RHEINISCHE FRIEDRICH-WILHELMS UNIVERSITÄT BONN

Faculty of Agriculture

Institute of Crop Science and Resource Conservation (INRES)

Master Thesis

As part of the Master Program:

Agricultural Sciences and Resource Management in the Tropics and Sub-tropics (ARTS)

Submitted in partial fulfillment of the requirement for the degree of:

“Master of Science”

Impact of rangeland rehabilitation strategies on drought resilience in Jordan

Submitted by:

Sarah Elizabeth Barnhart

Matriculation Number: 3108879

July 30, 2019

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First Supervisor:	Prof. Dr. Mathias Becker
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Declaration

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Bonn, 30.07.2019

Sarah Elizabeth Barnhart

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To my family, for their unwavering support.

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List of Abbreviations

AEZ	Agro-ecological zone
ASF	Alaska Satellite Facility
BRP	*Badia* Restoration Project
CCA	Constant comparison analysis
CDI	Composite Drought Index
DEM	Digital Elevation Model
DD	Double difference
DoS	Department of Statistics
eDPSIR	Enhanced Drivers-Pressures-States-Impacts-Responses
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
FE	Fixed effects
FGD	Focus group discussion
GEE	Google Earth Engine
GEP	Google Earth Pro
GoJ	Government of the Hashemite Kingdom of Jordan
ICARDA	International Center for Agriculture Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
ISRIC	International Soil Reference and Information Centre
IUCN	International Union for the Conservation of Nature
JAF	Jordanian Air Force
JAXA	Japan Aerospace Exploration Agency
MoA	Ministry of Agriculture
MoE	Ministry of Environment
MODIS	Moderate Resolution Imaging Spectroradiometer
MSAVI	Modified Soil Adjusted Vegetation Index
NARC	National Agriculture Research Center
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental organization
NPP	Net primary productivity
OCHA	United Nations Office for the Coordination on Humanitarian Affairs
OLS	Ordinary least squares
PCS	Projected Coordinate System
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathway
RCT	Randomized control trial
RSCN	Royal Society for the Conservation of Nature
SLC	Scan line corrector
SPI	Standardized Precipitation Index
UNCC	United Nations Compensation Commission
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VI	Vegetation index
WFP	World Food Program of the United Nations
WGS	World Geodetic System

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Abstract

Degradation of the Jordanian rangelands jeopardizes the food security and sustainable development of the country. In response, organizations have implemented micro-water harvesting, controlled grazing and protection rehabilitation techniques to improve vegetation cover; however, there is a dearth of impact evaluations to identify which strategies are effective and drought resilient. Using a remotely sensed vegetation index and two drought indices, I evaluated twelve past interventions (i.e. four sites per strategy) from 2004 to 2018. Five focus group discussions validated the causal framework and provided insight into the quantitative data. Over fifteen years, only seven sites had a positive vegetation cover trend, three of which were controlled grazing sites. A double difference impact evaluation for controlled grazing and micro-water harvesting interventions indicated that vegetation changes were minimal, but a pooled, ordinary least squares regression revealed that controlled grazing had a significant a positive impact and micro-water harvesting a negative effect, driven by late rainy season values. A fixed effects model similarly revealed that controlled grazing had a significant impact in the late rainy season, but this finding was not robust. The results suggest that rehabilitation did not transform the degraded system; however, this could be due to counterfactual site identification process, which may have captured barely cultivation or irrigated agriculture. Regardless, interventions appeared drought resilient based on the ANOVA, Spearman's correlation and regression results, but this is likely due to an overall lack of vegetation. Based on these results, decision makers may conclude that rehabilitation is not a worthwhile investment; however, rangelands provide essential ecosystem services. Inaction is not a viable option. Instead, organizations should promote controlled grazing, actively monitor ongoing interventions and conduct more robust evaluations to identify strategies that improve the long-term natural capital of the rangeland.

Keywords: desertification, eDPSIR, Landsat 7, pastoralism, vegetation indices

I. Introduction

Arid and semi-arid rangelands cover more than 80% of Jordan, from the northeastern border with Syria and Iraq to the southern border with Saudi Arabia (Al Karadsheh *et al*., 2012). The rangelands provide essential ecosystem services, including livestock forage, medicinal plants and water catchment (Al Tabini *et al*., 2012). Historically, pastoralists followed a customary grazing system and, under this management, the ecosystem provided sufficient forage for 800,000 sheep annually (MoA, 2015). Traditional management practices were dismantled in the early 20th century and new land tenure policies were introduced. Population growth and increased consumer demand for livestock products resulted in overstocking of the open access areas and an increase in rainfed barley cultivation. Mismanagement coupled with natural drivers of desertification, primarily drought, led to resource collapse and the rangelands currently produce only 10% of the potential forage yields (MoA, 2013). The rangelands continue to be under pressure from natural and anthropogenic drivers, further degrading the ecosystem services required for resilient livelihoods and food security (IWMI, 2014).

Environmental degradation has the potential to derail Jordan's development. The United Nations Development Program (UNDP) stated that the Human Development Index increased from 0.62 in 1990 to 0.74 in 2015, and the World Bank now classifies Jordan as an upper middle-income country (UNDP, 2018). The Department of Statistics (DoS) also reports that only 0.5% and 5.7% of Jordanian households are respectively food insecure and vulnerable to food insecurity (DoS, 2018). Jordan's Global Hunger Index rating of 11.7 indicates moderate hunger, where below 9.9 indicates low and above 50 extremely alarming hunger (von Grebmer *et al.*, 2018). Despite these achievements, the World Food Program (WFP) cautions that the national statistics mask pockets of high food insecurity (WFP, 2019). A recent Comprehensive Food Security Monitoring Exercise found that 59% of vulnerable Jordanian households were at-risk for food insecurity (UNHCR, 2019). Thus, attention should remain focused on eradicating hunger even though Jordan's standard of living has undoubtedly advanced.

Development strides have arguably decoupled Jordanian society from provisioning ecosystem services. Between 1991 and 2017, the number of households who stated agriculture was their main source of income decreased from 6% to 3.7% (ILO, 2018). Despite this shift, rural households in the poorest governorates still depend on the land and, in the face of drought and desertification, are vulnerable to food insecurity (FAO, 2018). Additionally, regulating, supporting and cultural rangeland ecosystem services are still essential to society as a whole.

Therefore, Jordan's progress may be jeopardized if the rangelands are not restored and properly managed.

The Government of Jordan (GoJ), international institutes and non-governmental organizations (NGOs) have responded to rangeland desertification by implementing rehabilitation projects to improve ecosystem services, focusing on fodder for livestock. The strategies fall into three main categories: Vallerani micro-water harvesting, controlled grazing and protection. Unfortunately, the results of these investments are often imperceptible (Badran *et al*., 2018). Impact evaluations of the rehabilitation techniques are needed; however, there is a lack of standardized monitoring due to the numerous organizations that operate independent projects (BRP, 2010). Evaluations also need to gauge whether interventions are resilient to drought, a common, slow onset hazard in Jordan (Mahmoudi *et al.*, 2018). Climate change models predict that drought frequency and severity will increase by 2070-2100 within certain watersheds (Rajsekhar & Gorelick, 2017). Therefore, an intervention may provide an immediate "greening" effect, but assessments should follow projects over time to determine whether the strategy can provide lasting benefits in spite of climate change (Suding, 2011).

Remote sensing technology can be leveraged to evaluate long-term impact of rehabilitation efforts. The historical data available on these platforms allows for a standardized, retrospective analysis of interventions across the country. Rehabilitation primarily aims to increase vegetation ground cover, making remotely sensed vegetation indices (VIs) an effective indicator of success. VIs have been used to monitor semi-arid and arid rangelands and track desertification globally, including in Kenya, Australia and the United States (Chen & Gillieson, 2009; Fern *et al.*, 2018; Mureithi *et al.*, 2015). In the Middle East, a study in Israel validated the use of remote sensing techniques to detect biomass changes under different land management strategies (Helman *et al.,* 2014). As an added bonus, VI data can be overlaid with historical, spatially explicit drought data. Thus, remotely sensed VIs can facilitate monitoring and evaluation, providing decision makers with sufficient data to prioritize effective strategies.

Jordan has already made the most important step to reverse rangeland desertification: recognizing the issue and investing in solutions. Therefore, this research aims to advance those efforts by identifying strategies that have the highest and most durable impact on vegetation cover, even under drought stress. By ensuring that interventions are resilient to climate change, Jordan can preserve the rangeland's essential ecosystem services to guarantee food security and sustainable development for both the pastoral communities and the nation.

II. Literature Review

2.1 State of global drylands and rangelands

Drylands, which include hyper-arid, arid, semi-arid and sub-humid areas, cover approximately 41% of Earth's surface and support a population of more than 2 billion people (Safriel *et al.*, 2005). Roughly two-thirds of all drylands are considered rangelands, a term that encompasses a broad category of land cover types, including grasslands, shrublands, woodlands, wetlands and deserts (Neely *et al.*, 2009). Rangelands are generally unsuitable for crop cultivation, but they are essential for pastoral societies. Pastoralism is the extensive production of primarily ungulate species (i.e. sheep, goats, camels and donkeys) where herds migrate based on climactic variability and resource availability (McGahey *et al.,* 2014). This production system is well adapted to the drylands, allowing societies to simultaneously exploit and maintain the ecosystem services.

Rangelands provide a range of provisioning, regulating, supporting and cultural ecosystem services. Ecosystem services are defined as "the combined actions of the species [and physical processes] of an ecosystem that perform functions that have value to society" (Walker & Salt, 2006). Land management decisions tend to focus upon the provisioning services, such as livestock fodder, medicinal herbs and raw materials (i.e. wood) that provide direct benefits to nearby communities. These are the easiest to quantify and value, substantiating the utilitarian argument for preserving nature (Haines-Young & Potschin, 2015).

