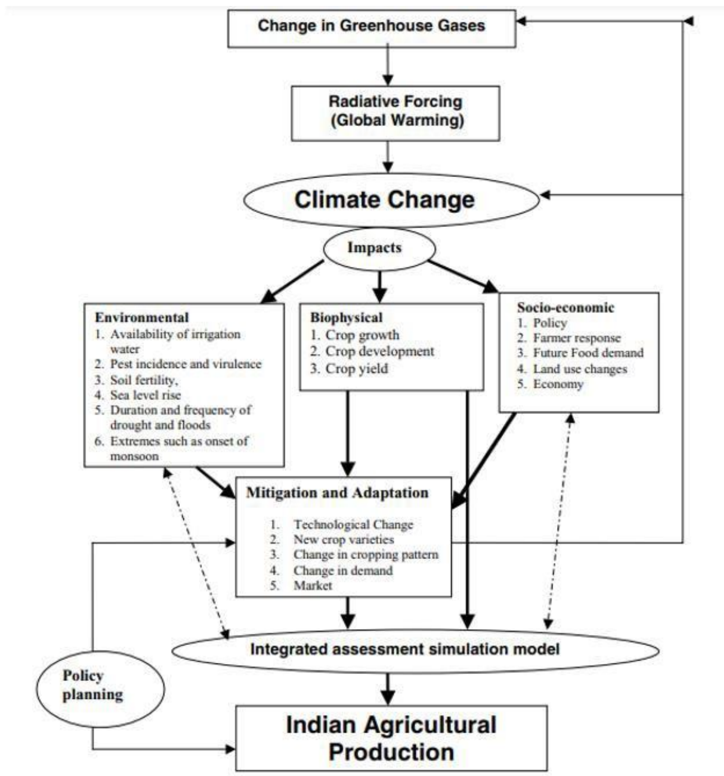

Figure 2. Climate change impacts on Indian agriculture and their responses (Mall et al., 2006).

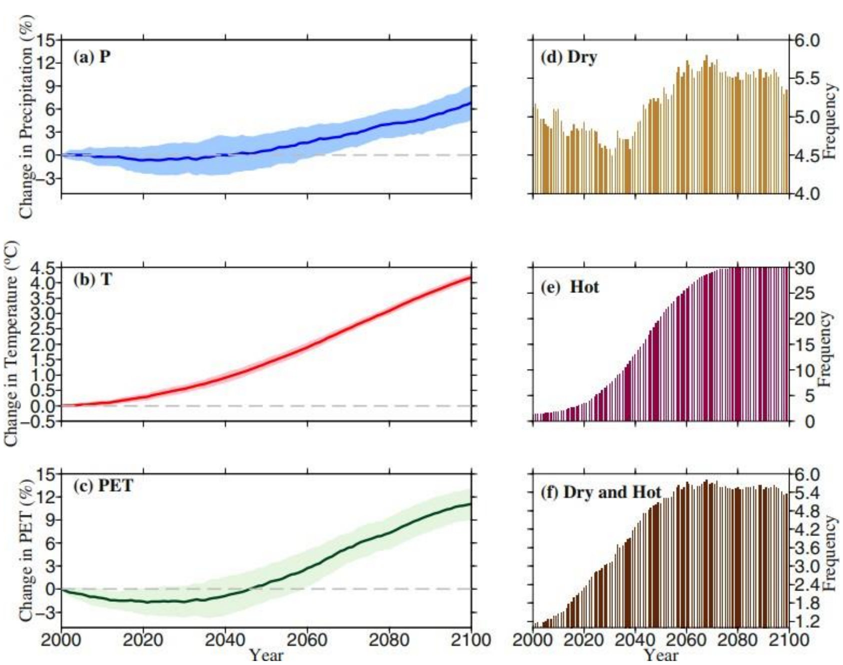

Figure 3. Climate change projections on precipitation, temperature, and evapotranspiration in India, 2000-2100 (Mishra et al., 2020).

Sustainable Development Goals

Despite the exuberance of the Green Revolution that modernized India's agricultural sector with a focus on groundwater in the 1960s, India's level of water stress (that is, freshwater withdrawal as a proportion of available freshwater resources) has stagnated for the last seventeen years (United Nations, n.d.). Encouragingly, however, since 2000 there has been an increase in the population with access to basic drinking water (United Nations, n.d.). The number of undernourished people increased from 198.3 million in 2001 to 224.3 million people in 2020, but the proportion of population suffering hunger was reduced from 18.4% to 16.3% in that same time (Figure 4; United Nations, n.d.).

