Desalination and Climate: How the Restructuring of Water is Shaping Oman

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Introduction

As the effects of climate change begin to manifest in the Persian Gulf region, oil-producing states are beginning to witness the consequences of climate change in the region. While researchers have generated substantial material predicting an array of environmental outcomes, little work has been done to translate those efforts in terms of human impact. This study attempts to contribute to understandings of the human (social, political, and economic) impact of climate change and rapid technological change in the Persian Gulf region through an analysis of Oman's adaptation efforts. Our work builds on existing scientific literature which describes environmental effects and provides projections for the expected environmental impact of climate change. We used this scientific research as a departure point in order to explore the social, economic, and political effects of water scarcity and technology in Oman.

As a critically water-scarce country, Oman has devoted significant efforts to water resource management in the past. These technological adaptations fit roughly into three strategic phases. Despite these adaptations, current and future environmental change is intensifying the challenge of water scarcity in Oman. In this paper we use political ecology to analyze how the physical restructuring of water, due to a changing climate and the widespread implementation of technological adaptation such as desalination, bureaucracy, and infrastructure, is altering social and economic arrangements in Oman. A political ecology approach reveals a mutually generative process in which human adaptation attempts to shape climatic outcomesand is in turn shaped by climatic factors. The result is a networked and negotiated process of adaptation which exists at the intersection of divergent paradigms and eludes simplistic categorization. Our results reveal key limitations to the adaptive capacity of the Omani government and the inevitable social and economic restructuring which is the result.

Literature Review

Introduction

In this study we will use political ecology to analyze the structural realities of water scarcity and adaptive technology and how they interface with social, economic, and political systems. This research focuses on two variables in this social-economic-political network: climate and technology. In preparation for this work, we review previous work in political ecology related to our topic and outline our definition of political ecology. We also touch on how existing power structures affect climate change adaptation efforts and the need to be aware of the ways in which adaptation can exacerbate or ameliorate inequality. We conclude with a survey of literature which deals with the intersection between society and technological change. This section problematizes modernization theory and development studies as appropriate frames for this study and explains our choice of a political ecology approach focused on two specific variables: climate and technology.

Political Ecology

Most definitions of political ecology place an emphasis on political economy, formal political institutions, and environmental change. The term first occurred in Eric Wolf's article, "Ownership and Political Ecology", in which he stressed a need to study ecological contexts alongside social and political history, and inter-group relations (Wolf, 1972). Later work has sought to expand political ecology beyond political economy. Timothy Mitchell argues that political ecology is a process in which the architecture of causality between environmental factors and human actions becomes increasingly complex as environment and human action mutually shape social, economic, and political dynamics (Mitchell, 2001). A key component of Mitchell's analysis is the 'agency' of non-human objects, which acknowledges that non-human artefacts, animals, and other phenomena can be said to 'act' within a political ecology network. Karen Bakker reinforces the idea by adding that, "...political ecology not only begins from the assumption that socio-economic and environmental change are co-produced, but also broadens the set of actors - non-humans, as well as humans - who are considered both as objects of study, and also as holders of legitimate claims to equitable treatment," (Bakker, 2011, 363).

Our View on Political Ecology

We use a traditional definition of political ecology to examine our two central themes of the "non-human" climate and the "human" technology as both products and producers of human action. The non-human climate can be viewed as shaping human action by causing droughts, floods, or providing the means to develop agriculture. We refer to 'anthropomorphic' climate change to describe the way in which human actions instigate weather events. Humans also alter ecology by building dams, wells, and irrigation mechanisms to develop agriculture. In particular, we consider how technical adaptation to water scarcity interacts with social, economic, and political structures in Oman.

Our research addresses environmental inputs such as water scarcity, climate change, and salination in conjunction with the impact of official and unofficial human efforts to respond to these inputs. The result is a politicized analysis of environmental factors. Similar to Mitchell's approach, this work reveals a highly interactive process in which the architecture of causality between environmental factors and human actions becomes increasingly complex as environment and human action mutually shape social, economic, and political dynamics. In order to discover these causal networks, we consider humans as "geographic agents", defined as actors who are enmeshed in complex interactions with technological objects and environment (Glacken, 1967). This includes a broad range of human action, including intentional adaptation and the "unthought known" of habitual, unconscious action (Rubenstein, 2010). In contrast to Mitchell's environmental history, our research examines the present day and recent history in order to identify current processes between human and non-human actors such as anthropomorphic climate change and the resulting consequences of these actions.

Adaptation

As described in our discussion of political ecology, we look at multi-directional flows of influence within networked systems. This can be characterized as the way that environmental factors shape human action, and conversely, the way that human action shapes the environment. In this section we focus on the literature which addresses the former of these two in order to set up our discussion of adaptation to climate change and water scarcity in Oman. Official discourse on climate change thus far has predominantly focused on mitigation, which attempts to prevent or reduce climate change. As the predicted effects of climate change begin to manifest, a transition from mitigation to adaptation strategies is gaining prominence (Fussel & Klein, 2002; Javeline, 2014; Howell, Capstick, & Whitmarsh, 2016).

Similarly, resilience policies have led the vanguard of policy discussions. Therefore, it is important to distinguish between resilience and adaptation. The IPCC definition for resilience, the "[d]egree to which a system rebounds, recoups, or recovers from a stimulus," is used to represent human responses to short-term environmental change, such as an unusually severe drought. The degree to which a system can respond to normal fluctuations in water availability or temperature would be considered resilience, for example. Adaptation, however, is "[t]he ability, competency, or capacity of a system to adapt to (to alter to better suit) climatic stimuli," (IPCC, 2001). This is synonymous with adaptive capacity. Adaptation is distinguished from resilience by taking the long view; it shapes action in response to a protracted or permanent change. An adaptation policy would be designed to address not just a single dry spell, but with the expectation of persistent reduction in rainfall over many years. Adaptation can be adopted concurrent with any mitigation or resilience efforts, but for some countries, such as Oman, adaptation is likely to be the primary response to climate change.

Adaptation in Oman: The Relevance of Political Ecology

In Oman, research about water has tended to skew towards scientific vulnerability and efficiency assessments. The literature of adaptation to water scarcity in Oman currently displays an unfilled gap in assessing the vulnerability of Omani society and political economy. A more integrative approach would benefit Oman. We suggest an integrative analysis by way of political ecology which integrates technical and scientific analysis with social, economic, and political analysis.

It is vital to remember that adaptation planning is an inherently political endeavor, and that the social and economic effects of adaptation often have political consequences. In their case study, "Adaptation as a Political Process: Adjusting to Drought and Conflict in Kenya's Drylands", Eriksen and Lind demonstrated how people can be forced to make adjustments to their livelihood, lifestyle, and their position in local power structures in response to climate change and adaptation policies. They emphasize that individuals undertake climatic adaptation in the context of political alliances, institutions, and government administration (Eriksen & Lind, 2008). While Kenya is admittedly a very different context from Oman, Eriksen and Lind provide an example of how adaptation can be politicized:

> "[n]ational economic and political structures and processes affect local adaptive capacity in fundamental ways, such as through the unequal allocation of resources across regions, [and] development policy biased against pastoralism… conflict is part and parcel of the adaptation process…there are relative winners and losers of adaptation, but whether or not local adjustments to drought and conflict compound existing inequalities depends on power relations at multiple geographic scales that shape how conflicting interests are negotiated locally," (Eriksen & Lind, 2008, 817).

Therefore, we suggest that a better understanding of political dynamics in relation to climatic vulnerability and adaptation will positively support social, economic and political resilience in Oman.