Regulating, supporting and cultural services are equally important, even if the benefits are less tangible. First, regulating services help maintain balance within the ecosystem, building upon each other in positive and negative feedback loops. For example, vegetation improves soil organic matter, which in turn increases vegetation productivity and captures carbon (Plaza *et al.*, 2018). Thus, proper management could mitigate climate change by sequestering 240-360 million tons of CO_2 in dryland soils each year (Lal, 2004). Additionally, vegetation cover reduces soil erosion by intercepting rainfall, slowing surface run-off and stabilizing soil aggregates (Zuazo & Pleguezuelo, 2008). Although water and wind erosion are natural mid- to long-term processes, in the absence of vegetation the rate of soil loss is greater than soil formation. High rates of erosion negatively affect soil fertility, infrastructure and human health. For example, wind erosion results in dust storms that increase the loading of particulate matter in the atmosphere, heightening the risk of cardiovascular disease, respiratory issues and meningococcal meningitis (Goudie, 2014; Middleton, 2016). Second, supporting services provide the habitats and genetic diversity required to maintain the ecosystem and contribute to its adaptive capacity. Third, cultural services include traditional customs, recreation and aesthetic value. These services are hard to quantify, but they are equally important and difficult to replace when lost (Chan *et al*., 2012). All of these rangeland ecosystem services are at-risk due to natural and anthropogenic drivers of degradation.

Degradation is any undesirable change in a system that negatively impacts the land's biological or economic productivity, while desertification refers to degradation specifically in drylands (Bestelmeyer *et al*., 2015). Desertification manifests in the physical, chemical, or biological characteristics of the ecosystem (Sivakumar, 2007). Reynolds *et al*. (2007) estimated that desertification has already impacted 10-20% of global drylands and these figures are anticipated to climb due to climate change and population growth (Maestre *et al*., 2016). Indeed, dryland climates are already changing; Huang *et al.* (2017) reported that surface temperatures have risen 20-40% more in drylands compared to their humid counterparts. Thus, mitigation strategies should be adopted to safeguard the world's dryland rangelands and ensure food security and sustainable development.

2.2 History of the Jordanian rangelands

Jordan is located in the eastern Mediterranean and has five agro-ecological zones (AEZs): desert, steppe, marginal, semi-arid and sub-humid (de Leo *et al*., 2016). These zones are clustered into three regions: the Jordan valley (sub-humid), highlands (semi-arid and marginal) and rangelands (desert and steppe). In 1973, the Ministry of Agriculture (MoA) Law No. 20 defined rangelands as any state-owned land that received less than 200mm of annual rainfall (MoA, 2015). The region is also known as the *Badia*, which refers to the administrative borders where the nomadic, pastoral *Bedouin* tribes traditionally lived. The terms are used interchangeably even though the boundaries differ slightly; however, I will only refer to the rangelands hereafter (Figure 1).

Rangeland vegetation decreases from north to south, mirroring the distribution of *Bedouin* communities. 71% of the pastoral tribes live in the northern rangelands and the rest are split between the middle and southern regions (Abu Zanat *et al.,* 2005). Abu Zanat *et al.* (2005) classified the pastoral production systems in Jordan into three groups: nomadic (highly mobile), transhumant (semi-mobile) and agro-pastoral (sedentary). Based on their analysis, the majority of the *Bedouin* are transhumant (59.2%) or agro-pastoral (30.4%); however, historically pastoralists were primarily nomadic and migrated throughout an open-access area called the *dirah* (Al Tabini *et al*., 2012). The *dirah* was not constrained by geopolitical boundaries, allowing the *Bedouin* to migrate depending upon the climactic conditions and fodder availability.

Within the *dirah*, *Bedouin* tribes followed a traditional grazing system called *Hima* that allowed for the sustainable management of the rangeland. Herders would shift their herds away from heavily grazed areas, allowing the land to lay fallow and regenerate. Although all the *Bedouin* could access the *dirah*, tribes and families controlled fluvial outwash zones, such as valleys (*wadis*) and low-lying areas (*marabs*). The *wadis* and *marabs* provided important “fall back” reserves for years when drought or other natural disasters decreased fodder availability. Until the 20th century, these systems functioned smoothly and provided adequate fodder for small ruminants (i.e. sheep, goats) and camels (Sixt *et al*., 2017). Sheep are the dominant form of livestock in the region, particularly the local Awassi breed that is tolerant to extreme temperatures, nutritional fluctuations and local diseases (DoS, 2017b; Galal *et al.*, 2008). Despite the Awassi sheep’s tolerance to the harsh climate, the anthropogenic and natural drivers of degradation pushed the landscape beyond the threshold where it could provide sufficient forage for even well adapted breeds. Both anthropogenic and natural drivers drove desertification of the ecosystem, decreasing reliance on the rangelands.

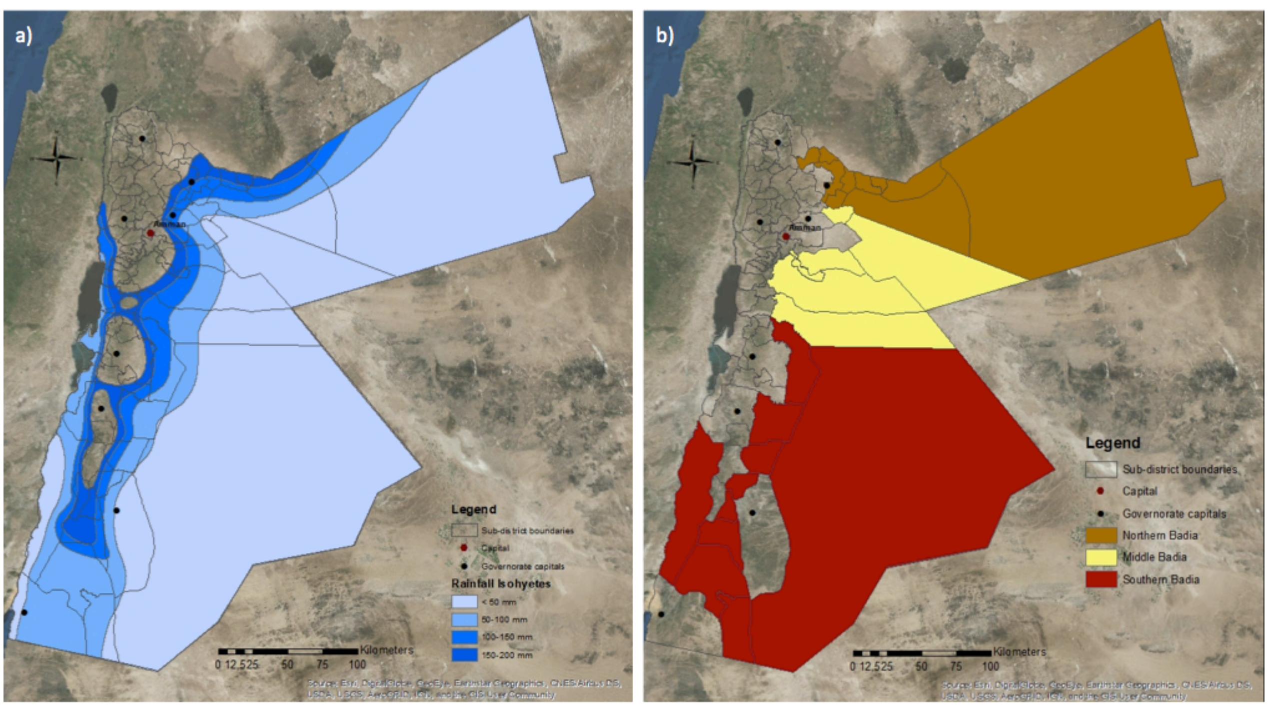

Figure 1. The Jordanian a) rangelands and b) *Badia*, where the rangeland is any government owned area that receives less than 200mm of annual rainfall and the *Badia* is the administrative boundaries where the *Bedouin* traditionally reside (data source: Badia Restoration Project).

2.3 Anthropogenic drivers of degradation

Regional politics and policies disrupted traditional management, degrading the ecosystem to the point where the rangelands became a place to keep small ruminants, not feed them (Rowe, 1999). First, the Ottomans encouraged the *Bedouin* to settle in permanent villages. This practice continued after World War II when the British colonial powers and then the Hashemite constitutional monarchy continued to sedenterize the population. As the *Bedouin* lifestyle transformed, pastoralists began to rely more on the rangeland resources near their communities and abandoned the *Hima* system. The government also claimed ownership of all uncultivated or unbuilt land under the new land tenure system. The *Bedouins* received land use permits, but the nationalization of the land decreased tribal influence and disrupted the traditional community-based management, resulting in overgrazed rangelands (Kakish, 2016).

Unproductive rangelands increased dependence on supplemental feed, primarily imported barley. In the 1980s, the price of barley spiked and the government began offering barley subsidies to sheep and goat owners. Although the subsidies alleviated the financial burden shouldered by pastoral households, it also accelerated degradation. In areas of high inter-annual variability, the "disequilibrium theory" claims that fodder availability will limit herd size, thus preventing overstocking and limiting the impact on vegetation (Behnke *et al.*, 1993). However, subsidies undermined this "control" on the system; herders were no longer constrained by the stocking capacity of the land and began keeping larger numbers of livestock to meet the growing demand for meat (MoE, 2015). When the Jordanian government phased out the barley subsidy in 1994/5 to comply with the World Bank structural reforms, the rangeland could not support the large number of livestock (World Bank, 1994). Overall, the production costs of sheep and goats increased 139% due to the cost of feed and veterinary services and, without the feed subsidies, the average profit margin per sheep decreased from 13.5JOD to 1.62JOD (Badran *et al.,* 2018; Oakley, 1997). The GoJ reintroduced feed subsidies in 2008 after a 300% increase in global fodder prices. Each head of livestock registered with the MoA received 10kg of feed at a subsidized price monthly (OCHA, 2008; Verme *et al.*, 2011). Thus, barley imports doubled, increasing from 470,000 tons in the 1990s to 850,000 tons in 2014 (Khraishy *et al*., 2015). Dependence upon subsidized barley feed was evident when one study found that only 1% of participants could graze their herds in the rangelands for three months, a trend that persists till today (Al Tabini *et al*., 2012).