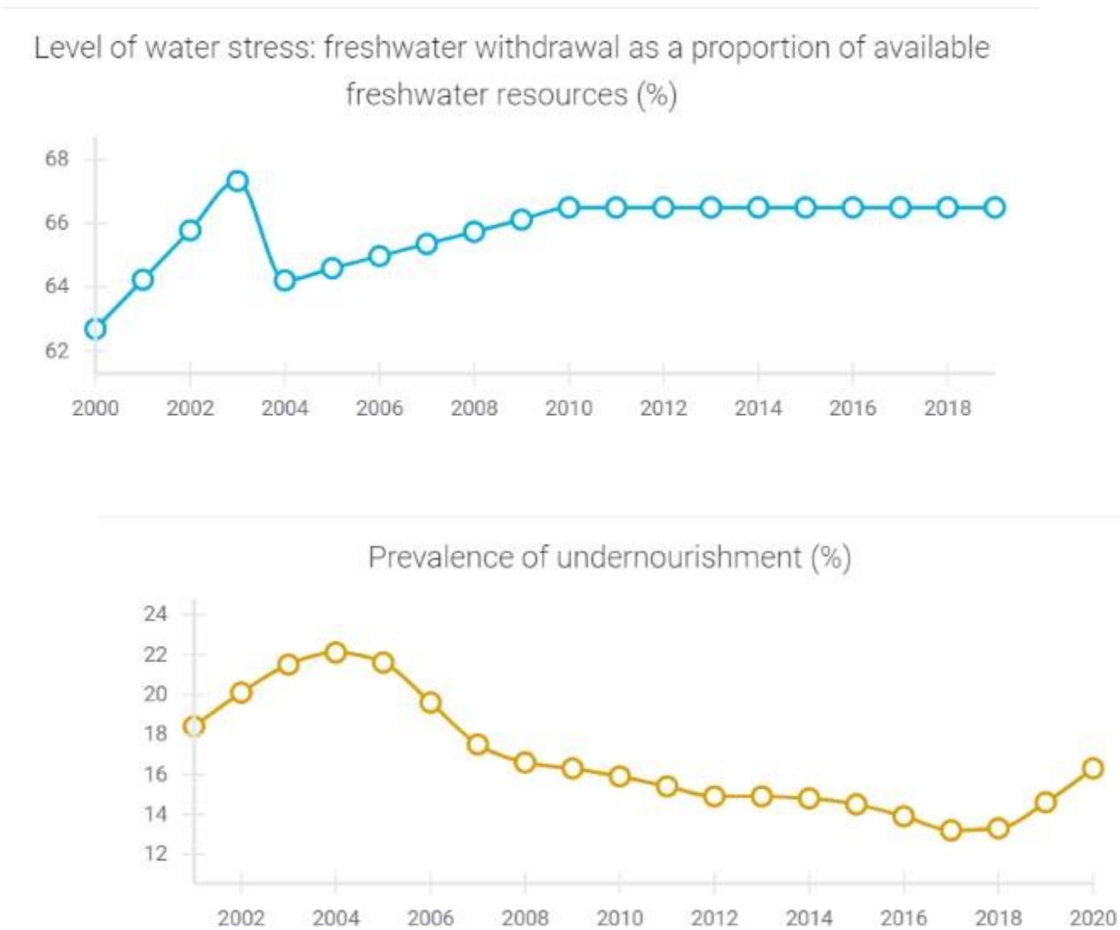

Figure 4. Level of water stress and prevalence of undernourishment in India over the last twenty years (United Nations, n.d.).

Water Resources & Governance in India

India accounts for 4% of the world's freshwater sources (India, 2017) and is the largest user of groundwater in the world due to poor service delivery from public authorities, inexpensive energy, and the relative stability of groundwater availability (Shah & von Koppen, 2016). India's water infrastructure and governance is a reflection of its colonial past that favoured large infrastructure projects and engineering solutions, rather than participatory approaches. To be sure, the British East India Company began building canals in 1810, transforming many dryland regions into intensified agricultural areas (Shah, 2009). While a centralized bureaucracy existed to manage water in India for many years, by the 1960's Green Revolution, groundwater became the dominant water source for Indian farmers, resulting in a shift from a "centralized, managed system to an individualistic, atomistically managed water-scavenging irrigation regime" (Shah, 2009, p. 3). This is evidenced by the fact that India is the largest groundwater user in the world, where 65% of irrigated agriculture is extracted from groundwater (Figure 5; Shah, 2009). Indeed, tube wells are now the most common source for irrigated agriculture in the country (Figure 6; India, 2017). This shift paralleled the neoliberal state retreat that saw water as an economic good, rather than a basic right.

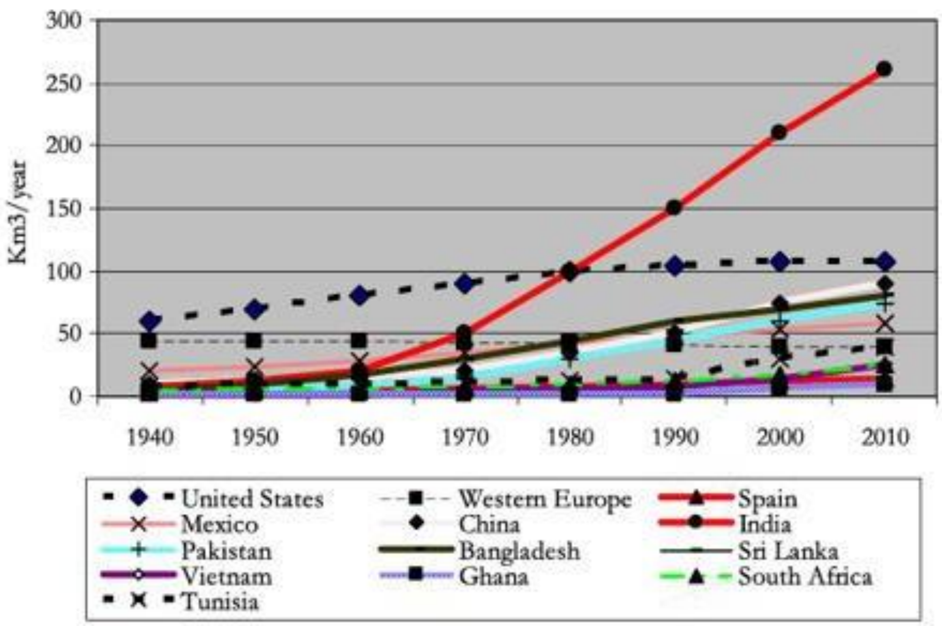

Figure 5. Growth in agricultural water use from 1940 to 2010 (Shah, 2009).

While neoliberal governance has generally not succeeded, it has resulted in a devolution of power to the local level, bringing about with-it new approaches to water security. This has led to a paradigm shift in Indian water policy from a technological or hydrological focus to a focus on issues of equity, social, and economic governance (Narain & Narayanamoorthy, 2016). Donors and NGOs are playing a larger role, and so too are research institutions focused on educating local water users. Further development of Indian water policy presents three challenges, according to Shah & von Koppen (2016): the dispersed nature and sheer number of users; utilizing demand-side strategies to address agricultural water issues is difficult because it will impact rural livelihoods; and the dispersed nature of users represents an opportunity for a varied institutional approach. Addressing these challenges is key to meeting the country's Sustainable Development Goals.