Regional Analysis Suggests Strong Need for Adaptation

This analysis is particularly salient in the Middle East and Northern Africa (MENA) context of water scarcity. In their article "Climate Change Impacts in the Middle East and Northern Africa

(MENA) Region and their Implications for Vulnerable Population Groups," Waha et. al. predict that climate change will increase MENA rural poverty, drive farmers off their land, increase migration flows, potentially contributes to political instability, and may damage traditional societal structures (Waha et al., 2017). Our findings suggest that these areas of concern are highly relevant to Oman.

Usually undertaken as a last resort, internal and international migrations have been connected to extreme climate events and political instability. While Oman's situation does not currently suggest the potential for crisis on this magnitude, it is useful to consider that migration may be adopted as an informal or formal adaptation (Habib, 2017; Schwartzstein, 2017; Selby, 2017; Selby, 2014; Gleik, 2017; Gleik, 2014; Kelley, 2017; Kelley, 2014; Hendrix, 2017). Tacoli describes migration as a form of adaptation, and describes how individuals change location in response to shortages, sometimes crossing international borders or contributing to urbanization in the process, in order to access more resources and stable shelter. She encourages politicians to adopt formal migration as part of adaptation strategy planning (Tacoli, 2009). Furthermore, in their article "Climate shocks and rural-urban migration in Mexico: exploring nonlinearities and thresholds," Nowrotzki et. al. find that "[p]olicy and programmatic interventions may...reduce climate induced rural-urban migration in Mexico through rural climate change adaptation initiatives, while also assisting rural migrants in finding employment and housing in urban areas to offset population impacts" (Nawrotzki et al., 2017, 1). The Omani government would benefit from a richer discussion of options and areas of concern regarding migration in designing future adaptation policy.

Society and Technology

As stated earlier in the section on adaptation, this paper looks at multi-directional flows of influence within networked systems. We now look at literature which considers how human action shapes the environment. Desalination technology provides an uneasy transition, as it can properly be said to be both an adaptation as well as a human activity which shapes the environment. In this section we set up our approach to the effect of technology on environment and society. This topic might be approached via modernization theory or development theory. There are some drawbacks to these approaches, however, which we avoid by reframing our study as outlined below.

We will briefly address and dispense with the ideas of 'modernity' and 'modernization'. Then we will take a closer look at 'development', the successor to 'modernization', and touch on some of the criticisms which have been levied against development studies. We then discuss related issues, such as the use of terms like 'traditional'. Finally, we clarify how our approach detours these pitfalls by employing an a-normative view of 'socio-technical change' and identifying the variables and relationships under consideration. By doing this using a political ecology approach we avoid narrowness which reifies technology or specific forms of economic or social development, or linearity which might not accommodate unexpected outcomes.

Modernity: Introducing the Problem

This theoretical particularity is of special relevance to Oman. From 1970 onward, the Sultanate has engaged in a delicate balancing act between, on the one hand, rapid development and 'modernization', and on the other, curated narratives of 'traditional' society. Modernization is a term which has been so problematized and debated that it is difficult to know what is even meant by the word. Berger proposed that, "Modernization, … consists of the growth and diffusion of a set of institutions rooted in the transformation of the economy by means of technology," (Berger et al., 1974, 15). This definition fails to identify which "set of institutions" are included, the criteria for their selection, and the historical context of these institutions and criteria. It also does not specify what kind of "transformation" will take place. This emphasis on technology as a defining feature of civilization formed a central feature of modernization theory. The modernist emphasis on technology and transformation reinforced and manufactured global power structures based on the production of global winners and losers, however, and thereby entrapped whole continents in sweeping judgements of inequality.

Description of the Problems Posed by Modernization

The shortcomings of Berger's description point to some of the most critical issues plaguing modernization theory. Max Weber's assertion that: "The fate of our times is characterized by rationalization and intellectualization and, above all, by the 'disenchantment of the world,'" (Isaac, 2015, 1), suggested that 'progress' of a scientific and intellectual nature had delivered an elite class of society to an exclusive brand of enlightenment. Modernization theory was criticized for its elitist facilitation and colonial instrumentalization. Scholars of the Middle East, and particularly the Gulf region, would quickly recognize in the colonial and post-colonial history of the Middle East, a, "...self-confidence about the state's ability to foster progress and redirect human nature through top-down social engineering ...famously identified with high modernist ideology" (Isaac, 2015, 1). Oman's own close relationship with Britain has opened debates about the influence of modernist ideology and colonialism on Oman's foundational state structures, infrastructure, and bureaucracy. Furthermore, attempts to decolonize modernization have largely failed, resulting in ambiguous and loaded terminology. For the purposes of this research we will avoid engaging in claims to modernization and modernity, which would only serve to muddy the discussion and distract from the subject we wish to address in this study.

After Modernism: Origins of Development Theory and Pitfalls

After modernization, development studies gained traction as a way of thinking about rapid political, economic, and infrastructural change. Development studies have received criticism for furthering colonial attitudes and power structures through a kind of neoliberal paternalism. Where ideas of 'modernity' were rooted in the adoption of 'rationality' as a core value, 'development' tended to draw inspiration from Darwinian evolution.

Development was first created as something which was done by 'First World' countries to 'Third World' countries (Eisenstadt, 1973). This perspective highlights an implicit superiority complex which haunts development studies. Beyond theory, the practical application of 'development' policies often perpetuated inequality intentionally. Colonial powers frequently leveraged development projects such as roads, railways, and dams in order to facilitate control of their colonial subjects (Piper, 2014). More recent postcolonial approaches to development, such as IMF and World Bank financing in the 1970's-1980's, manipulated and coerced less 'developed' countries to abandon social, political, and economic arrangements which did not conform to an extreme neoliberal vision of the world order. Contemporary 'development' efforts through international aid, IGOs, philanthropy, and humanitarian NGOs, continue to stumble on the hubris that is Western problem-solving in non-Western contexts, often in spite of good intentions. Given our positionality as American researchers in Oman, it is important to avoid framings which perpetuate hierarchical or normative narratives and expectations. By fronting Omani voices, specifically identifying our variables in non-normative terms, and analyzing networked systems we hope to generate constructive feedback which respects and supports the unique needs and achievements of Oman's people.

In discussing the limits of development studies, we would be remiss in not acknowledging the way in which these limitations affected the use of the terms 'tradition' and 'traditional'. While it can be challenging to find alternate wording to express what is often described by 'tradition', it should be noted that 'developed' societies have frequently been posited in contrast to 'traditional' societies. This juxtaposition incorrectly implies a backwardness and deficiency inherent to 'traditional' societies. Worse, these claims often rely on racial and religious predeterminism, implicitly or explicitly.

Development's Antithesis: Tradition

While 'traditional' is a term frequently embraced by the Omani government and Omani people, it can sometimes have the unintended effect of obscuring and flattening the ingenuity or value of 'traditional' society and technology by way of simplification and condescension. In societies which have embraced a neoliberal vision of linear progress, 'traditional' is usually posed as the antonym to 'progress', tinged by backwardness, romance, and inferiority. As has been demonstrated in many contexts around the world, however, traditional practices which are the product of generations of experience often hold wisdom which is superior to recent practices or can be combined with new innovations to great benefit. It is also helpful to be aware of the subjective meaning of 'tradition' in Oman. In the Omani context there is no one delimited period in time or social context which constitutes a homogenous 'traditional' identity or set of practices. Rather, Oman's history is uniquely rich in its social diversity. When using or reading these terms it is useful to bear the inconsistent history of them in mind in order to avoid inaccurate judgements. Oman's official narrative seemingly draws a clear line between 'traditional' and 'development'. In practice, however, Oman continues to support a unique fusion of these ideals.