The tenure system introduced post-World War II also encouraged households to cultivate rainfed winter barley (*Hordeum vulgare L.*) in unsuitable AEZs, placing pressure on the system

(Zucca, 2017). Barley was, and still is, recognized as a sacred crop; by planting winter barley, households broadcast that the land is privately owned and not open to communal grazing (Jerba FGD, see Appendix C). Rainfed winter barley cultivation continues to expand 20,000ha every year; however, the overall yield is negligible (Abdi *et al.*, 2019; Badran *et al.*, 2018). In poor rainfall years, barley does not produce any grain and is grazed for approximately one month (Jerba FGD). In addition to providing limited benefits to pastoral households, barley cultivation also exacerbates degradation by destroying natural vegetation and increasing soil erosion (see Appendix D, Figure A).

External anthropogenic drivers also increased pressure on the system. During the 1990/1991 Gulf War, Iraqis fled the crisis and sought refuge in Jordan, bringing 1.8 million heads of sheep with them (BRP, 2010). The population has continued to grow with the influx of Syrian refugees and migrant workers. Over the span of ten years, the population has increased from 5.7 million in 2007 to 10 million in 2017 (DoS & Macro International Inc., 2007; DoS, 2017b). Due to the growing population, Sawalhah *et al.* (2018) found that between 2013 and 2015 the extent of the Jordanian rangelands decreased by 9.6%, while urban areas and cropland expanded by 11.4% and 0.2% respectively. The arrival of refugees, migrant workers and livestock over the years increased food, water and housing demands, placing increased pressure on the rangelands (MoE, 2015).

2.4 Natural drivers of degradation

Jordan has a semi-arid and arid climate; limited rainfall is a permanent element of the climate. Precipitation is limited to the winter season, with the traditional rainy season beginning in October and ending by March. According to Al Qinna *et al.* (2011), droughts in Jordan commonly occur at the beginning of the rainy season, either due to a delay in the onset of the rain or a reduction in precipitation events; however, the highest drought magnitudes occur between January and March. Climate change; however, has already begun to alter precipitation patterns. Between 1970 and 2013, average rainfall decreased 0.44mm/year across the country, with that figure rising to 1.2mm/year at 66% of the rain gauges (Rahman *et al*., 2015). These changes pose a threat to Jordan's already scarce water resources and increases vulnerability to drought.

Drought is a recurring climactic event that is classified into four categories: meteorological, hydrological, agricultural and socioeconomic. Meteorological drought refers to a lack of precipitation, hydrological to a lack of surface water or groundwater, agricultural to the amount of water available to crops (i.e. soil moisture) and socioeconomic to the impact on human consumption patterns (Wilhite & Glantz, 1985). For the purposes this research, the focus will be on meteorological, hydrological and agricultural drought.

Climate change models predict that Jordan will experience higher temperatures and decreased annual precipitation under both Representative Concentration Pathway (RCP) 4.5 and 8.5 (Rajsekhar & Gorelick, 2017). Therefore, even if climate policies successfully reduce emissions to stabilize radiative forcing at levels outlined in RCP 4.5, drought incidences are still expected to increase (Thomson *et al.*, 2011). Available freshwater has already declined due to drought and population growth; per capita water availability has decreased to $135m^3$ annually, falling below the $500m^3$ international threshold of "absolute water scarcity" (Al Ansari *et al.*, 2014). Therefore, a multi-pronged approach is required to tackle the water scarcity problem in Jordan and inclusion of rangeland rehabilitation will be essential.

The rangelands play an important role in the hydrological cycle, a fact that is reflected in the National Climate Change Policy and Updated Rangeland Policy (MoA, 2015; MoE, 2013). Precipitation is partitioned into either "blue water" that flows into water bodies or recharges groundwater, or "green water" that is stored in the soil and transpired by plants (Sposito, 2017). Three stages determine whether water enters the "blue" or "green" pools: at the soil surface, vadose zone and root zone. Based on rangeland conditions, water will respectively either a) infiltrate or become overland flow; b) remain in the root zone, recharge aquifers or evaporate, or c) be transpired or evaporate (Wilcox *et al.*, 2017). Vegetation, among other factors, influences how water moves through the three junctures by altering run-off rates, decreasing erosion and increasing permeability (Edwards *et al*., 2019). Therefore, improving vegetation cover through rehabilitation interventions has implications for productive water management, an essential service given Jordan's place among the world's most water-poor nations and future drought predictions.

2.5 Rangeland rehabilitation strategies

Rehabilitation aims to reverse degradation, increase biodiversity and reestablish the ecosystem services required for a sustainable system. The terms restoration and rehabilitation are used interchangeably; however, rehabilitation does not aim to return the system to the prior state. Paleontologists theorize that Jordan's desertification began approximately 6,000 years ago in the mid- to late-Holocene era due to anthropogenic activities (Henry *et al*., 2017). Therefore, if a restored ecosystem entails a return to the Bronze Age, rehabilitation is a more appropriate goal.

The GoJ began investing in rangeland rehabilitation in the early 2000s. The Gulf War served as the impetus to request funding from the United Nations Compensation Commission (UNCC) who, in 2005, awarded $160 million USD to the GoJ (BRP, 2010). Under the auspices of this award, the

GoJ founded the Badia Restoration Program (BRP). The BRP's mandate was, and continues to be, the rehabilitation of the rangelands to improve ecosystem services. The BRP also recognized that the rangelands were a socio-ecological system and invested in livelihood development schemes, supported cooperatives and built dairy processing facilities (BRP, 2010). Other organizations also began focusing on rehabilitation; the MoA established 32 reserves across Jordan, NARC applied water harvesting and re-vegetation strategies and RSCN protected areas from human activities (AECOM, 2014). Although numerous actors were engaged in rehabilitation projects, similar management strategies were applied.

This study focused on three rehabilitation strategies: Vallerani micro-water harvesting, controlled grazing and protection. First, the mechanized Vallerani strategy combines rainwater-harvesting techniques with the reintroduction of native species. Named after the inventor, Venzanzio Vallerani, a Delfini plow digs intermittent pits in a contour line, which captures and slows surface run-off (Gammoh & Oweis, 2011). Native plant species are then out planted in each pit. In Jordan, *Atriplex halimus* and *Salsola vermiculata* are commonly introduced as they are native saltbush species that are tolerant to drought and salinity (Al Satari *et al.*, 2018). The Vallerani pits reduce soil erosion and increase the survival rate of the shrubs by concentrating water (Al Satari *et al.*, 2011). Although the pits eventually erode, by that time the shrubs are well established and capable of withstanding shocks. Second, controlled grazing protects an area for approximately two years, allowing the vegetation to regenerate. Then, a management plan is developed to synchronize grazing with plant growth, enforce a set stocking capacity and rotate the grazed area. Third, protected areas prevent human resource use and extraction. Protection aims to preserve the ecosystem's biodiversity and reestablish the supporting, regulating and cultural ecosystem services. All three rangeland management strategies have been implemented in sites across Jordan.

2.6 Changing the state, not the drivers

Rehabilitation projects focus on changing the state of rangeland without necessarily easing the underlying drivers and pressures that cause desertification. An effective tool to conceptualize the problem is an enhanced drivers-pressures-states-impacts-responses model (eDPSIR; Niemeijer & De Groot, 2008). The eDPSIR framework visualizes the causal relationships within the Jordanian rangelands that result in the undesired state (i.e. a lack of native vegetation) and the resulting impact on food security (Figure 2). Granted, my eDPSIR framework is far from comprehensive. For example, only three responses (i.e. those under investigation) were listed; however, other strategies are also implemented to target different variables that drive desertification. Despite the gaps