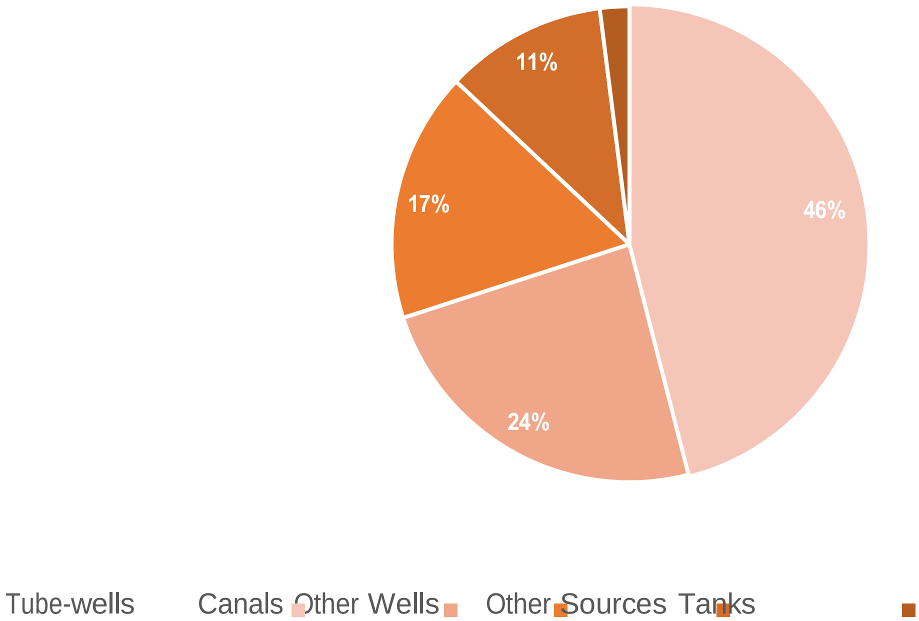

Figure 6. Source of water for irrigated agriculture in India (India, 2017).

Agricultural Sector

India's agricultural sector utilizes 80% of available water sources (India, 2017). Dryland farming accounts for 44% of total food production in India (Vijayan, 2016), even though drylands account for 68% of net sown area (India, 2017). Indian agriculture is characterized by a preponderance of small (1-2 hectares) or marginal (less than 1 hectare) land holdings, with 85% of operational farms falling into this category (India, 2017). The number of large farm holdings declined by 11% between 2000 and 2010 such that the average agricultural land holding was 1.15 hectares in 2010 (India, 2017). Therefore, addressing SDGs necessitates solutions for small-scale farming (Figure 7). At the same time, the share of agricultural workers as a proportion of the total workforce has declined from 69.9% in 1951 to 54.6% in 2011 (India, 2017). Unfortunately, agriculture's share of the country's Gross Domestic Product (GDP) has declined at a significantly greater pace, resulting in widespread rural poverty (Aggarwal et al., 2004).

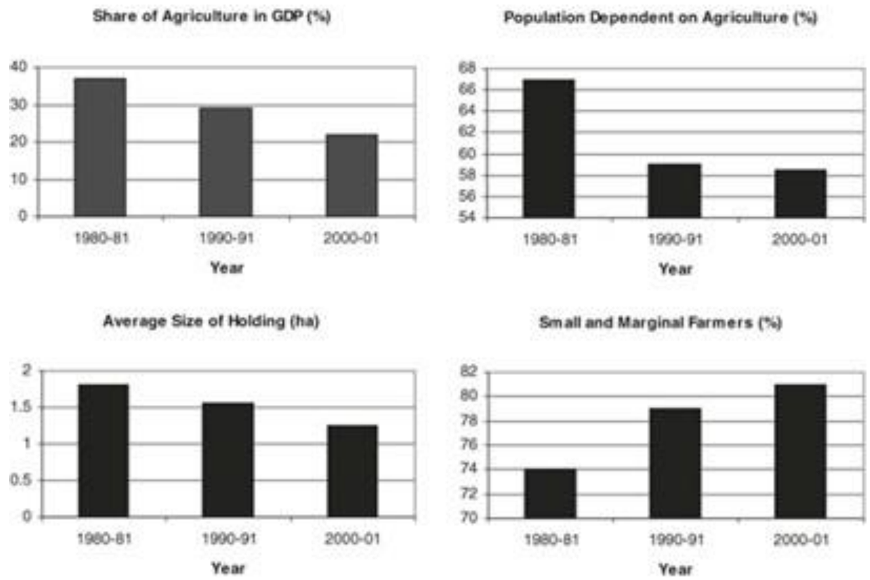

Figure 7. The characterization of the agricultural sector in India over time (Aggarwal et al., 2004).

The agricultural sector in India's dryland regions faces numerous challenges. First, small or marginal land holders are more likely to experience poverty than large land holders (India, 2017). Second, land degradation through soil and water erosion continues to negatively impact crop yields in drylands (Chary et al., 2022). Third, the alfisols soil of dryland regions has poor soil retention capabilities, subjecting dryland soils to drought stress (Vijayan, 2016). Fourth, the choice of crops in drylands remains limited such that monocropping becomes the dominant form of agriculture, reducing the variety and resiliency of crop yields. This is likely because food security is linked to the *krabi* season monsoon rainfall (see Figure 8). Lastly, increasing demand for water sources from other sectors such as industry and urban areas following rapid urbanization means that India's agricultural sector faces a complex challenge of producing more food using less water and less land, while reducing rural poverty (UNESCO, 2006, p. 244).