The relevance to our research of these terms lies in the application of 'traditional' to many of the behaviors which we will consider. To avoid ambiguity, we will clarify the scope of behaviors which this encompasses. Although 'traditional culture' is often romanticized and limited to a narrow range of activities (particularly the arts), traditional behaviors encompass a wide range of socially valuable human activity, to include the mundane and procedural. Mandana Limbert's ethnographic work in Oman revealed how the daily mechanics of water management can be every bit as rich in social and cultural significance as a song. In one chapter she describes an Omani man who still maintains an ox-and-pulley well system, a method which has largely fallen out of use in Oman. His character is significant in her narrative because of his habit of recording the pulley system on cassette tapes. He then drives his car around town listening to the sounds of squealing pulleys, sloshing water, and heavy ox breaths as if they were songs on the radio (Limbert, 2010). Limbert's work describes a lived dialogue between 'nostalgia' and 'modernity', and discusses the role of urban migration, religion, and national development narratives on Omani sociality and water use. In our research we looked for this kind of socio-technical interplay. In order to avoid the diminishment of Omani society or technology, we should reframe our discussion to acknowledge the complicated reality which exists at the nexus of, or in spite of, a 'tradition' and 'development' binary.

Outlining Our Approach: Technology and Climate

In our paper we look at water in its multiple localized meanings and roles to understand how two variables, adaptive technology and climate change, are affecting Omani society, economy, and politics. By isolating technology and climate as our primary variables in a highly networked system, we refocus our approach in order to avoid the shortcomings of development studies and modernization theory. For our study, we adopt Moss's approach to technology and social change. "Socio-technical change is conceived of here less as a transition from one path to another, but rather as a largely messy, contested and discursive process strongly framed by contexts of action and contingent events," (Moss, 2014, 1435). In this study 'technology' is a broad term which encompasses mechanical instruments, infrastructure and bureaucratic systems. A political ecology approach further helps us remove this work from the field of development studies and approach it with from a more nuanced angle. We instead identify behaviors, rather than 'traditions', which are experiencing change as a result of altered technological processes and water scarcity. We found that recent changes in these technologies and in climate are altering human behavior in Oman. The effect of water scarcity and adaptive technology may have wide-ranging consequences. We hope this study will contribute to the understanding of how behaviors are affected and support policies to mitigate negative effects and adapt to change which is unavoidable.

Context

Water Scarcity in Oman

Most of Oman's terrain with the seasonal exception of a narrow portion of the Dhofar coastline, is extraordinarily arid and hot. Although it seems remarkable that any life could eke out an existence under such extreme conditions, the deserts and mountains support a range of wildlife based on seasonal rains and seepages from underground reserves. Average rainfall in Oman as of 2013 stood at 250–500 mm/year, and Oman's climate is expected to become drier and hotter, with large portions of the Hajar Mountains where Jabal Akhdar is located receiving up to 40 mm less in annual rainfall by 2070 (Al Charaabi & Al Yahyai, 2013). In spite of the harsh environment, Oman's water supply compares favorably with the other Gulf Cooperation Council (GCC) countries due primarily to the existence of large underground aquifers, and somewhat due to seasonal rainfall in Salalah and the northern mountains (Charaabi & Al Yahyai, 2013; Abdulrazzak, 1995). However, this relative abundance of water compared to other GCC countries is tempered by the existence of a much larger population, at roughly 4.5 million people (Al Markaz, 2018). Oman is also more conservative in water use per capita compared to the other major GCC countries. Omanis use 200-250L of water per day vs. 500-700L of water per day in Saudi Arabia, Qatar and the UAE (PAEW interview, March 11, 2018; MRMWR interview, March 15, 2018). This difference reflects the way in which Oman's smaller supply of oil wealth and greater financial responsibility to its large population has resulted in more cautious and forward-looking policies. Nonetheless, the fact remains that Oman must find a way to flourish under conditions of extreme and intensifying water scarcity.

Political History

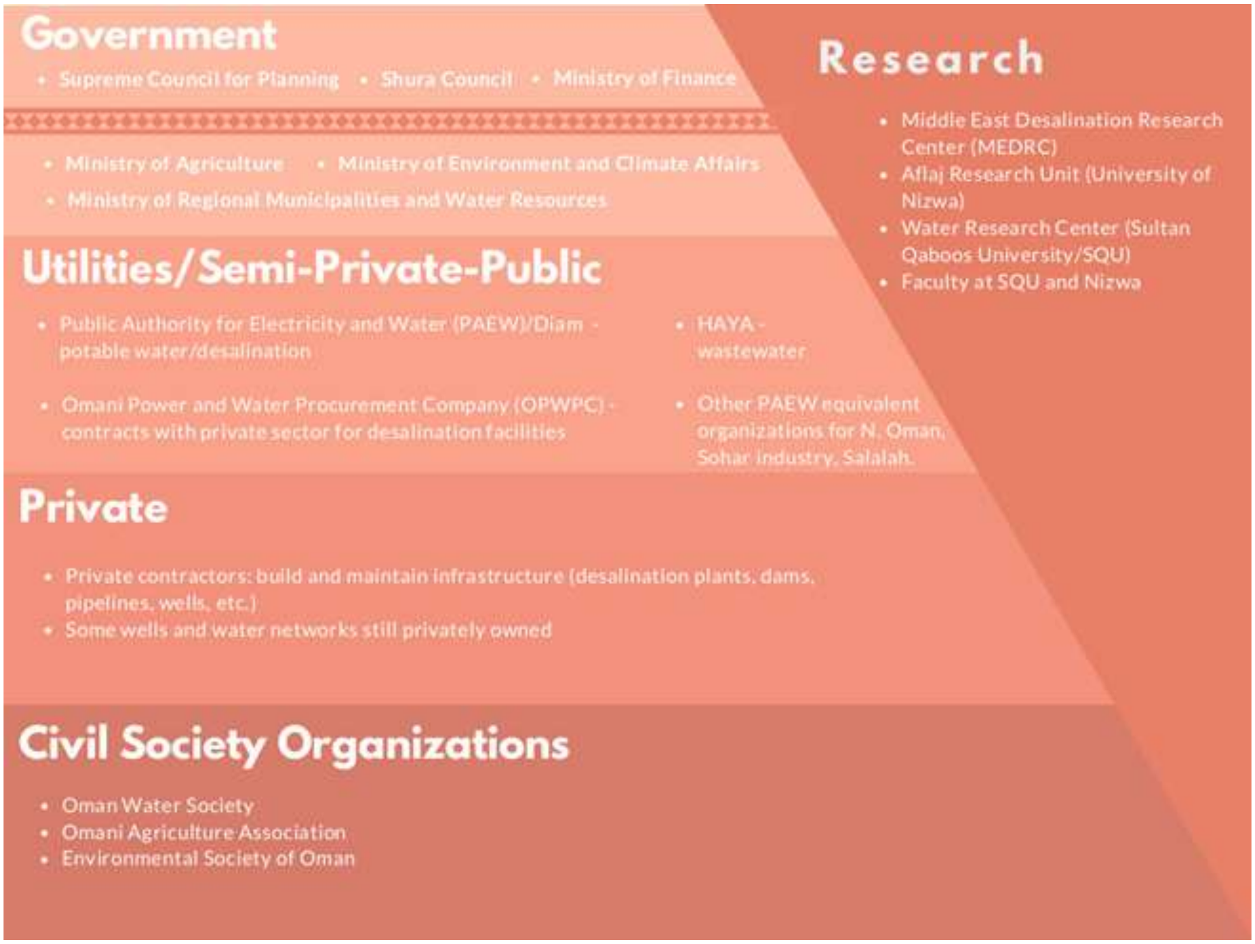
For our analysis of Oman's historical water management and current adaptation strategies, it is important to include a note on the political context of water in Oman. A critical turning point for water management in Oman, as with so many other aspects of Omani life, was the accession to power of Sultan Qaboos in 1970 and the near-simultaneous influx of oil wealth. Under Sultan Qaboos, Oman was established for the first time as a unified nation-state according to the modern, international definition. Sultan Qaboos's rule brought about what is called in Oman the "Renaissance," which transformed the way Omanis live through the widespread implementation of infrastructure, technology, and bureaucratic structures (Valeri, 2009; Takriti, 2103; Skeet, 1992; Limbert, 2010). The population at the time of Sultan Qaboos's succession stood at less than a million (Peterson, 2004). After 1970, rapid expansion of Oman's population raised that number to approximately 4.5 million in 2016 (Al Markaz, 2018). In spite of the country's apparent lack of resources and an initial level of near-nonexistent infrastructure and poor national cohesion, the country has flourished and grown. This brought significant changes to the national waterscape and related social and economic arrangements.