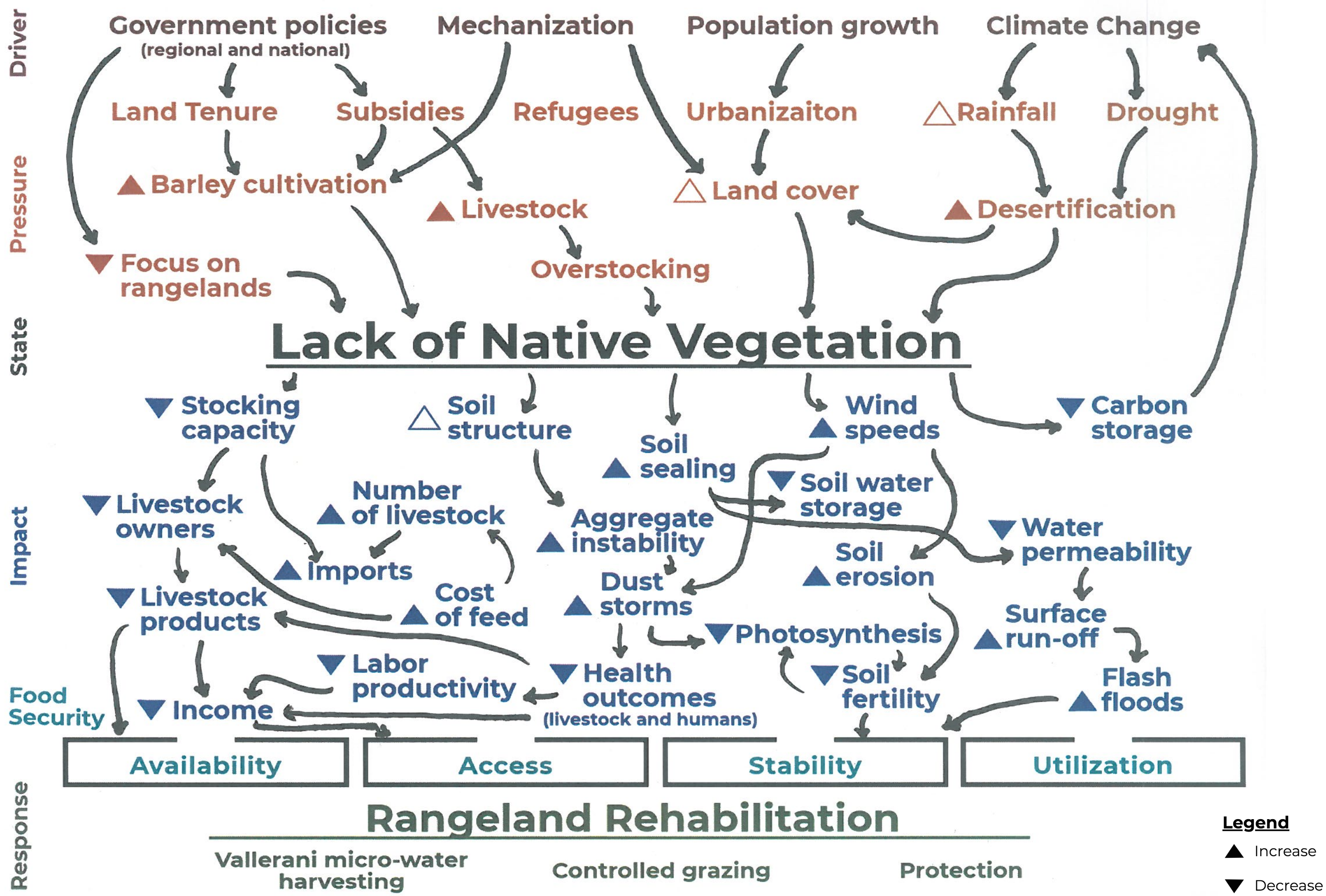

Figure 2. Enhanced Driver Pressure State Impact Response (eDPSIR) framework for the Jordanian rangelands.

and shortcomings of my eDPSIR framework, it proved useful to simplify the complex system.

Anthropogenic and natural drivers of degradation are respectively within and outside the government's sphere of influence. Theoretically, the rehabilitation strategies reduce pressure caused by anthropogenic drivers; within the designated intervention areas management practices are enforced to reduce the influence of government policies, mechanization and population growth. On the other hand, climate change and the increasing prevalence of drought are outside the government's control. Arguably, increasing rangeland vegetation improves carbon storage in the plants and soil, thus mitigating climate change; however, this strategy requires a global commitment to introduce and enforce emission reduction policies. Therefore, I assumed that this driver is beyond the GoJ's immediate jurisdiction and will continue to place pressure on the system. Thus, rehabilitation strategies need to be capable of improving and maintaining vegetation cover despite drought.

Rehabilitation may transform the rangelands from a degraded to desired state; however, the ecosystem must also be resilient to the drivers of degradation. Resilience is defined as the ability of a system to absorb shocks without restructuring or collapsing (Holling, 1973). Human societies are part of a social-ecological system. Thus, communities' resilience are linked to the status of the ecosystem services and natural resources. Although resilience was declared the "development buzzword" of 2012, the concept is important when assessing interventions and prioritizing future programs (Wenning *et al.*, 2017). Therefore, the impact of rangeland rehabilitation should be evaluated relative to their ability to transform vegetation cover and improve resilience to future disturbances to ensure the food security of the nearby communities.

The World Food Program (WFP) recognizes that environmental rehabilitation is an important component of long-term food security, particularly in light of potential climate change (DoS & WFP, 2016). Food security is defined in the *Rome Declaration on World Food Security* (1996) as a state "when all people, at all times, have access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". The concept is generally broken down into four pillars: availability, access, stability and utilization. Assuming that all four of the pillars are achieved, an individual, household or country is food secure. As outlined in the eDPSIR framework, rangeland desertification has cascading impacts on these pillars, with the exception of utilization (Figure 2). Although national statistics suggest that food insecurity is a minor issue, certain regions report that 26% of the population is food insecure (WFP, 2019). The WFP cautions that geographic inequalities result in "poverty pockets" that can exacerbate hunger. The FAO's 2018 Food Security Resilience report echoed these concerns, cautioning that these food insecurity may climb, particularly for female and non-Jordanian headed households (FAO, 2018). The same report identified drought as a driver of food insecurity, highlighting the importance of interventions that improve communities' resilience to climatic shocks.

2.7 Monitoring dryland rangelands with remote sensing

Remote sensing technology can be harnessed to monitor desertification and rehabilitation of the rangelands. The main indicators of rangeland desertification are changes in net primary productivity (NPP), soil organic matter, functional diversity, indicator species and ratio of vegetation to bare soil (Hanke *et al*., 2014; Yirdaw *et al*., 2017). Vegetation cover and NPP can be detected using remotely sensed vegetation indices (VIs). VIs measure canopy "greenness" by exploiting the reflectance of plants; chlorophyll absorbs visible light (0.4 – 0.7µm) for photosynthesis and reflects Near Infrared light (NIR; 0.7-1.1µm). Thus, chlorophyll content, leaf area, canopy cover and canopy structure influence the ratio of red light absorbed and NIR reflected. Using satellites that capture hyper-spectral bands, the resulting ratio can be used to differentiate variations of "greenness" (Pettorelli *et al*., 2005).

One of the most common VIs is the Normalized Difference Vegetation Index (NDVI; Le *et al.*, 2016). In Jordan, Al Bakri & Abu Zanat (2007) found that NDVI was highly correlated to vegetation cover and biomass in the rangelands when employing a high-resolution satellite. Similarly, Hammouri and El-Naqa (2007) used NDVI and Standard Precipitation Index (SPI) data to assess drought risk in Jordan's Yarmouk water basin. Thus, VIs are sensitive to drought and can be an effective proxy indicator for ecological drought resilience (Shi *et al*., 2017). Despite the widespread use of NDVI, it is sensitive to soil reflectance, atmospheric conditions and leaf canopy shadows (Xue & Su, 2017). Vegetation in the Jordanian rangelands is sparse with high spatial and temporal variability, resulting in high soil exposure (Lu *et al.,* 2015). Therefore, alternative VIs have been developed to better reflect dryland land cover.

The Enhanced Vegetation Index II (EVI II) and Modified Soil Adjusted Vegetation Index (MSAVI) are two indices adapted these AEZs. EVI II and MSAVI II are respectively derived from the original Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI). First, EVI optimizes the vegetation signal for dense biomass while also correcting for soil and atmospheric effects. EVI is more responsive to vegetation growth; however, a major limitation is that it requires a blue band. Unlike EVI, EVI II requires only two bands and is less sensitive to background reflectance for a myriad of land cover categories (Rocha & Shaver, 2009). Therefore, I chose to use EVI II over the original EVI. Second, SAVI modifies the NDVI calculation using an L-factor, which adjusts for soil brightness. The L-factor is normally set at 0.5 to account for most land cover types; however, it can be adjusted based on known vegetation cover to improve performance. Developing a site-specific L-factor; however, is data intensive. MSAVI II overcomes this limitation by using an inductive L-factor (Qi *et al*., 1994). Rocha & Shaver (2009) found that MSAVI II reduced soil noise better than SAVI, improving sensitivity to vegetation. MSAVI II is commonly used to assess desertification trends, monitor drought and calculate soil erosion (Xue & Su, 2017). Therefore, I selected MSAVI II over SAVI. Each VI has advantages and disadvantages; however, the literature identifies NDVI, EVI II and MSAVI II as viable indices for drylands.

Remote sensing can help managers monitor rehabilitation in Jordan and globally to determine if, despite the ongoing pressures and drivers, interventions improve the state of the system (Figure 2). The data is freely available and easy to use, thanks to tools such as Google Earth Engine (GEE). Depending upon the satellite, historical data is also available, allowing researchers to assess interventions ex post. This methodology can also be scaled up, allowing for global comparisons of dryland rangelands. Monitoring rangeland rehabilitation is particularly relevant since the United Nations General Assembly declared 2021-2030 the “Decade on Ecosystem Restoration”, underscoring the need to track restoration interventions and identify best practices (Eisele & Hwang, 2019). Remote sensing is not a silver bullet; it cannot fully replace field observations and sampling. Instead, remote sensing can provide landscape level analyses to consistently monitor rehabilitation and better target labor-intensive field surveys to improve the outcome of rangeland investments.

III. Hypothesis & Objectives

I hypothesized that rehabilitation interventions would improve the vegetation cover of the Jordanian rangelands and, due to native perennial plants' adaptation to natural aridity, be more resilient to drought. Thus, the intervention areas would provide greater ecosystem services to the nearby communities, improving livelihoods and food security. In order to test this hypothesis, I developed three research objectives:

1. Analyze the impact of rangeland rehabilitation strategies on vegetation cover.
2. Determine the effect of rehabilitation strategies on ecological drought resilience.
3. Understand how communities depend on the rangelands, cope with drought and perceive rehabilitation interventions.

I addressed these objectives by conducting a retrospective analysis of past rehabilitation interventions that were strewn across the country. In summary, I aimed to determine which strategies successfully transformed the current, degraded state of the ecosystem (i.e. lack of vegetation), whether the interventions improved vegetation cover stability during drought shocks and how these efforts affected and were perceived by the project beneficiaries.