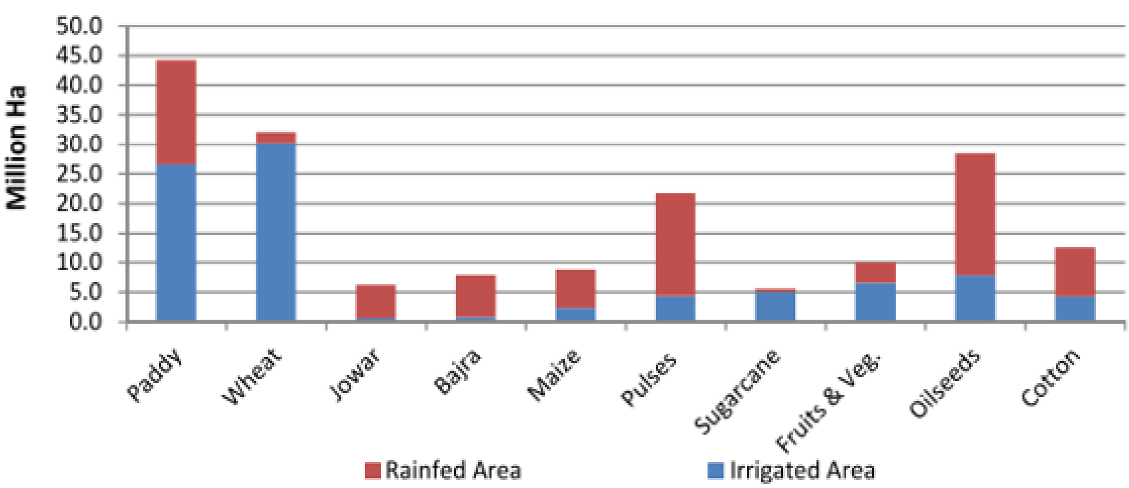

Figure 8. Types of crops grown in India and their water source (India, 2017).

Successes, Innovations, and Lessons

While the Indian government has historically focused on technocratic, engineering-centric solutions to water and food security, more recent efforts have turned to a multi-faceted approach that values local knowledge and participation. This shift comes as Integrated Water Resource Management efforts in India also come under scrutiny. For Shah and von Koppen (2016), IWRM is fundamentally at odds with the existing informal nature of the water sector in India. Shah and von Koppen (2016) reference the informal pump irrigation that serves one-third of India's gross irrigated area as evidence that IWRM cannot succeed in its current form because it does not provide guidance on the existing informal water networks, and instead replaces functioning informal networks with poorly functioning, costly, formal networks. Rasul and Sharma (2016) build on this in suggesting that IWRM's focus on water and hydrological boundaries reinforces the siloed approach, and instead argue for seeing the water-energy-food nexus that can complement IWRM (Benson et al., 2015). Essentially, for IWRM to be effective, solutions need to be context-specific, and India needs to reach a certain level of development for the formal water network management to be successful (Shah and von Koppen, 2016).

Efforts to adapt dryland agriculture to changing climatic conditions in India have taken many forms with varying degrees of success. The "Pradhan Mantri Krishi Sinchayee Yojana" agricultural development program's slogan "Har Khet Ko Paani" (or "more crop per drop") has focused on adopting precision irrigation, sustainable water conservation practices, and promoting water harvesting, management, and crop alignment (India, 2017). The shift from an infrastructure-based approach to development-oriented adaptation is supported by the Indian government, with the Secretary of the Jal Shakti Ministry (the Department of Water Resources, River Development and Ganga Rejuvenation), suggesting that small-scale, participatory solutions are needed. In the Secretary's view, "how will people know how much water is under their land? They will have no way to know if they are running out of water" (Gupta & Ahmad, 2019). The small village of Hiware Bazar in the State of Maharastra is often heralded as India's greatest water and food security success story. In the 1990s, with the help of a charismatic leader, Hiware Bazar prohibited borewell drilling and by 2002, undertook participatory water budgeting to match available water resources with village demand. The result was increased agricultural production and an increase in household income (Figure 9).

YEAR	1992	2003#
Summer/Jayaad Irrigated Area (ha)	7	72
Land in Horticultural Production (ha)	7	54
Pulse Cultivation (ha)	54	188
No. of Milk-Producing Livestock	19	476
Household Income (1 rps/a)	830	11,900
Families below Poverty Line (%)	92	1

* *based on State Government survey data of corresponding years*
\# *considerable further improvements appear to have occurred by 2007-08 (year of current survey)*

Figure 9. Changes in agricultural production in Hiware Bazar, Maharashtra, between 1992 and 2003 (Foster et al., 2009).

Despite the success of Hiware Bazar, their solutions to water and food security have come under scrutiny for their replicability, transferability, and scalability given they relied on a charismatic leader and personal sacrifice from village residents through collective action (Fernandes, 2007). More recent efforts in India have taken on a livelihoods approach. Maharashtra state has been the focus of "Pani

Panchayats" (local water council's), where community lift irrigation systems succeeded in delivering water to 1,500 families and irrigating 1,200 hectares of land (Foundation for Ecological Security, 2017). Pani Panchayats are founded on the idea that rural communities are natural stewards, as "people tend to steward a resource with greater care when they feel they benefit from it and have taken part in deciding for whom and how the resource is used" (Dargantes et al., 2012, p.5). The Cauvery Calling program in the Tamil Nadu region, supports farmers to plant trees in the river basin to improve soil health and revive the river and groundwater levels through improved soil water retention (Isha Foundation, 2017). Tree planting is seen as one agronomic approach to dryland agriculture that both augments farmer income while improving agricultural potential (Vijayan, 2016).

As an alternative to the demand-side approach to water security, the Andhra Pradesh Farmer Managed Groundwater Systems Project (APFMGS) took a supply-side approach by engaging over 650 villages across seven districts of Andhra Pradesh. The goal was to educate farmers through data collection and knowledge-transfer on groundwater availability and its dynamics (World Bank, 2010). While no incentives were offered to farmers who participated, the expected knowledge transfer was an incentive in leading to successful agricultural practices. The program also facilitated an organizational component where a groundwater management committee oversaw resources at a village level. The committees were comprised of all groundwater users in each individual community and the data gathered for crop water budgeting was used to help farmers understand water availability when making crop decisions, and to better align water availability with demand (World Bank, 2010; FAO, 2008). APFMGS differs from the experience of Hiware Bazar because the solutions do not involve individual sacrifice, nor are they reliant on a charismatic leader. The success of APFMGS highlights the multi-pronged approach that is needed in India, where technological innovations are integrated with local knowledge in context-specific solutions that involve local communities in the stewardship of their own resources.