Although these changes would not have been possible without the sudden influx of oil wealth, and the significant investment of foreign expertise and aid, which were also mostly attracted by oil wealth, Sultan Qaboos is widely credited for his country's notable prosperity and stability in spite of geographic austerity (Valeri, 2009; Takriti, 2013; Skeet, 1992). Sultan Qaboos's ability to increase the quantity and quality of water supply was an unprecedented development with profound political and social consequences.

Because of the social position of water in Omani society, it assumed a special role in the 'renaissance' narrative and outcomes. Historically, water was understood as a gift from God and descriptions of water and gardens feature prominently in juxtaposition with desert imagery in the Qu'ran (Skeet, 1992). While it was historically considered inappropriate to sell drinking water, the distribution and sharing of water resources was ultimately at the discretion of tribal leadership (Zimmerman, 1984). By sponsoring water development projects, Sultan Qaboos inserted his government between tribal leaders and their dependents and consolidated the Omani state. Furthermore, the extreme water scarcity and the ability to alleviate it provided Sultan Qaboos with very practical environmental tools for political manipulation, as ready access to water offered security and economic opportunity. By taking over the provision of essential services such as water, employment, healthcare, and housing, and by reducing the isolation of Omani populations through the construction of roads and communications networks, the Sultan effectively undermined previous structures of power and security and put them to work in service of the Sultan's new centralized absolutist system (Takriti, 2013; Clements, 1980; Valeri, 2009). It was for these reasons that the Sultan's Dhofar Development Officer, Robin Butler, selected the drilling of a water hole in Barsa for loyal Kathiri Sheikhs in 1970 as the first of many development projects. The project was, "…meant to increase the local leverage of the Sheikhs as well as the government," (Takriti, 2013, 268). The same motivation can be traced in the construction of desalination plants and recharge dams in the remote and sparsely populated Musandam Peninsula in 1978-1979 which effectively dissuaded those communities from joining politically with the neighboring UAE sheikhs (Zimmerman, 1984). The promise of water was therefore a powerful incentive, with transformative consequences.

Methodology

Our inquiry into climate change and technology featured interviews and site visits relevant to our question. We used the Jabal Akhdar region of Oman's northern mountains as a case study and conducted a site visit to several villages near the Saiq Plateau (Ash Sharaijah, Al Ayn, and Al Aqr). This gave us the opportunity to explore the aflaj and agricultural terraces firsthand. We had the opportunity to document how water is structured in the region and how it differs from the coastal urban areas. In Jabal Akhdar we documented how water distribution is structured in each place and analyzed the long-term viability of the water sources. We conducted eleven interviews with officials at the Oman Power and Water Procurement Company (OPWPC), the Public Authority for Electricity and Water (PAEW), the Ministry of Regional Municipalities and Water Resources (MRMWR), researchers at the Water Research Center at Sultan Qaboos University (SQU) and other faculty at SQU, and the Middle East Desalination Research Center (MEDRC). Based on these interviews we were able to construct a graphic representation of water management bureaucracy in Oman, included below.



(Source: Author interviews)

We toured MEDRC's on-site small desalination plant and observed how a desalination plant works in practice. We visited our case study site, Jebel Akhdar, in Oman's northern mountains about two hours southwest of Muscat to see the aflaj and agricultural terraces. We also used the opportunity to document how water is structured in the region and how it differs from the coastal urban areas. We approached all of our site visits with the fundamental question of how water distribution is structured in each place and the long-term viability of the water-distribution methods at each site.

Results

Governments tend to portray adaptation efforts as an undertaking which aims to preserve the status quo in human processes as much as possible. The potential political benefits for governments in this approach are obvious. Change is a inherent in adaptation, and we believe our research highlights the way that even the best options available can result in adaptation which works for most, but not all. We dispel the myth that adaptation means life will proceed exactly as it has before. Each adaptation strategy implemented in Oman has brought change, and it is reasonable to expect that future adaptation strategies will bring further change.

As mentioned earlier, these technological adaptations fit roughly into three strategic phases, outlinedbelow. Then we review the current situation in Oman with regard to climate change and water scarcity. Next, we introduce our case study in Jabal Akhdar and discuss the challenges particular to that region, and what it can tell us about the future of climate change adaptation.

Waves of Adaptation

1st wave: Economic Networks and Aflaj Irrigation

During the first phase, encompassing a vast period of time prior to 1970, the primary adaptations to water scarcity were the development of aflaj irrigation and networked niche economies. In *Monsoon Revolution*, Abdel Razzaq Takriti illustrates complex seasonal movements of various segments of Dhofari society, and the networked economy which had evolved in support of these specialized movements (Takriti, 2013). Likewise, B.R. Pridham refers to the complex socio-economic networks of the inhabitants of the northern mountains, "…between large agricultural towns, more scattered cultivators in the Jabal Akhdar, shawawi herders, true badu and providers of specialized services such as the 'Awamir falaj-diggers," (Pridham, 2016). Nonetheless, during long periods of drought waves of migration to other locations, even as far as Zanzibar, were periodically the only solution (Al Ismaily, 1998).

The falaj-diggers were part of the other major adaptive innovation during this time: the *aflaj* (singular: *falaj*) irrigation systems. Aflaj systems in Oman have provided water to the mountain regions for over 2,000 years (Limbert, 2010; MRMEWR, 2005). These *aflaj* facilitated agriculture and, for some, a settled lifestyle. Still important, the aflaj provide some 30% of Oman's agricultural water to this day (SQU interview, March 13, 2018).

Similar to historical irrigation systems also used in a number of other countries, such as the qanat in Iran, the aflaj systems draw water from underground aquifers and springs, using subterranean tunnels and gravity to channel water to agricultural areas (MRMEWR, 2005; Al Ismaily & Probert, 1998; SQU interview, March 13, 2018). The entire village collectively owns the right to the water, but the aflaj water rights administration is undertaken by a local representative, and access to irrigation water is allocated in time increments. The rights to these time allowances are passed through families as inheritance. Maintenance responsibilities and costs are also shared collectively by the village. Critically, water used for drinking and bathing was free to all and unrestricted (Limbert, 2001). While there was some leeway to trade rights to the time increments allotted for irrigation (‘water-time’), water itself was not the object of commercial trade (Limbert, 2001).