IV. Materials & Methods

4.1 Background of the organizations

I cooperated with the International Center for Agriculture Research in the Dry Areas (ICARDA), National Agriculture Research Center (NARC), International Union for the Conservation of Nature (IUCN) and Royal Society for the Conservation of Nature (RSCN) to conduct my research. ICARDA is a member of the Consultative Group on International Agriculture Research and was my primary contact and host. ICARDA focuses on the drylands of Asia, Middle East and Africa. The organization's 2017 – 2026 strategic plan aims to improve food security, strengthen climate change resilience and reverse or halt resource degradation, aligning with my research objectives (ICARDA, 2017). The ICARDA Amman office has an ongoing experimental Vallerani site that began in 2016; however, due to the timeframe of my study, I could not include that project in my analysis. Therefore, I expanded my site selection to include interventions implemented by NARC, IUCN and RSCN.

The three organizations are respectively a government institute, international non-governmental organization (NGO) and national NGO. First, NARC is the research branch of the MoA. According to Article 5 of Bylaw 42, NARC is responsible for identifying national agriculture priorities, developing and disseminating technology, training farmers, conducting biodiversity surveys and managing the National Seed Bank (NARC, 1993). Second, IUCN was founded in 1948 to conserve and safeguard nature around the world. In Jordan, IUCN aims to improve the resilience of drylands by investing in sustainable rangeland management and supporting pastoral livelihoods (Laban *et al.,* 2018). Third, RSCN is a local NGO focused on environmental conservation. RSCN was established in 1966 to formalize a national network of protected areas, conserve Jordan's biodiversity and support local community development. They also work to improve public awareness and support for environmental protection in both Jordan and the region (RSCN, n.d). All three organizations actively work to improve Jordan's rangelands and implement projects throughout the country.

4.2 Overview of methodology

The methodology can be delineated into four work streams: identification of sites, discussions with focus groups, acquisition of drought indices and processing of VI data. In the following sections, I provide details of each work stream, but the overall process flow is presented in Figure 3.

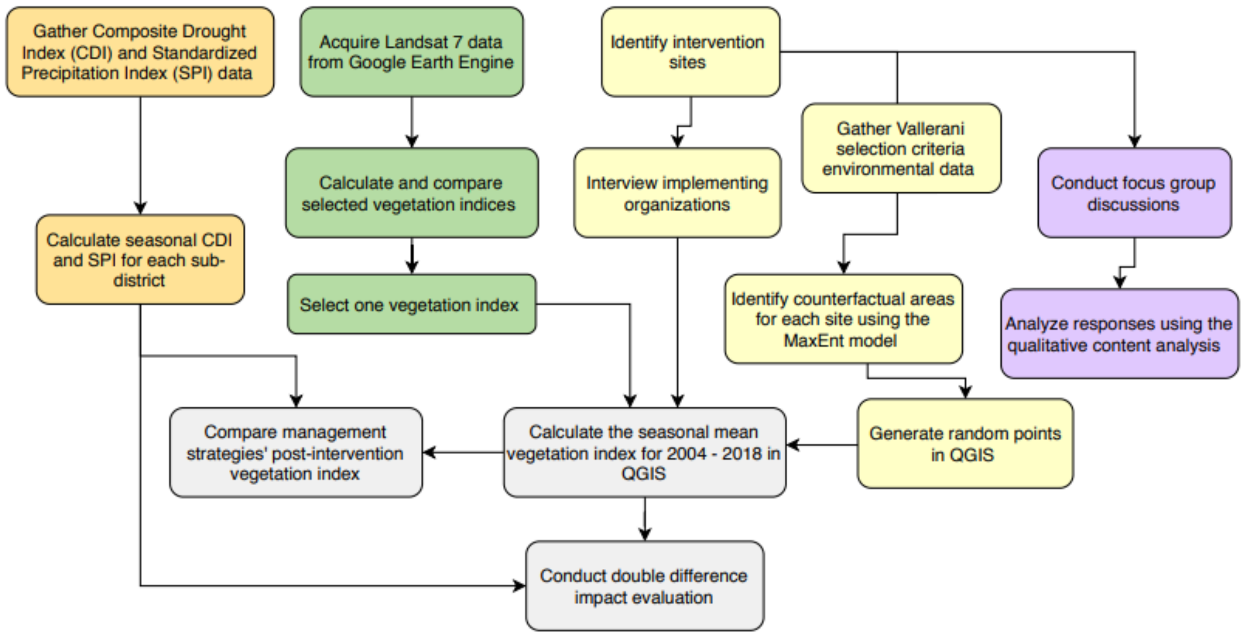

Figure 3. Methodology process flow to identify, gather and process the data.

4.3 Selection of management strategies and intervention sites

To identify potential sites for analysis, I conducted key expert interviews with Mohammad Mudabber (NARC), Amer Meadat (IUCN), Anas Sabberinie (RSCN), Omar Abed (RSCN) and Mohammad Kdaisat (Jordanian Air Force). Based on the information gathered during those interviews, I selected 21 potential sites and refined my selection using the following criteria:

- Located in isohyet areas of 0-250mm of rainfall
- Distributed across the country
- Established prior to 2015
- Documented in sufficient detail

I narrowed the selection to twelve sites using the aforementioned criteria, four for each of the three strategies. Although the small sample size may have limited the robustness and applicability of the results, according to Hubbard (2014), even a small sample can provide useful information. Therefore, I proceeded with the twelve sites and gathered the site characteristics and geographic data from the relevant organizations (Figure 4, Table 1).

First, NARC implemented the four Vallerani micro-water harvesting sites, an active form of rehabilitation. Using a Vallerani Delfini plow adapted to local conditions, pits were dug in contour lines (Figure 5a, c; Gammoh & Oweis, 2011). Each pit was planted with two shrubs sourced from the MoA nursery, either *Atriplex halimus* or *Salsola vermiculata* (Figure 5b). The sites were protected for two years after implementation and then opened for controlled grazing. NARC provided the geographic coordinates for each site and I generated the intervention polygons using Google Earth Pro (GEP; Figure 5d; Google, 2019).

IUCN, NARC and RSCN implemented the controlled grazing projects, a passive form of rehabilitation. First, IUCN reintroduced the *Hima* system in collaboration with the Bani Hashem community by protecting the area for two years and then allowing rotational grazing. The grazing plan is still in place, but anecdotal evidence suggests that after the project ended the community could not effectively exclude nomadic pastoralists (Bani Hashem FGD). Second, NARC designated Daba'a and Wadi Al Botum as rangeland reserves. These reserves were protected for two years prior to managed grazing; however, there was a dearth of documentation to confirm the management practices. Third, RSCN, in collaboration with the Aqaba Economic Zone, established the Wadi Rum grazing zone in 2015. Only local people are allowed to graze during specified periods of the year (RSCN, n.d.). The boundaries of each controlled grazing site was provided by the responsible organization, with the exception of Wadi Al Botum, whose boundary was generated in GEP based on expert information.

RSCN managed the protected areas, a passive form of rehabilitation designed to limit resource extraction and allow for natural regeneration. The majority of protected areas under RSCN's purview permit limited resource extraction; however, I identified sites where grazing is forbidden or natural/man-made barriers prevent entry. For example, the terrain protects the Qatar reserve and man-made barriers seal off the Shaumari and Azraq reserves. Shaumari reserve does host a small population of Arabian oryx (*Oryx leucoryx*); however, these oryx are generally kept in smaller enclosures within the reserve. I also concluded that oryx would be the natural grazers in the system, unlike herds of sheep and goats. The Wadi Rum protected zone does not have a physical barrier; however, it was recently established. Therefore, I assumed that the zoning regulations were still actively enforced. RSCN provided the boundary data for all of the protected zones.

Once mapped, all of the intervention polygons were re-projected to World Geodetic System (WGS) 84/Universal Transverse Mercator (UTM) 37N using QGIS 2.18 (QGIS, 2019). The WGS 84/UTM 37N projected coordinate system (PCS) covered the majority of Jordan's area, improving the zonal statistic calculations. All spatial data mentioned hereafter was re-projected to the same WGS 84/UTM 37N PCS and analyzed in QGIS 2.18.