Israel

Israel in Context

The State of Israel, a democratic country, is located on the southeastern shores of the Mediterranean Sea and is approximately 21,640 km² in area (UN Water, n.d.). Bordered by the countries of Syria, Lebanon, Jordan, and Egypt, outlined in Figure 10, the region has a history of geo-political complexities, including water rights, that have been the cause for human conflict for generations (Ward and Becker, 2015). Israel is densely populated with approximately 9.6 million people (Central Bureau of Statistics, 2022), and whereas annual growth rates are considered high among developed countries, the population is projected to reach 15 million by 2048 (Central Bureau of Statistics, 2022). This high population growth, mostly located within urban areas, makes up nearly 93 percent of the population (FAO, Israel, 2023).

Figure 10. Map or Israel (Israel 360, 2023)

The weather and climate within Israel consists of both semi-arid and arid regions (World Bank, 2021). The northern and coastal areas have a 'Mediterranean' climate with hot and dry summers and mild winters, while the southern and eastern portions of the country are arid (Israel Science, 2023).
Average annual rainfall fluctuates within the country and ranges from 1000 mm in the north to as little as 30 mm in the south (Israel Science, 2023). It is noted that most precipitation occurs from December to February, however, up to 75 percent is lost through evapotranspiration (Marin, et al., 2017). Considered a water-scarce country, drought conditions are common and can last for several years (WTO, Trade Policy, 2018).

Technology and innovation have played a major role in Israel's ability to not only adapt to challenging climate conditions, but to become a global leader in the production and reuse of marginal water. This is achieved through governance, policy, and significant financial investment, which has translated to efficiencies in irrigation, wastewater treatment and desalinization. As a result of these geographical, political, and social constraints, water management is both crucial and complex as it relates to supplying the country's agricultural, industrial, and domestic needs (Luckmann, et al., 2014).

Climate Change Impacts

The larger Mediterranean region, including Israel, has experienced a general warming trend since the 1960's, with a rise in frequency and 'intensity' of heat waves (Green, et al., 2013). A little more divisive is the debate on whether precipitation patterns have changed over the long-term; however, climate data suggests the last ten years have experienced a reduction in precipitation, and a further 30 percent decrease in future precipitation is predicted due to changes in the climate (Green, et al., 2013 and Ward and Becker, 2015). As a result of a warming region, combined with a reduction in precipitation, the agricultural sector will be required to increase its irrigation inputs to keep up with current crop production (Zelingher, et al., 2019). Climate modelling indicates certain agricultural practices, such as open field cropping, will be forced to abandon portions of land due to constraints on irrigation, or possibly ending rain-fed agricultural practices altogether (Zelingher, et al., 2019). Consequently, this may lead to a further reliance on imported food sources, or virtual water, for the country (Zelingher, et al., 2019).

Sustainable Development Goals

Israel scores well as it relates to SDG 6, mostly due to their innovative water solutions. Significant investments have been made within both the water and sanitation sectors, which has benefited the Israeli population in terms of clean drinking water and safe sanitation facilities (SDG 6.1 and 6.2) (UN Water, n.d.). At least 99 percent of the population has access to a safely managed water system, while at least 95 percent of the population has access to a safely managed sanitation system (UN Water, n.d.). Technological advancements in irrigation, treated wastewater and desalination (SDG 6.4) have created water efficiencies not only within the country, but have supported water scarce countries around the world (SDG 6.a) through government and private sector partnerships. This technology and innovation also allow for the restoration of water-related ecosystems (SDG 6.6) though the replenishment of surface and sub-surface water sources (Feitelson and Rosenthal, 2012).

Water Resources & Governance in Israel

The State of Israel's water geography is defined by four eras', with the first starting in the early 20th century using basic systems of cisterns and wells to supply rural populations, with only major cities being supplied with non-local water sources (Feitelson and Rosenthal, 2012). The second era, beginning in the 1930's, was identified as the 'Zionist Hydraulic Mission', which produced a nation-wide water distribution system running approximately 130 kilometers from the water-abundant north to the drylands of the south (Feitelson and Rosenthal, 2012). Known as the 'National Water Carrier', this water conveyance system connected and transferred renewable water from the country's three major sources, including the Sea of Galilee (Lake Kinneret), the Mountain Aquifer and Coastal Aquifer (Fischhendler and Heikkila, 2010).

The third era, from the late 1980's to early 2000's, was a turning point in how water was managed within the country as a result of excessive extraction and low rates of renewal (Feitelson and Rosenthal, 2012). This new water management took a 'technocratic' and 'water-wise' approach, whereby innovative data and modelling were utilized and applied within both the agricultural and wastewater treatment sectors (Feitelson and Rosenthal, 2012). These advancements, although fraught with policy changes and significant drought events, allowed the country to move in a direction to 'decouple' agriculture's reliance on natural water sources, and instead rely upon re-used water for much of its irrigation needs (Feitelson and Rosenthal, 2012).

The fourth era, which is the most current, is based on innovations related to efficiencies, water re-use and desalinization technology, and is discussed further in the subsequent '*Successes, Innovations and Technology'* section. It is noted that water resources within Israel have always been considered a public good and owned and regulated by the State, under the current jurisdiction of the Israel Water Authority (Municipal Water Leader, 2023). However, operations of water supply have been performed by a private utility company, 'Mekorot Water Company', since the inception of the National Water Carrier (Mekorot, 2023). The Ministry of Energy and Water manages the national-level policy, while Municipal and Regional utilities are responsible for distribution, as seen in Figure 11 below (Marin, et al., 2017). It is further noted that recent policies support a move away from heavily subsidized water rates to a more sustainable approach where tariffs allow for cost-recovery within the sector (Marin, et al., 2017). With the latest institutional structure, and related to IWRM, Israel is now considered to have a 'high degree' of integration within its water management practices (Fischhendler, 2007). However, this has not always been the case, where agriculture was once overrepresented politically, and therefore, received an unfair and higher allocation of the country's available water resources (Fischhendler, 2007). In combination with a series of significant drought events, this poor management almost collapsed the country's water resources (Fischendler, 2007).