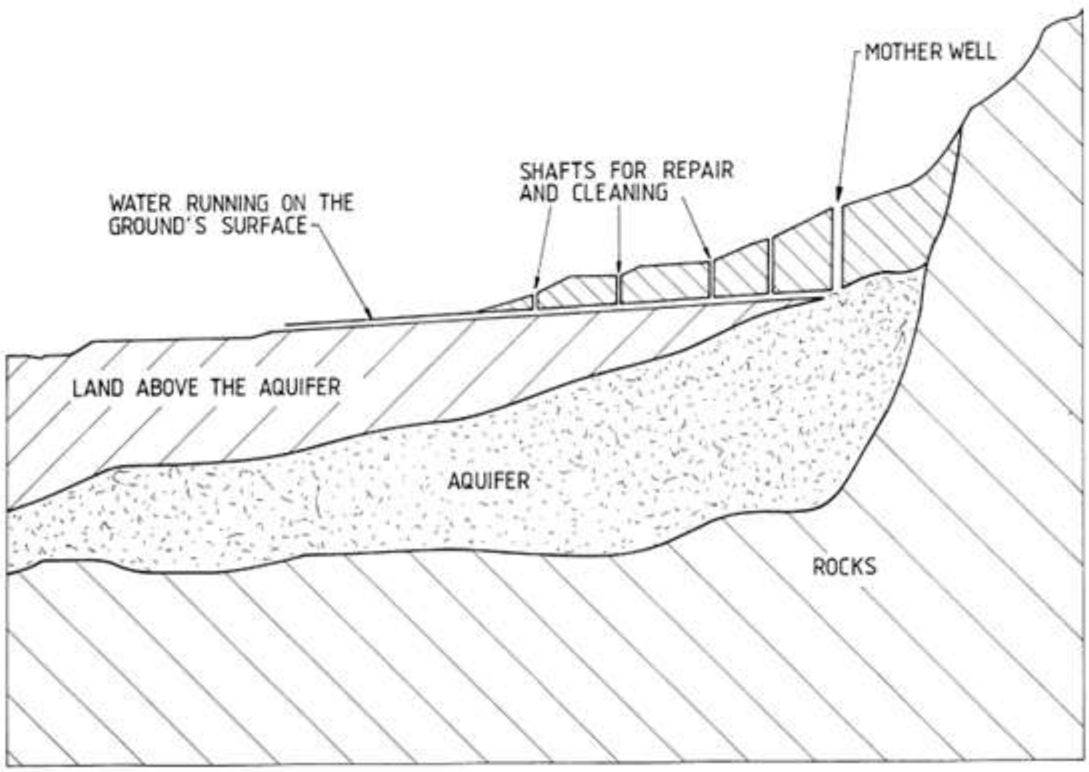


Fig. 2. Schematic vertical cross-section for a falaj in Oman.

(Source: Al Ismaily, 1998)

In spite of the remarkable endurance of the aflaj systems, recent technological change has altered Oman’s relationship with the aflaj (Limbert, 2001). Limbert notes that until the 1970’s all water was sourced from groundwater via wells and aflaj systems (Limbert, 2010). With the introduction of new technologies and the expansion of infrastructure, water derived from alternate sources began to arrive directly to private homes and businesses, circumventing the previous system of communal management (Limbert, 2010). Nowadays, the maintenance of the aflaj is increasingly becoming the domain for the elderly (MRMWR interview, March 15, 2018; Limbert, 2001; Al Kalbani, 2017).

2nd wave: Infrastructure, Recharge Dams and Wells

The second wave of Omani adaptation relied on wells, dams, and infrastructure such water pipelines. After the 1970 coup which brought Sultan Qaboos to power, Oman built extensive infrastructure, developed government ministries to manage water distribution, and created inventories of wells and aflaj throughout Oman. The production of oil, begun in 1969, combined with high oil prices in the 1970’s injected immense amount of capital into the Omani economy to facilitate these changes. “The post-coup state used and continues to use the language of development not only to claim that the nation is founded on the building of modern infrastructure but also to contrast itself with the supposed isolation and backwardness of the previous era." (Limbert, 2001, 38). The Sultanate recognized the need to address water scarcity early on.

> "Water policies and distribution were of primary concern to the young post-coup d'état state. The new state began its initiatives by...establishing government ministries to manage water distribution, initially for the capital area and then for the rest of the country. The early research projects and ministries were concerned with documenting and establishing inventories of the wells, canals, and water levels throughout Oman. The development of water policies also meant laying down pipes in the capital and opening and subsidizing a new market for selling pipes, pumping equipment, and pumps throughout the country," (Limbert, 2001, 39).

This phase was characterized by the idea that water scarcity could be solved if only technology were implemented to gain access to it. There were no incentives to conserve water and the depletion of the groundwater table also led to the increased salinity of Oman's groundwater. From 1970 until 1976, all water was sourced from aquifers (Al Ismaily & Probert,1998). Water demand in Oman had increased substantially by 1974, so a decision was made to build Oman's first combined power generating station and desalination plant. The Ghubrah power generating station and desalination plant was completed in 1976 (Dawood & Leidholdt, 1986). "The original Ghubrah desalination plant consisted of one unit that produced 18 to 28 ML of water per day. Multistage Flash Distillation (MSF)...was used." (Dawood & Leidholdt 1986, 81). While Oman continued building desalination plants throughout the late 1970's and 1980's, groundwater and wells continued to be Oman's primary source of water. In 1986, Oman received 70% of its water through the aflaj, 21% of its water from wells in the Batinah, and 4% of water from wells on the Salalah plain (Anderson, 1986). There were no restrictions on well drilling and groundwater extraction for agriculture, and no incentives for conservation. The depletion of the groundwater table also led to the increased salinity of Oman's groundwater (MRMWR interview, March 15, 2018). The government realized that this policy was unsustainable and decided to take drastic measures to restructure Oman's water.

3rd wave: Desalination

In 1985, Oman established the Ministry of Water Resources, consolidating the responsibilities of recharge dams and aflaj under one ministry (MRMWR, 2008). A more radical change came a few years later. In 1988, Sultan Qaboos issued a decree which declared water an Omani natural resource and gave the Omani state authority to take any action necessary to develop, protect and conserve underground water (MRMWR, 2008).

This law marked a complete change in the structuring of water in Oman. Control of water resources and attendant livelihoods and luxuries were transferred wholesale from local communities and tribal authorities to the person of Sultan Qaboos, who encompassed the Omani state. The effects were immediate. The MRMWR declared a moratorium on new wells and conducted a national well inventory. The MRMWR then issued certificates for existing wells and installed plates on certified wells. The size and locations of the wells are now kept in a national inventory, and changes to existing wells or development of new wells now require a permit (MRMWR interview, March 15, 2018). From 1992-1994, all contractors for drilling wells must register with MRMWR, and incur a severe penalty for not doing so (MRMWR interview, March

15, 2018). Oman began using water meters in the 1990's. As a result of these policies, agricultural water demand has not increased since the 1988 Water Law. (MRMWR interview, March 15, 2018). Rather, "the level of water extraction from aquifers in Muscat has remained at approximately at the 1985 rate, i.e. at about 12,000 cubic meters per day," (Al Ismaily & Probert, 1998).