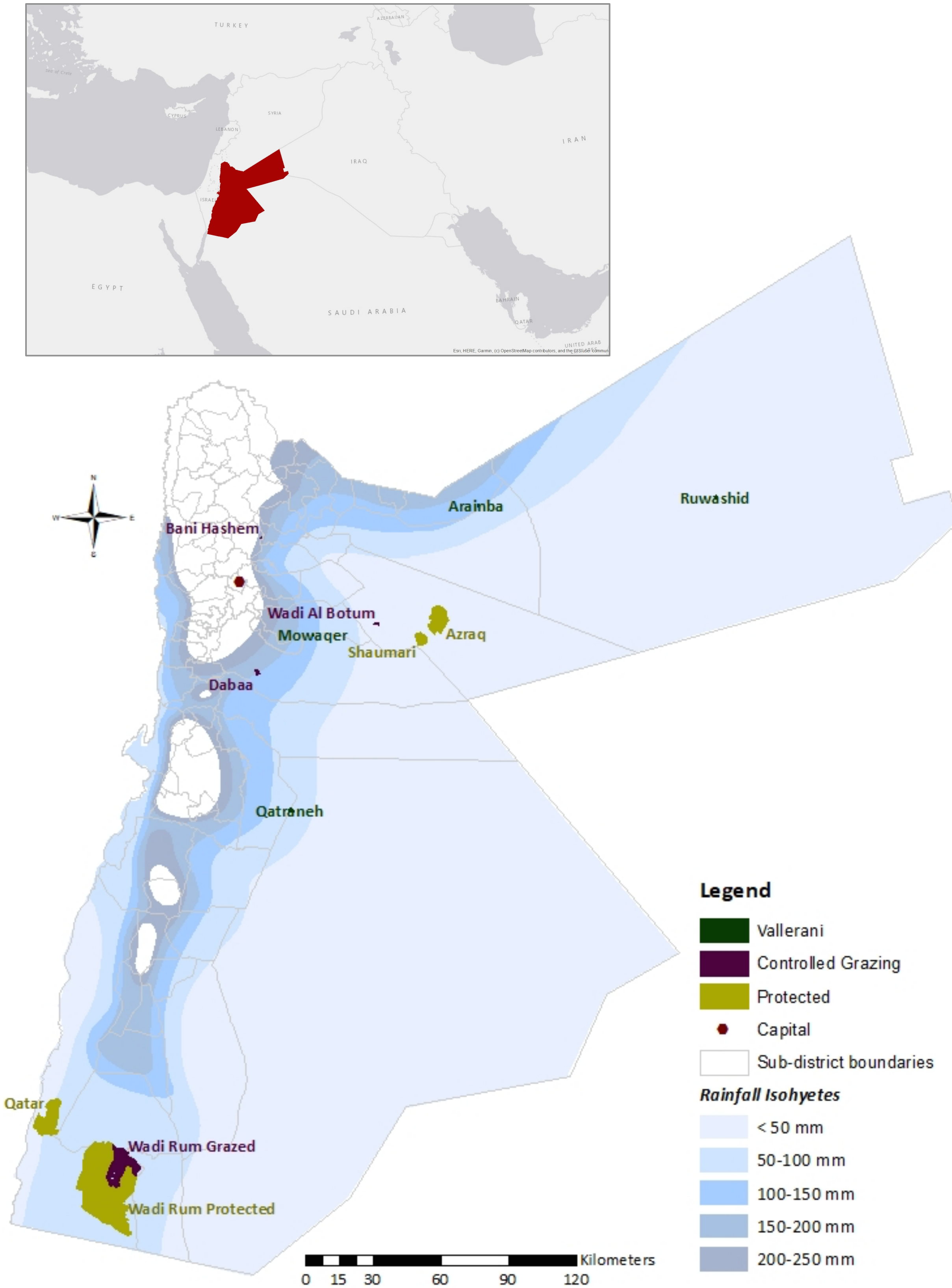

Figure 4. Selected rangeland rehabilitation interventions differentiated by strategy: Vallerani, controlled grazing and protected (data sources: ICARDA, BRP, RSCN, IUCN and NARC).

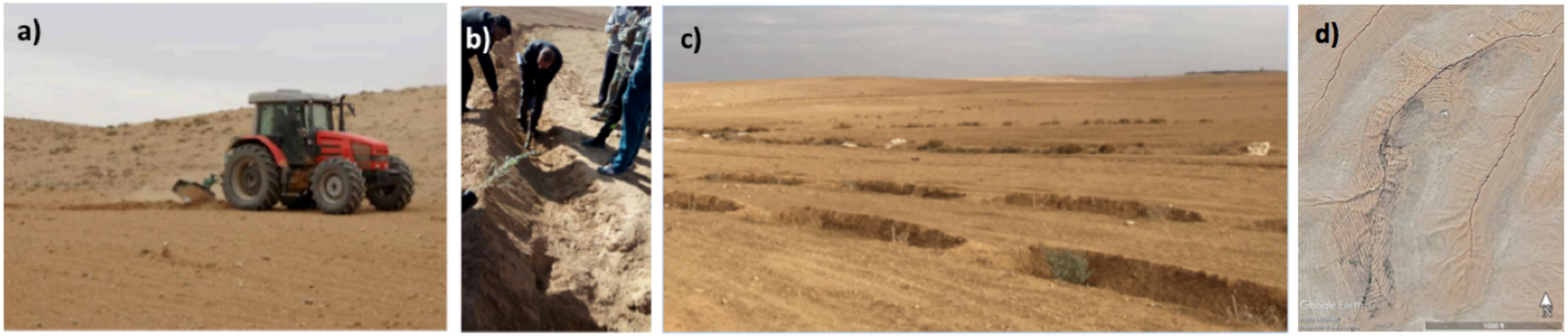

Figure 5. An overview of the Vallerani micro-water harvesting establishment process, using ICARDA'S Majidyya site as an example: a) land preparation with the Delfini plow (photo credit: Mira Haddad); b) out planting of native shrubs (photo credit: Mira Haddad); c) site in the first month post-establishment; d) satellite image of the same site (source: Google Earth Pro).

Table 1. Characteristics of the 12 selected intervention sites.

Site	Management	Sub-District	Governorate	Badia District	Organization	Established (yr)	Size (ha)	Isohyet (mm)
Arainba	Vallerani	Deir Al Khaf	Mafraq	North	NARC	2009	31	100-150
Ruwashid	Vallerani	Ruwashid	Mafraq	Middle	NARC	2012	227	50-100
Qatraneh	Vallerani	Qatraneh	Karak	North	NARC	2010	136	<50
Mowaqer	Vallerani	Jiza	Amman	Middle	NARC	2010	26	100-150
Daba'a	Controlled	Jiza	Amman	Middle	MoA	2015	338	150-200
Wadi Rum	Controlled	Quweira	Aqaba	South	Aqaba Economic Zone	2015	11,732	50-100
Wadi Al Botum	Controlled	Azraq	Zarqa	Middle	MoA	pre-2004	179	<50
Bani Hashem	Controlled	Bereen	Zarqa	N/A	IUCN	2012	15	200-250
Shaumari	Protected	Azraq	Zarqa	Middle	RSCN	pre-2004	2,090	<50
Wadi Rum	Protected	Aqaba	Aqaba	South	AEZ	2015	61,695	50-100
Qatar	Protected	Wadi Araba	Aqaba	South	RSCN	pre-2004	11,011	<50
Azraq	Protected	Azraq	Zarqa	Middle	RSCN	pre-2004	7,428	<50

4.4 Development of counterfactual sites

The selected interventions lacked established controls; however, I needed counterfactual sites (i.e. the without scenario) to assess the impact. Thus, I used a species modeling software called MaxEnt to identify areas where the interventions could have occurred. MaxEnt is a maximum entropy model that predicts a species' geographic distribution based on given environmental characteristics (Phillips *et al*., n.d.). That being said, the model can be applied in other contexts. Frey *et al.* (2018) employed the MaxEnt model to predict how infrastructure improvements would influence soybean expansion in the Brazilian Amazon. In a similarly unconventional use of the model, I leveraged MaxEnt to identify counterfactual sites that had environmental characteristics similar to each intervention site.

Five environmental variables and one administrative variable were used to identify the counterfactual sites. These variables were based on Vallerani watershed selection criteria, which included average annual rainfall, slope, dominant soil type, soil depth and land use (Ziadat *et al.*, 2006*)*. Land ownership was also a criterion; however, this data was not available on a national scale and was excluded. Although the controlled grazing and protected sites presumably had different selection criteria, I assumed that the Vallerani interventions had the most stringent requirements. Therefore, I applied the Vallerani biophysical requirements to all three strategies.

I gathered the required data from multiple sources. First, I obtained the average rainfall isohyet data from the Badia Restoration Project. Second, I downloaded dominant soil type and soil depth data from the ISRIC – World Soil maps. Based on soil profile observations and MODIS satellite data, Hengl *et al.*, (2017) used machine learning techniques to generate spatially explicit predicted soil characteristics. Dominant soil type was defined as the most probable soil class based on the FAO classification scheme (WRB) and the soil depth was calculated as absolute depth to bedrock. Third, the slope percentage was calculated using the 30m Advanced Land Observing Satellite-1 PALSAR Digital Elevation Model (DEM) data from the Alaska Satellite Facility (ASF) and Japan Aerospace Exploration Agency (ASF-DAAC, 2015). In ArcGIS, the DEM tiles were mosaicked and clipped to Jordan prior to calculating the slope percentage. Fourth, I collected 2015 land cover data from the BRP and ICARDA. I used the BRP data for six out of seven of the sites. The Bani Hashem site; however, was located outside of the *Badia* administrative area so I used the ICARDA 2015 land cover map. Fifth, I obtained sub-district boundaries from ICARDA to guarantee the counterfactual sites were in the same geographic area. Both the rainfall and sub-district layers were converted from vector to raster data files. Then, all six environmental layers were aligned and resampled to a 250m resolution.

Once the environmental layers were gathered and properly formatted, I proceeded to prepare the intervention data for the model. Each intervention site was a polygon; however, I needed individual points to mimic a species "presence" distribution. Therefore, I generated random points for each site using a built-in research QGIS tool. The number of points for each site depended upon the 30m-pixel count. Wadi Rum Protected was the largest site with 800,034 pixels/points, whereas Bani Hashem was the smallest with 191 pixels/points. The randomly generated points lacked spatial data, so I calculated the geometry for each point with another built-in QGIS tool.

I ran the MaxEnt model for each site, selecting the cloglog option. The cloglog output identified the probability that an area would be selected for the intervention based on the environmental characteristics. The probabilities ranged from 0 to 100% (Phillips *et al.*, n.d.). I converted the cloglog raster to a polygon and extracted only the highest probability pixels (Figure 6a). The maximum probability differed for each site, ranging from 13.3% for Daba'a to 86.4% for Shaumari. Despite the low value for Daba'a, I assumed that MaxEnt provided a more robust selection method than subjectively selecting an area adjacent to the intervention. The counterfactual areas did not have the same area as the intervention sites, so I generated random points within the counterfactual area using the aforementioned process to guarantee a balanced comparison (Figure 6b).