Institution	Scale	Main responsibilities
Ministry of Energy and Water	National	Policy
Israel Water Authority	National	Planning, allocation, and tariff regulation for all water use
Mekorot Water Company	National	Production and transmission of bulk water • Aquifer pumping and potable water treatment from the Sea of Galilee • Desalination of seawater (as off-taker under BOTs) and brackish water • Operation of national bulk water network
Municipal and regional water utilities	Municipal or regional	Distribution of potable water to domestic and industrial consumers, sewage collection and wastewater treatment
Drainage and river authorities	Basin	Management of basins, aquifers, flash floods, and surface waters

Figure 11. Institutional setting for water management, Israel (Marin, et al., 2017).

Israel's renewable freshwater availability has remained between 1,300-1,500 million cubic metres (MCM) per year, for the last 40 years (Becker, 2013). Consumption rates of water, however, are currently about 2,500 MCM per year, with projections of up to 3,000 MCM required by 2030 (Becker, 2013). This represents a utilization rate of over 200 percent of available freshwater, as seen below in Figure 12. It is through alternative methods of water re-use that Israel has been able to cope with such a large discrepancy of their freshwater availability versus consumption rates.

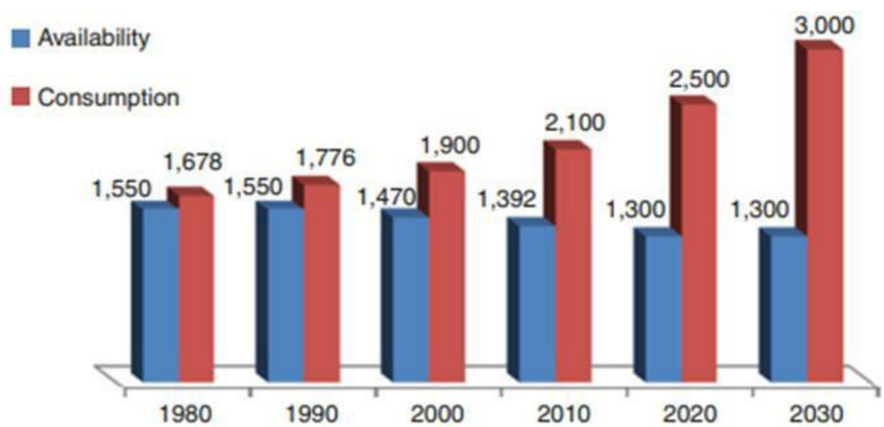

Figure 12. Availability and Consumption rates, in million cubic metres, of freshwater sources (Feitelson and Rosenthal, 2012)

Agricultural Sector

The government has a strong grip on the agricultural sector within Israel, through control and distribution of production inputs, including land and water (WTO, Agriculture, n.d.). Up to 94 percent of agricultural land is State owned, which is provided to farmers for a fee through the 'Israel Lands Administration' (WTO, Agriculture, n.d.). A notable feature of the Israeli agricultural system is its 'cooperative organization' in the Kibbutz and Moshav, making up approximately 80 percent of the country's output of agricultural products (WTO, Agriculture, n.d.). This communal system, based on equality, environmental stewardship, and community well-being, aligns well with IWRM principles. The agricultural sector in Israel is limited due to several factors, including the amount of arable land, at just under 20 percent of the total land area; the availability of water; as well as challenging climate conditions (WTO, Trade Policy, 2018). As it relates to irrigation, water scarcity is considered one of the limiting factors for agriculture within the country; however, as seen in the sections below, water- related technology has provided opportunities to grow food in challenging conditions, with irrigation supplying over 50 percent of arable land (WTO, Trade Policy, 2018). The 1980's proved to be a pivotal point for irrigation, with a shift away from freshwater sources to 'marginal' water, and whereas the quantity of water plateaued, the output of crops, per unit of water, increased dramatically, as seen in Figure 13 (Kislev, 2013). It is noted that water innovations alone were not the sole reason for increased crop production, and instead, success was also based on increases in fertilizer and herbicide use, mechanization, and foreign labour (Kislev, 2013).

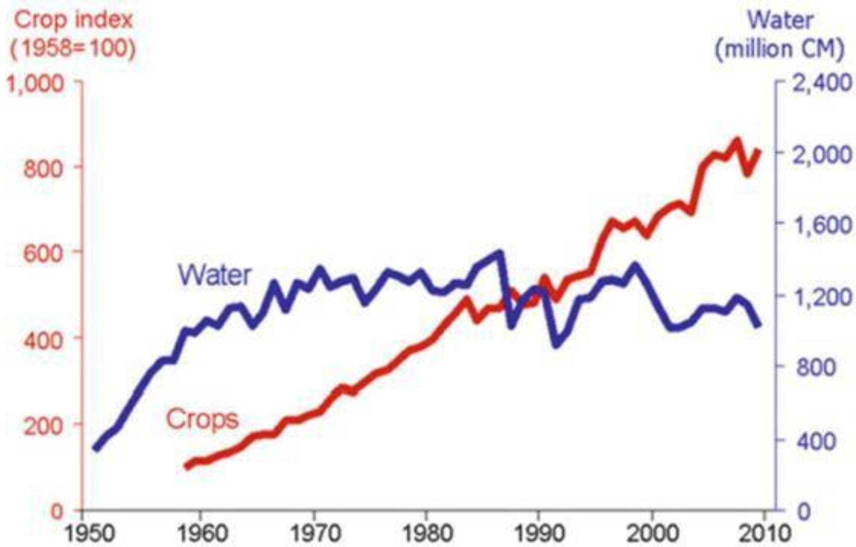

Figure 13. Water use and crop production 1950-2010 (Kislev, 2013)