Oman also dramatically increased its production of desalinated water. Today, Oman produces most of its drinking water via desalination. In 2016, the Public Authority for Electricity and Water (PAEW) supplied 329, 786, 568 m^3 of portable water to the Sultanate, with 85% from desalination plants and 15% from wells (Oman Energy, 2018). The present-day narrative of water in Oman has largely focused on desalination as the cure-all miracle. This can be seen through how Oman plans to meet future increased water demands. "With the aim to substantially raise the country's water desalination capacity within the next six years, the state-owned Oman Power and Water Procurement Company (OPWPC), has taken major steps to increase the desalination capacity of Independent Water Projects (IWPs) by 123.6 million imperial gallons of water per day (MIGD) in the next six years. The increase will take the capacity to almost 310 million gallons, a 66% increase from the current 186 million gallons per day" (Oman Energy, 2018).

The reality of water production and water scarcity in Oman is more complex. It is important to remember that desalination is primarily a solution for drinking water and is not practical for agriculture due to the high cost. While desalinated water is sometimes injected into aquifers near coastal farms to prevent further saltwater intrusion into the groundwater, this is uncommon (MRMWR interview, March 15, 2018).

Moreover, desalinated water is very expensive to produce and transport, as well as being heavily subsidized for Omani consumers. The cost to produce a liter of desalinated water is 3-4 times more than what consumers are charged (SQU interview, March 13, 2018). According to the ministries, most urban middle-class Omanis pay around or less than 1% of their monthly income on water (PAEW interview, March 14, 2018). This total is low for any country and incentivizes wasteful behavior. Piped desalinated water is primarily available to flat, coastal areas. For inland areas at elevation, transportation infrastructure raises expense and water losses. Some areas are too costly to reach via pipeline distribution networks (PAEW interview, March 14, 2018). Where there are no pipeline networks, desalinated water is brought by tankers. (PAEW interview, March 14, 2018) The cost of desalinated water for the consumer is the same everywhere in Oman, from urban coastal areas to rural mountain areas (PAEW interview, March 14, 2018). For residential dwellings, customers are charged 2 baisa per gallon (1 cent/gallon) for 1000-5000 gallons of water use per month, and 2.5 baisa per gallon (1 cent/gallon) for using more than 5000 gallons per month. Commercial sector businesses are charged a flat rate of 3.5 baisa per gallon (1 cent/gallon) (PAEW interview, March 14, 2018).

Issues Emerging from Past Adaptation Strategies

A major issue with Oman's robust adaptation response is that it has cultivated a sense of entitlement by Oman's population. Omanis have gotten used to water being plentiful, especially in urban areas. The abundance of clean drinking water for Omanis brought about by technological change in Oman cemented public expectation that the government continue to provide good quality water (SQU interview, March 13, 2018). Clean water is seen by Omanis as a required service to be provided by the government. Government representatives do not hesitate to invoke the narrative of water as a human right. The 1988 Water Law, which established government control of Oman's water, arguably contributed to this unintended consequence.

Another issue with Oman's adaptive strategy of using desalinated water has been a reluctance to use reclaimed wastewater. Oman is currently only using about 3% of reclaimed wastewater, and it is mostly used for ornamental use such as highway medians. Much of Oman's treated wastewater is being dumped into the ocean (SQU interview, March 13, 2018; MEDRC interview, March 12, 2018).

Effects of Climate Change

The Sultanate of Oman has worked hard to address water scarcity. The Omani government has invested heavily in water infrastructure and has linked the urban population to desalination pipelines. Moreover, about 50%-60% of all Omanis are linked to desalination pipelines. PAEW's goal is to have 90% of all Omanis linked to a water piping network by 2040 (PAEW interview, March 14, 2018). Oman has and continues to invest heavily in universal desalinated water access for all Omanis. To this end, Oman's government has engaged in expensive and inefficient projects. These include the construction of eight desalination plants in rural areas between 1982 and 1988 (Al Sajwani, 1998), as well as a pipeline from the coast to Jabal Akhdar scheduled for completion in 2018 (PAEW interview, March 14, 2018; Bin Badr Al Thani, 2016).

Despite the economic inefficiency and impracticality of providing an adequate supply of desalinated drinking water to remote rural areas, Oman's government feels it has a social and political obligation to provide piped drinking water for all Omanis (PAEW interview, March 14, 2018).“The country's [Oman's] policy has been based on increasing the living standards in all areas to maintain regional development equilibrium and to discourage people from immigrating to the central densely populated areas by utilizing the natural resources and increasing the variety of income sources,” (Al Sajwani, 1998, 53). Governmental support for rural areas discourages urbanization and attempts to prevent rural economic and social collapse. Conversely, urbanization increases pressure on the government to provide employment and services (PAEW interview, March 14, 2018). Given that Oman already has a shortage of jobs for its urban population, additional population movement into urban areas risks political instability. As a result, Oman's government invests in rural self-sufficiency for political and economic reasons (PAEW interview, March 14, 2018).

Due to Oman's increased budget deficits in recent years and a government desire to attract foreign investment, the Omani government is moving towards privatization in the water and power sectors. The privatization of Oman's desalination was inspired by the electricity sector's success with privatization (OPWPC interview, March 11, 2018; PAEW interview, March 14, 2018; PAEW, 2018). OPWPC solicits contract bids to construct desalination plants from foreign investors. While the companies own the desalination plants, they are required to provide 20-year leases for the government on the water produced (OPWPC interview, March 11, 2018). This partial privatization of desalination frees up more funds for the Omani government to spend elsewhere while attracting foreign investment. It also promotes the commodification of water in Omani society, which differs from past attitudes towards water access and valuation represented by aflaj management practices.

Although the Sultanate of Oman has been proactive in ensuring Oman's people have adequate water supplies, climate change is threatening the current viability of Oman's water adaptation. In recent years, Oman has seen a decline in their already scarce rainfall due to climate change. This has resulted in worsening aridity in Oman, and the lack of rainfall threatens the groundwater supply and the viability of the aflaj. This means a reduced recharge of aquifers and difficulty obtaining consistent water supply for agriculture (SQU interview, March 13, 2018; Al Shibli, 2014; Ahmed & Choudri, 2012). Agriculture currently uses 80%-90% of the country's water supply (SQU interview, March 13, 2018; Al Ismaily, 1998; Al Shibli, 2014). Furthermore, population increase, higher living standards, and a growing industrial sector are leading to increased water consumption. All of these factors, combined with climate change, are increasing pressure on Oman's limited water supply.

Adaptation Planning Linked to Economic Strength

Going forward, Oman's water adaptation planning is at risk due to reduced economic capacity. Oman's national debt reached $7.8 billion dollars in 2018 (Reuters Staff, 2018). The IMF forecasted that government revenue as a percentage of GDP will decline from 49.1% in 2013 to 42% in 2018 and that government gross debt as a percentage of GDP will increase from 5.1% in 2013 to 48.3% in 2018 (MEED Business Review, 2017). As a result, Oman's latest 5-year water plan was not adopted because it was too costly. Instead, the water plan is being implemented piecemeal as funds become available (MRMWR interview, March 15, 2018). Currently, Oman's economy relies heavily on oil and natural gas. Hydrocarbons were responsible for 30.7% of Oman's GDP between January and September 2017 (Prabhu, 2017). Although the price per barrel of Omani crude oil increased from $38.30 in 2016 to $50.60 in 2017, overreliance on high oil revenues as a large percentage of GDP for long-term planning is unpredictable and destabilizes national budgets (Prabhu, 2017). This can be seen in the chaotic budget planning of oil-rich states following the sudden drop in oil price from its 2007-2008, high of $144.96 per barrel in July 2008 to $29.44 per barrel in February 2016 after the global recession (Macrotrends.net, 2018). While oil prices have rebounded, future fluctuations in oil price are to be expected. Past instability in oil prices and a worldwide move to natural gas and renewable energy sources suggest that it is impractical to base water adaptation planning on the premise that oil prices will reach and sustain high prices in the future.