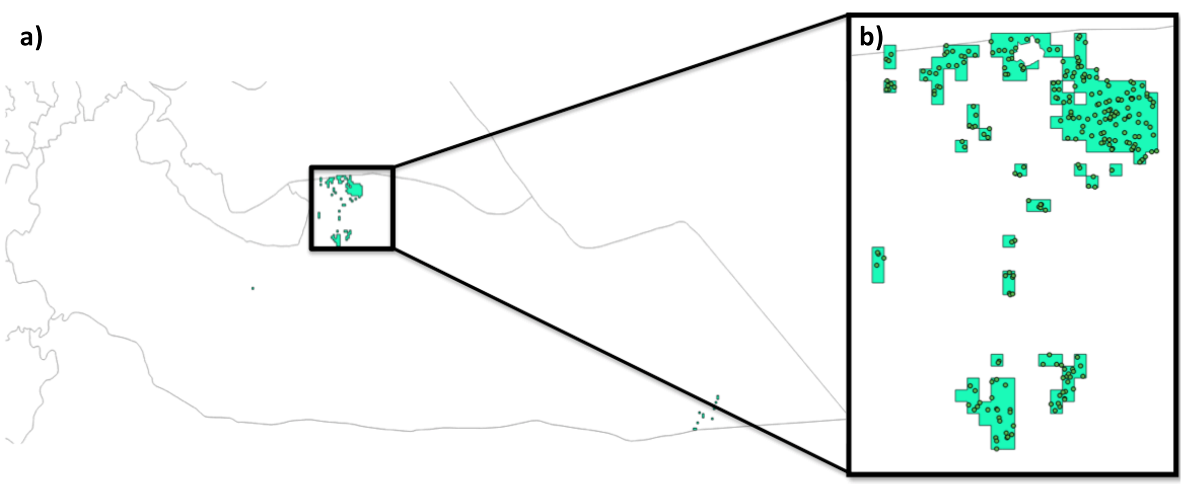

Figure 6. Example of counterfactual site identification process where a) is the area that had the highest probability of being selected for the Mowaqer intervention based on the MaxEnt output, and b) are the random points generated with the high probability areas.

Table 2. Descriptive statistics of the five environmental variables used for the MaxEnt model, comparing each strategy's pooled intervention (int; Vallerani n = 5,856, controlled grazing n= 159,044, protected n = 1,066,255) and counterfactual (cnt; Vallerani n = 5,856, controlled grazing n= 159,044, protected n = 1,066,255) points. The average and [standard deviation] were calculated for slope and soil depth while soil type, land cover and rainfall were calculated as the percentage of the dominant category.

Variable	**Vallerani**		**Controlled Grazing**		**Protected**	
	Int	*Cnt*	*Int*	*Cnt*	*Int*	*Cnt*
Slope (%)	9.48 [5.89]	9.59 [5.90]	22.07 [15.67]	18.39 [14.08]	19.58 [15.43]	16.78 [12.69]
Soil Depth (cm)	9674.25 [1180.66]	9674.79 [1326.69]	5643.77 [1868.07]	6019.16 [2069.00]	9522.05 [3064.35]	8954.83 [1695.57]
Soil Type (%)	82.69	62.22	85.76	69.47	82.80	79.98
Land Cover (%)	85.62	85.07	44.30	55.21	59.37	66.13
Rainfall (%)	1.00	85.46	95.09	94.73	95.41	95.41

In order to assess the MaxEnt model output, I generated descriptive statistics of the environmental variables for the intervention and counterfactual points, pooling the results into strategy averages (Table 2). For the continuous variables (i.e. slope and soil depth), I calculated the averages and standard deviations. I also ran a Welch two-sample t-test for each strategy and overall to compare the intervention and counterfactual averages (R Core Team, 2019). All the p-values were greater than 0.05, allowing me to accept the null hypothesis that the counterfactual and intervention strategy averages were equal. For the categorical variables (i.e. dominant soil type, land cover and rainfall isohyets), I identified the dominant category for the intervention sites and calculated that category's percentage. Using the intervention's dominant category, I selected the corresponding category in the counterfactual points and calculated the percentage. Although I did not apply a statistical test to these percentages, the differences between treatments appear to be minimal. Overall, these results suggest that MaxEnt properly identified matching counterfactual areas based on the given environmental data.

4.5 Identification of drought incidences

The International Center for Biosaline Agriculture (ICBA) developed a Jordan-specific monthly Composite Drought Index (CDI) to identify extreme, severe and moderate drought and rain events. ICBA calculated the CDI using:

- 2-month Standardized Precipitation Index (SPI) using CHIRPS data;
- Surface temperature anomalies (STA) using MODIS data;
- Root zone soil moisture (RZSM) anomalies using a LIS model;
- Normalization Difference Vegetation Index (NDVI) from MODIS.

In order to account for the different measurement units, the four indicators were normalized to percentiles. The normalized data was then weighted and compiled into a single CDI value:

$$CDI = (SPI * 0.4) + (STA * 0.2) + (RZSM * 0.2) + (NDVI * 0.2) \tag{1}$$

The final CDI value ranged from exceptional drought (-3) to exceptional wet (3). The monthly CDI data had a resolution of $5km^2$ resolution (Bergaoui, personal communication, June 2019). ICBA validated the CDI internally by comparing the output against observed drought events; however, these results have yet to be published (ICBA, 2019).

I calculated the monthly CDI averages for each Jordanian sub-district from 2004 to 2018 to account for spatial variance (Figure 7). Using the monthly averages, I generated seasonal means (October - December, January - March) to differentiate between the early and late rainy season. Similar to Rajsekhar & Gorelick (2017), I focused only on the rainy season under the assumption that droughts during this time would have the greatest impact. I used the CDI sub-district averages to account for the spatial variability of drought, while simplifying the comparison between intervention and counterfactual sites. This decision hinged upon the hypothesis that drought incidence was similar at the governorate level. To test the hypothesis, I calculated the seasonal, intervention and counterfactual CDI averages from 2004-2009. I applied a Welch two-sample t-test to determine whether the population means (intervention vs. counterfactual) were equal. The t-tests results were not significant for either season (Table 3a). I also compared the sub-district averages with the combined counterfactual and intervention seasonal CDI means. The results were also not significant, allowing me to accept the null hypothesis that the means of the two groups were equal and I proceeded to use the sub-district CDI values (Table 3b).

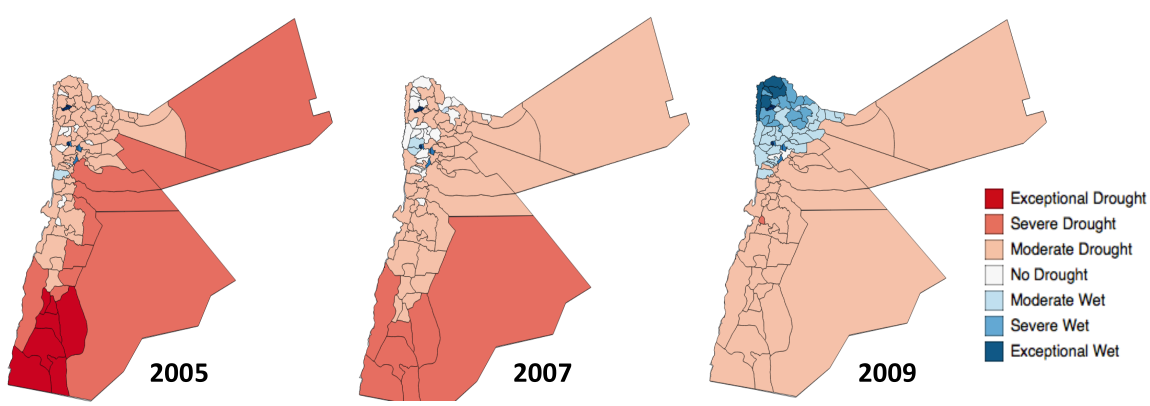

Figure 7. Examples of average October to December sub-district Composite Drought Indices (CDI) in 2005, 2007 and 2009, capturing the spatio-temporal variability of drought (data source: ICBA).

Table 3. Welch two-sample t-test results of a) intervention and counterfactual sites' and b) sub-district and intervention/counterfactual sites seasonal CDI averages ($p<0.05$).

a)

Season	t	df	p-value	95% confidence interval Lower	Upper
Oct – Dec	-0.043	141.19	0.966	-0.387	0.334
Jan – Mar	0.702	141.74	0.484	-0.186	0.391

b)

Season	t	df	p-value	95% confidence interval Lower	Upper
Oct – Dec	-0.093	139.58	0.926	-0.325	0.296
Jan – Mar	-0.014	140.88	0.989	-0.118	-0.116

A major limitation of CDI was that it included NDVI, resulting in potential multicollinearity with MSAVI II. Therefore, I also used 3-month SPI as a second drought indicator. SPI uses historical precipitation data to determine how current rainfall patterns deviate from the long-term mean (McKee *et al.*, 1993). SPI does not account for evapotranspiration or rainfall intensity, which may alter surface run and overall water availability (WMO, 2012). Despite these limitations, SPI has been frequently been used to measure drought in Jordan and around the world because it is simple, flexible and powerful (Mohammad *et al.*, 2018). Even in the CDI, SPI was assigned the highest weight (Equation 1). I generated sub-district SPI averages using National Oceanic and Atmospheric Administration (NOAA) data housed with the International Research Institute for Climate and Society at Columbia University (Janowiak & Xie, 1999). Similar to CDI, the SPI values ranged from extremely dry (-3.5 to -2), very dry (-2 to -1.5), moderately dry (-1.5 to -1.0) near normal (-1 to 1) and the corresponding positive ranges for the wet categories. The NOAA 3-month SPI data was generated using a Pearson III distribution and had a coarse resolution of 1 decimal degree (i.e. ~12,321km^2), therefore I did not need to compare the counterfactual and intervention sub-district SP averages (Guttman, 1999).

4.6 Calculation of the vegetation indices

To generate the remotely sensed vegetation index data, I selected the United States' National Aeronautics and Space Administration (NASA) Landsat 7 ETM satellite. Launched on April 15, 1999, Landsat 7 captures images of the same point on Earth every 16 days at a resolution of 30m. Landsat 7 provided data for the necessary timeframe and geographic coverage, with the added benefit that all the products were free (USGS, 2017). Using the Landsat 7 Tier 1 Surface Reflectance image collection available from the Google Earth Engine (GEE) repository, I downloaded, composited and processed the images using the Java Script GEE code editor (Gorelick *et al.,* 2017). I received coding help from GEE, Stack Overflow and ICARDA experts.