As a result of these challenges, including rising population growth, Israel is largely dependent on imported food, including staples such as oils, grains, and feedstock, which 'preclude' it from self- sufficiency (USDA, 2022). Based on available water resources and a best-case scenario, Israel could produce enough food for half its population (Kislev, 2013). An important note about the Middle East region and its reliance on virtual water, is the contribution of imported food to the 'prevention' of war, whereas if food could not be imported, "the regions inhabitants would have fought desperately for every drop of water" (Kislev, p.54, 2013). In terms of growing regions within the country, the southern deserts of the Negev make up a large portion of the productive agricultural lands (Kislev, 2013). This desert region is highly important, as the more densely populated northern areas of the country have urbanized, thereby relying upon rural landscapes from a food security perspective (Israel's Agriculture, 2002). Desert locations do offer some growing advantages in the form of extended sun exposure and high temperatures, and combined with access to reclaimed water for irrigation, support year-round cultivation of certain high-value crop varieties (Israel's Agriculture, 2002). It is important to note the fruit industry, which is heavily dependent on reclaimed irrigation water, makes up a large percentage of the cultivated desert area for both domestic consumption and for the export market (Ministry of Agriculture, 2023).

Employment in the agricultural sector has decreased over the last 30 years within Israel from approximately 3.5 percent of the population to just over 1 percent in 2021 (World Bank, 2023). The main reason for the reduction of agricultural workers is attributed to increased salaries in other sectors, and to some extent, advances in 'water utilization' requiring less labour (Kislev, 2013). Of this small percentage, just under half of those employed in agriculture are represented by women (Israel Economics, 2023).

Successes, Innovations and Technology

Israel is considered a leader when it comes to water management, with the country placing an emphasis on the utilization of innovation and technology to ensure water is used as efficiently as possible (Becker, 1994). Significant capital investment and research in water sector technology, including desalination, the use of treated wastewater and drip irrigation, have contributed to the economic viability in high value crops, as well as contributing to domestic and industrial needs. Figure 14, below, showcases the breakdown of water sources within Israel, highlighting the success of implementing recycled and desalinated water, which help to offset reliance on natural sources.

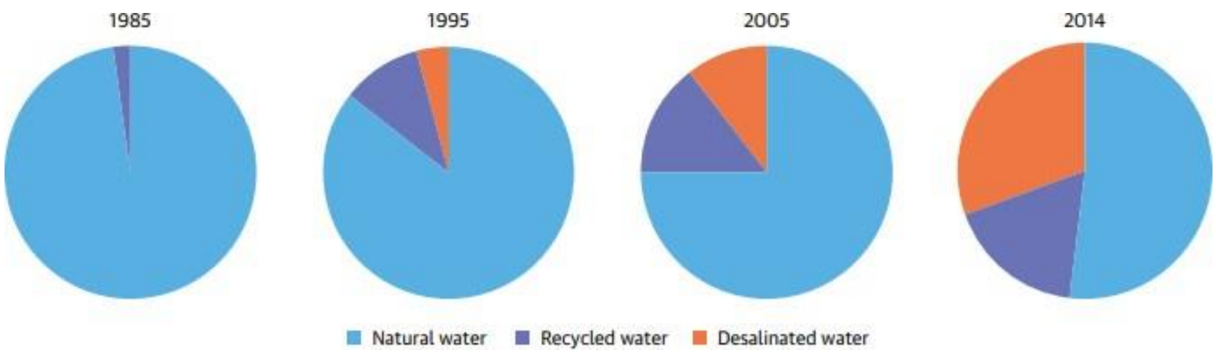

Figure 14. Breakdown of water sources in Israel, 1985 – 2014 (Marin, et al., 2017)

Desalination has been one of the most impactful innovations related to the water sector and has reduced the country's reliance on natural sources. Until the early 2000's, desalination was only being utilized on a small-scale; however, under the new 'Water Master Plan', policies were introduced to increase the supply of marginal water, including 'rapid expansion' of desalination (Feitelson, 2013). By 2011, 296 MCM of seawater and 45 MCM of brackish water had been processed by desalination technology, and by 2020, some 750 MCM out of a total water demand of 1750 MCM for the entire country (Feitelson and Rosenthal, 2012). Desalination is responsible for supplying 85 percent of potable water for municipal and regional distribution, which has further allowed Israel to become 'potable water secure' and essentially decouple domestic needs from rainwater and aquifer extraction (Marin, et al., 2017).

Up to 92 percent of wastewater in Israel is treated, with 87 percent being utilized for irrigation purposes, making up almost half the water used by farmers nationwide (Marin, et al., 2017). A significant amount of the wastewater used for agriculture receives tertiary treatment, indicating it can be used on any crops without restriction (Marin, et al., 2017). A world leader in wastewater treatment technology, Israel has increased the available amount of wastewater for agricultural use from 450 MCM in the mid 2010's to 600 MCM in 2020, with predictions of 700 MCM by 2030 (Becker, 2013). As it relates to pricing, treated sewage for irrigation costs considerably less for farmers than freshwater sources, which is a strategic decision to incentivize its use (Marin, et al., 2017). Figure 15 indicates the significant rise in treated sewage from the early 1960's to 2015.