Jabal Akhdar: Case Study

Climate change is particularly problematic for the northern mountains in Oman, creating a unique challenge for adaptation efforts. In our case study we demonstrate some of the ways in which present adaptation efforts are falling short in Jabal Akhdar. We selected Jabal Akhdar for our case study because it is representative of the regional aflaj systems, and there exists a significant body of previous scientific research for Jabal Akhdar (e.g. vulnerability assessments, irrigation practices and efficiency assessments, and climate analysis). The decline of Jabal Akhdar's aflaj suggests that there are limits to the government's ability to preserve the aflaj and that technological adaptations are not suited to the preservation of social institutions, cultural practices, and economic structures.

Water scarcity in Jabal Akhdar is most critically related to both quantity and timing of rainfall. Located at approximately 1,900 m elevation, the Saiq Plateau receives an annual mean of approximately 250-400mm annually, and from 1979 to 2012 the average annual rainfall was

295.3mm, displaying monthly average highs and lows of 45.8 and 8.2mm. (Al Kalbani et al., 2014). The three primary sources of water in Jabal Akhdar are: groundwater (wells), lotic (natural springs), and lentic (dams) (Al Kalbani et al., 2014). All of these sources rely on rainfall. The greatest challenge to water management in Jabal Akhdar is the variability of rainfall, a phenomenon which is expected to intensify (Al Kalbani et al., 2014). This is because the northern mountains do not possess large aquifers in which to collect water.

Jabal Akhdar is also an important tourist destination, somewhat ironically promoted for its lush agriculture and temperate weather (Al Kalbani et al., 2014; Al Charaabi & Al Yahyai, 2013). It has recently seen a significant increase in the number of visitors, jumping from 102,000 visitors in 2009 to 162,500 visitors in 2016 (Mufawaq, 2017). Concurrently, Jabal Akhdar also experienced significant increase in built structures, infrastructure, and demand on resources. Increasingly, the residents and businesses of Jabal Akhdar rely on desalinated water or, to a much lesser degree, reclaimed wastewater which is carried up the mountain via tanker. Because Jabal Akhdar communities still rely primarily on aflaj water for irrigation, the increase in rainfall variability holds profound consequences for the area.

Despite heavy government investment, the groundwater supply in mountainous areas such as Jabal Akhdar is disappearing. A 1990's survey of the aflaj in Oman revealed that out of 4,112 aflaj, only 3,017 were still carrying water at the time (UNESCO, 2006). Current estimates say that closer to 50% of the aflaj are left (SQU researcher, March 13, 2018). This change is evidenced by a lowered water table and due primarily to changes in rainfall volume and variability (SQU interview, March 13, 2018; Bin Badr Al Thani, 2016; Al Kalbani et al., 2014; Al Kalbani et al., 2016; Al Shibli, 2014). The effect of changes in rainfall patterns in Jabal Akhdar manifests most visibly in the occurrence of barren agricultural terraces, pictured below. (Author site visits, 2017, 2018; Al Rawahi, 2014).

(Source: Author site visits in Jabal Akhdar: July 2017 and March 2018, respectively.)

Extensive surveys in the same villages which we target in our study were conducted in 2007, 2008, and 2009 by Al Rawahi et. al. They documented the percentage of agricultural area under active cultivation and monitored changes in the choice of crops. Their study showed how farmers attempted to adapt to drought by planting low-water crops and crops with short growing seasons. The results also showed that the percentage of area under active cultivation fluctuated between only 36% and 8.5% of the land area. This demonstrates both low utilization of agricultural land overall, as well as extreme variability in cultivability depending on rainfall patterns. Similar declines in agricultural land use have also been reported in other areas in the northern mountains of Oman (Siebert, 2007). Rainfall variability threatens the viability of agriculture in the region when it renders agriculture too unreliable to depend on for a livelihood.

A researcher at Sultan Qaboos University explained that agriculture is already unprofitable for many farmers because other food sources in Oman are cheaper (SQU interview, March 13, 2018). As the population turns to other sources of income, this pulls labor away from the farms and increases the motivation to abandon agricultural plots. The trend in Oman is towards inward urban migration, especially among the younger generations looking for alternative sources of employment (Luedling, 2008).

Urbanization trends leave behind a reduced and aging labor pool to work on farms. In 2005, 80% of farmers were over the age of 50 (Luedling, 2008). This reduced labor pool has meant a shortfall in maintenance for aflaj water infrastructure and an underutilization of water resources during the wet season (Luedling, 2008). Additionally, the inherited distribution of aflaj water rights sometimes leads to inefficiencies in water utilization when combined with the abovementioned labor trends. This is because while some farmers may experience water shortages, others may have an un-used surplus if they are relying on other sources of income besides agriculture and neglecting their land (Luedling, 2008). Interestingly, there are reports of some agricultural plots being maintained at a monetary loss for sentimental or cultural reasons. In some cases, foreign labor is hired to take the place of the owners in aflaj management (SQU interview, March 13, 2018).

Common Adaptation Strategies Not Successful

Research has repeatedly called for aggressive measures to address climate change in Oman's northern mountains. "There is… an urgent need for mitigation and adaptation to climate change impacts since the region is expected to face further increases in temperatures and decreases in rainfall over the coming decades," (Al Kalbani et al., 2014, 3131). In spite of the numerous suggestions for methods to do just this, and significant government investment in adaptation measures, the issue of water scarcity in Jabal Akhdar continues to intensify. This is because many of the common strategies used in Oman are not successful in this region, or they have only marginal impact. A quick survey of the technical options will demonstrate how these strategies fall short.

The most publicized water management technology in Oman, desalination, is relatively unhelpful for a high elevation community in the interior like Jabal Akhdar. Currently, some desalinated water is provided to Jabal Akhdar by tankers. Also, as a perfect example of the government's heavy investment in water adaptation, a much-publicized pipeline project is scheduled for completion in 2018. The pipeline will pump desalinated water from the coast to Jabal Akhdar. This will likely ensure a sufficient supply of water for homes, the tourist industry, and the nearby military facilities (OPWPC interview, March 11, 2018; PAEW interview, March 14, 2018).

While this may seem like a rare success story, it is important to keep a few points in mind. First, the project is expensive and economically inefficient. The beneficiaries of this project, the permanent population of the Jabal Akhdar region, number only about 8,000 people. Second, the desalinated water will be costly to use, in spite of government subsidies, because not only does it have to go through the desalination process, it must also be transported from the desalination plant on the coast to the interior of Oman and then lifted approximately 1,900 meters in elevation to Jabal Akhdar with pumps which run on fossil fuels (OPWPC interview, March 11, 2018; MEDRC interview, March 12, 2018; PAEW interview, March 14, 2018; Al Kalbani et al., 2014). Even with Oman's high rate of subsidization, the water subsidies are unable to facilitate agricultural production (OPWPC interview, March 11, 2018; SQU interview, March 13, 2018; PAEW interview, March 14, 2018). Given that the pipeline will not be able to resupply groundwater supplies which were once freely available, desalinated water is mostly useful for urban and domestic uses, but not practical for irrigation. Third, such a pipeline project is an exception to the rule, and most rural and mountainous communities like Jabal Akhdar will not receive similar government investment. Other communities, such as Jabal Shams, currently rely on tanker water just as Jabal Akhdar does, and will do so until it simply becomes too costly to sustain (PAEW interview, March 14, 2018), or until the population involved in agriculture simply ages or migrates away. Clearly, the pipeline provides a solution for some in Jabal Akhdar, like the signature five-star resort, but not for all.

The next most common strategy, recharge dams, are a used throughout Oman to capture rainfall and direct it into the groundwater supply. These have a limited application in Jabal Akhdar. Designed to capture flash flood waters and slow their movement in order to facilitate absorption into the ground, recharge dams work best in wadis where the water can be absorbed into the groundwater supply. Jabal Akhdar communities received 26 recharge dams by 1994 which primarily support irrigation (Al Ismaily, 1998). However, there are no large-scale aquifers in the mountains, and water tends to slip rapidly off the rocky face of the mountainside. Thisleavesmountain communities literally high and dry even after torrential rains, which tend to be brief and infrequent. (PAEW interview, March 14,2018; MRMWR interview, March 15, 2018).

Treated wastewater is another option in use, albeit to a lesser degree. It is also delivered to Jabal Akhdar by tanker and is costly for reasons similar to those for desalination Nonetheless, it is a strategy with room for significant growth in the urban areas of Oman, and marginal utility in Jabal Akhdar for domestic and commercial uses. (SQU interview, March 13, 2018).

Another popular theme explored in previous research has been water-use efficiency in agriculture. However, for a community which relies on aflaj irrigation, such as the villages of Jabal Akhdar, efficiency measures provide only marginal improvements. The relative efficiency of aflaj agriculture has been supported by a number of studies, albeit with various degrees of enthusiasm. While in 1998 Al-Ismaily et. al. went so far as to say that it was impossible to over-use water from an aflaj, more recent work by Al-Rawahi suggests that in Jabal Akhdar increased demand for irrigation water has played a role in the deterioration of the aflaj (Al Rawahi, 2014; Al Ismaily, 1998). A 2007 study of the Balad Seet aflaj found a range of efficiency varying from

60-90% (Siebert, 2007). Farmers are already engaged in adaptive behavior by adjusting their choice of crops in response to precipitation levels, but even this is not sufficient to keep the agricultural plots at capacity (Al Rawahi, 2014). Furthermore, while inefficiencies via pipeline losses would be worth addressing, this is also an approach which promises marginal benefit (Al Ismaily, 1998). The general consensus seems to suggest that while efforts could be made to increase the water efficiency of aflaj agriculture and slow its deterioration, the overall effect would not be enough to fully counteract the impact of climate change.

The fact is that even the most effective solutions which improve irrigation efficiency would result in the restructuring of the aflaj to such an extent that the social and cultural character of the aflaj is fundamentally altered. We can see similar restructuring already with the introduction of commodified water via desalinated or reclaimed wastewater. A system of water provision in exchange for money directly supplants and erases the community time-allotment system of management which forms the cornerstone of the aflaj as a social institution (Limbert, 2001). New technology options for agriculture which facilitates profitable agricultural production, such as greenhouses, root-delivery watering systems, and hydroponics, would render the architecture of the aflaj irrelevant, effectively supplanting aflaj technology (SQU interview, March 13, 2018; Al-Ismaily, 1998). Furthermore, the initial cost of transitioning to the new technology would require government support. While these technologies may be more efficient and economically viable, they would irreversibly change structure of water in Oman. This is important because the aflaj are not merely a technical object, they are also a social institution. Their disappearance will have consequences for the ways in which communities operate and individuals interact (Limbert, 2010).

Considering the current predictions for future precipitation trends in the northern mountains of Oman, it is likely that the aflaj are facing certain degradation in higher mountain elevations. Because of the particular vulnerability of these communities, they are positioned to act as an indicator for water scarcity in Oman. Decreased rainfall and groundwater degradation will necessitate changes in Omani agricultural practices if the Omani agricultural sector is to survive. However, these adaptations structurally threaten the aflaj, both as a technical object and as a way of life. Agriculture represents only 1.5% of Omani GDP, suggesting that the importance of agriculture, particularly the aflaj, lies in its social and cultural significance. As one SQU researcher pointed out, agriculture in Oman is increasingly not a for-profit endeavor, instead, "...it is based on history and culture," (SQU interview, March 13, 2018). This is particularly true for small-scale aflaj farming, as opposed to larger operations in the coastal areas. Officially, Oman places great emphasis on the reproduction of its cultural heritage, demonstrating that, on some level, these cultural and social practices also hold political importance in Oman.

Conclusion

In spite of notable efforts by the government of Oman, adaptation planning is reaching a stage in which the limits of human ability to control the environment is increasingly evident. In this paper we have focused on the way in which water scarcity is interacting with technological change in order to shape Omani adaptation efforts. As we discussed earlier, political ecology is a process in which the architecture of causality between environmental factors and human actions becomes increasingly complex as environment and human action mutually shape social, economic, and political dynamics (Mitchell, 2001). In Oman the complexity of this process is particularly evident, preventing easy classification under any one paradigm. In spite of a common perception that the GCC countries are living out a modernist fantasy in which humanity has transcended the limitations of nature, the story of water management in Oman aligns with Timothy Mitchell's suggestion that, "As one unravels these interwoven forces, human agency appears less as a calculating intelligence directing social outcomes and more as the product of a series of alliances in which the human element is never wholly in control," (Mitchell, 2001, 20). Various iterations of adaptation in Oman reflect the continuing human effort to respond to, and shape the experience of, water scarcity in Oman. We conclude that technology, urbanization and the decline of the agricultural sector as a result of climate change is altering social structures and economic practices in Oman.

Due to the decline of aflaj agriculture as a result of climate change, Oman faces a weakened links to its historical and rural social structures. The changes observed in Jabal Akhdar ask us to consider the fate of the aflaj as groundwater supplies fail. What will it mean for the fabric of Omani society if aflaj become a luxury object based on social or cultural values rather than a living social institution? How does the value of the aflaj change if they are managed as a kind of national monument or commodified as tourist attractions? Both of these latter options would effectively displace the community and maintain the materiality of the aflaj without the attendant social heritage. Our research also raises questions about limits on the capacity of the Omani government to provide everything which is demanded of it (e.g. water). A combination of population entitlement and a weakened governing capacity raises interesting questions about the future nature of the social contract between Oman's population and the government. Furthermore, if these limitations are observable for a country which is as well prepared and equipped to deal with climate change as Oman, we should be asking what will be become of other countries which are not positioned as favorably. With the wealth of scientific analysis now available to policy makers, we suggest that it is time to consider the deeper ramifications of climate change adaptation.

Future Research

Due to the limited time for our study there are some areas which we would have liked to explore further for this project but which we were unable to include. Most significantly, we would have liked to have spent more time in the Jabal Akhdar communities in order to interview local residents about their experiences. We would also like to expand our study area to other communities in the northern mountains, such as Balad Seet and Jabal Shams. A more in-depth approach which employs anthropological methods would enrich our findings. Also, we would have like to have met with several additional ministries and organizations (e.g. the Supreme Planning Council, Ministry of Agriculture, Ministry of Environment and Climate, the Aflaj Research Unit at the University of Nizwa) which are involved in water management processes in order to understand the strengths and weaknesses of Oman's water bureaucracy more specifically. Our initial impressions suggest that a system which eases the flow of information and data between all parties involved in water management efforts, such as government agencies and public utilities, would help improve planning effectiveness (MRWMR interview, March 15, 2018). Finally, we would be interested to see research which clarifies the social linkages between rural and urban populations in Oman and the social importance of rural cultural practices in an urbanizing country.

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