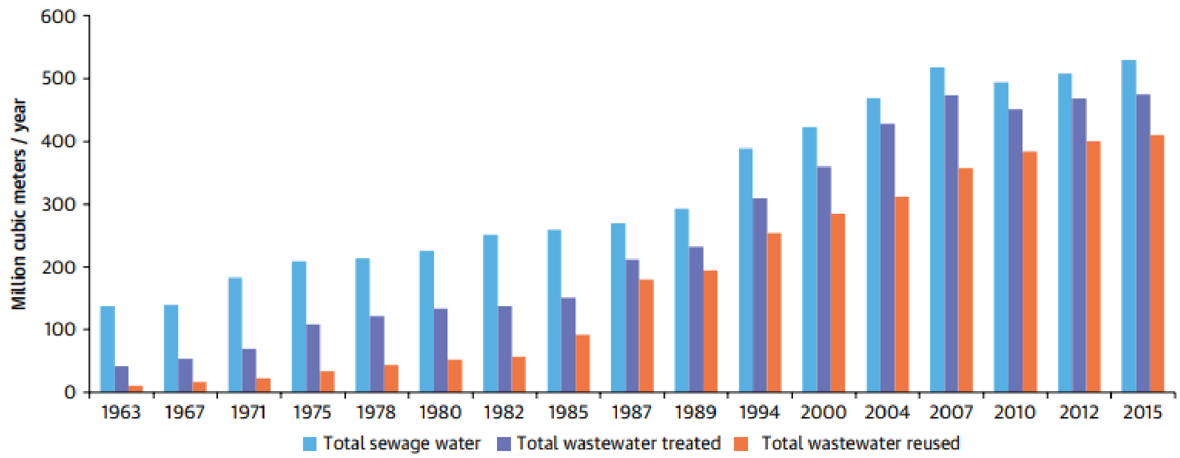

Figure 15. Collected, treated, and used sewage, 1963 – 2015 (Marin, et al., 2017)

Although not as substantial, water harvesting accounts for up to 70 MCM and consists of capturing run-off from various sources, further outlining the efforts within the country to make use of all available water (Becker, 2013). This combination of technologies, as seen below in Figure 16 on marginal water use, has allowed the Israeli population to consume more water than what is currently available through natural sources and has also allowed for aquifer recharge, with treated wastewater, during 'low-demand months' (Marin, et al., 2017). This is a considerable change in aquifer health from an overexploited past just a few decades ago (Marin, et al., 2017).

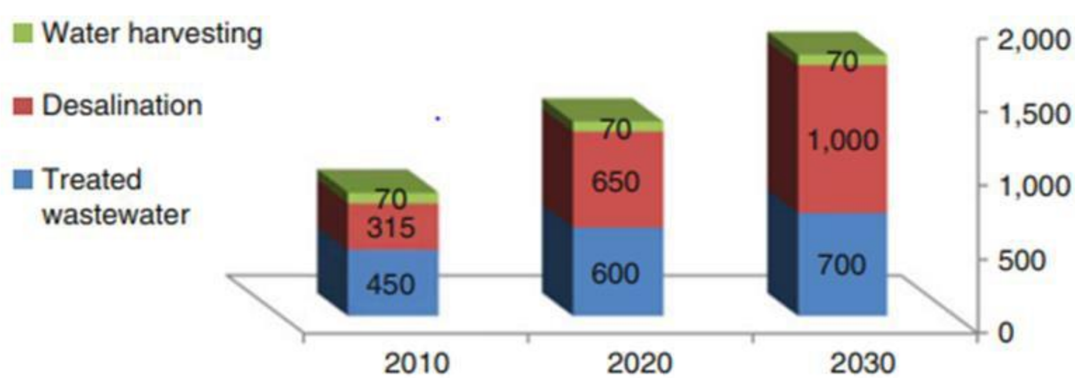

Figure 16. Israel's marginal water use in MCM (Becker, 2013)

The country's other form of water efficiency comes from drip irrigation, which was developed in Israel out of necessity to do more with less. As an 'originator' and world leader in micro irrigation technology, Israel has achieved significant reductions in irrigation usage from 7,000 m³ per hectare in the 1990's to 5,000 m³ by the early 2000's (Marin, et al., 2017). Combined with 'crop substitution', which utilizes crops with a "higher value per unit of water" (Feitelson, p.21, 2013), efficiency rates were able to achieve 90 percent, compared to 75 percent with sprinklers and 60 percent with surface irrigation (Marin, et al., 2017). This efficiency has translated to a "thriving irrigation industry in Israel", with 80 percent of irrigation-related equipment sent out of country for the export market (Marin, et al., p.29, 2017).

Conclusion & Lessons Learned

The cases of India and Israel show the transformative nature of dryland agricultural innovations, as well as the overwhelming need to continue such innovations in the face of climate change. The centrality of technology to Israel's solutions were charted, demonstrating how desalination, wastewater treatment and drip irrigation are part of an effort to improve water efficiency. Water efficiency is also central to the Indian experience, where "more crop per drop" has guided dryland agricultural solutions towards a development-oriented approach. In this sense, both India and Israel are striving toward the same goal; however, while Israel is focused on capital intensive, technological and infrastructure-based solutions of efficiency, India has turned to participatory and small-scale solutions that seek more equitable outcomes for the majority of small or marginal scale farmers.

This paper began by considering what solutions to equitable dryland agriculture would be transferable, replicable, and scalable. In the case of Israel, the technological innovations have been demonstrated to be transferable, replicable, and scalable, with Israel becoming a major exporter of agricultural irrigation technology across the world. Despite this success, the large-scale, top-down, and highly expensive technological solutions of Israel are unlikely to succeed in India given the demographics of its agricultural industry where small and marginal-scale farmers prevail. The significant capital required to adopt such solutions may be successful for the small percentage of large-scale commercial farmers, but not for the nearly 85% of farmers who work on less than 2 hectares of land. The success of Israel is also underpinned by a strong central, institutional water governance framework, which remains absent in the case of India. In summary, the technological solutions found in Israel are transferable, but may not be transferable in all contexts. Alternatively, the experience of India demonstrated here shows us the immense potential of a country in the Global South shifting its focus to not only water efficiency, but also water stewardship in an effort to find sustainable and equitable dryland agricultural solutions. This is evidenced in the Pani Panchayats (local water council's) and the involvement of Indian farmers in data collection in the case of Andhra Pradesh. While the specific programs adopted in India may or may not find success in other countries, the concept of water stewardship and participatory solutions can find success across all societies. In summary, there is no single approach to equitable dryland agriculture in the face of climate change, but the solutions must be based on the needs and existing capacities of local residents and institutions.

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