Prior to calculating the vegetation indices, the images were screened and corrected for cloud cover and the Scan Line Corrector (SLC) gaps. First, I only included images with less than 10% cloud cover. Although this decreased the images available for each seasonal composite, it guaranteed that cloud cover did not obscure vegetation reflectance. Second, the Landsat 7 images had data gaps that appear as black bands that required "filling". Orbiting satellites move in a zigzag motion, creating an "along and across track" image. Normally, the SLC combines the along-across data to generate a single image; however, in May 2003, the Landsat 7 SLC hardware failed (Masek *et al.*, n.d.). To account for this issue, I applied SLC gap fill code provided by ICARDA (Biradar, personal communication, March 2019). After correcting for cloud cover and SLC gaps, I generated the composite images for two, three-month periods: October to December and January to March. In order to increase the number of images available for the composite image, I increased the range by 15 days on each end of the timeframe (i.e. September 15 – December 31 and January 1 – April 15). Using these seasonal composite images, I calculated the VIs in the GEE code editor (see Appendix A).

Initially, I calculated three VIs: NDVI, EVI II and MSAVI II. I selected these VIs based on a literature review of common indices used in arid and semi-arid rangelands. Although I only required one VI for the analysis, I first wanted to compare the VI results to make an informed decision. NDVI was calculated as (USGS, 2017):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{2}$$

EVI II was calculated as (Jiang *et al.*, 2008):

$$EVI\ II = 2.5 \times \frac{NIR - RED}{NIR + 2.4RED + 1} \tag{3}$$

MSAVI II was calculated as (Jiang *et al*., 2007):

$$MSAVI\ II = \frac{2NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8(NIR - RED)}}{2} \tag{4}$$

where NIR was the near infrared band reflectance and RED the red band reflectance for all three VIs. For the Landsat 7 data, band 4 represented the NIR (871–876nm) and band 3 the RED (620–670nm). I downloaded each seasonal VI and used the built-in zonal statistics plugin and SAGA 2.3.1 in QGIS to calculate the VI mean, median, standard deviation, minimum and maximum for the intervention sites and counterfactual points from 2004 till 2018 (Conrad *et al.*, 2015).

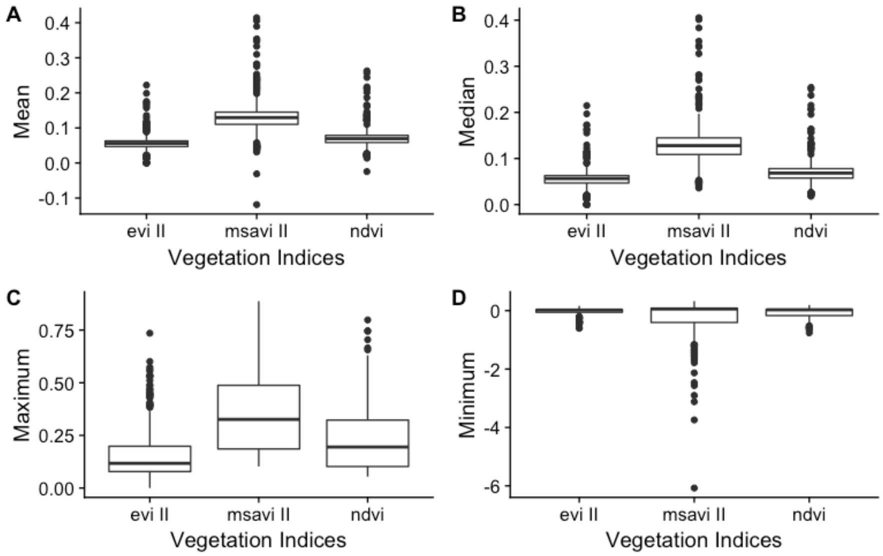

Figure 8. Mean, median, maximum and minimum of the three vegetation indices (VIs) for all intervention sites from 2004 - 2018.

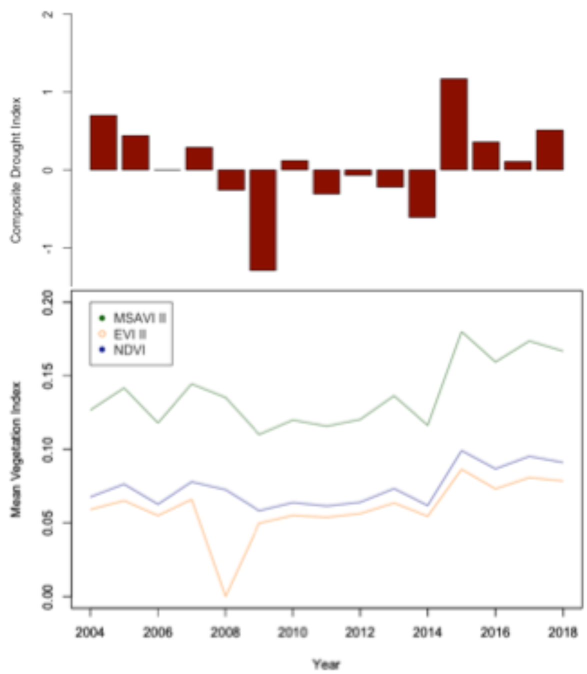

Figure 9. Average January to March a) CDI for the Jiza sub-district over 15 years, and b) vegetation indices (i.e. MSAVI II, EVI II and NDVI) from the Mowaqer Vallerani site in the same sub-district.

Overall, MSAVI II had the highest mean, median and maximum values compared to EVI II and NDVI (Figure 8). The minimum value of MSAVI II was lower than EVI II and NDVI; however, this was expected since MSVAI II was not a normalized index. Without field biomass data, I was unable to validate which vegetation index most accurately reflected the vegetation cover; however, it appeared that MSAVI II amplified the vegetation signal (Figure 9). The only value that did not follow a similar trend was EVI II in 2008, where the signal dropped to zero. I assumed that this result was an error and ignored that value. Based on the finding that MSAVI II amplified the VI signal and the body of literature focused on drylands, I decided to use MSAVI II for the rest of the analysis (Chen & Gillieson, 2009; Xue & Su, 2017).

4.7 Comparison of the rehabilitation strategies

I compared rehabilitation strategies by looking at overall changes in MSAVI II and post-intervention differences. First, I evaluated the MSAVI II trends for each intervention site using a non-parametric Mann Kendall test in R (McLeod, 2011). I assessed the overall change in vegetation cover to circumvent the conceptual problem of defining what degree of vegetation cover constitutes "successful rehabilitation". Second, I conducted a three-way, unbalanced ANOVA with Type II (SS) test, where the counterfactual sites were included as controls, to assess the interaction of MSAVI II with intervention strategies, drought indices and seasons.

In order to use a three-way ANOVA, I had to test the assumptions, which were 1) a continuous dependent variable; 2) two or more variables for the independent variables; 3) independent observations; 4) no significant outliers; 5) normally distributed dependent variable; and 6) homogeneity of variance for each combination of the independent variables. The data automatically met the first three observations so I proceeded to test the final three. First, I checked for outliers using the Chi-Square test, which found that -0.118 and 0.414 were outliers; however, these values were within the expected range so I kept them in the dataset. Second, I tested for the normal distribution using a QQ-plot and Shapiro-Wilkes test. The QQ plot showed that while the majority of the data was normally distributed, there were tails on either end of the distribution. The Shapiro Wilkes test confirmed that the data was not normally distributed ($p= 2.2*10^{-16}$). Third, I examined the independent variables' homogeneity of variance using a Levene test. The result was significant, so I rejected the final assumption that variance was homogeneous ($p=0.002$). Given the large sample size and equal groups, violations of normality and homogeneity of variance were not expected to impact the results (Solutions, 2019). Therefore, despite rejecting two assumptions, I proceeded to use the three-way ANOVA.

4.8 Assessment of the double difference impact

The double difference (DD) impact assessment was a quasi-experimental design that compared how MSAVI II changed over time for areas with and without rehabilitation (Figure 9). I gathered 15-years of MSAVI II data for four Vallerani sites and three controlled grazing sites, plus their respective counterfactual points. I excluded Wadi Al Botum and the protected sites as they were established prior to 2004. First, I calculated the simple DD average impact of each intervention strategy using the following formula (Khandker *et al*., 2010):

$$DD = E\left(Y_1^T - Y_0^T \middle| T_1 = 1\right) - E\left(Y_1^C - Y_0^C \middle| T_1 = 0\right) \quad (5)$$

where Y_t^T and Y_t^C were respectively the intervention and counterfactual areas before (t=0) and after (t=0). The concept can be visualized, as seen in Figure 10:

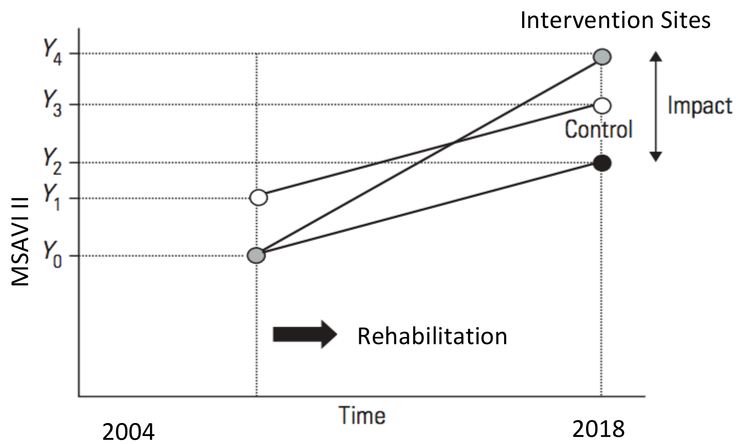

Figure 10. Visualization of the double difference concept for rehabilitation interventions (adapted from Khandker *et al*., 2010).

Average impact was calculated as the difference between before and after the intervention minus the difference between before and after the control (see respective Y values in Figure 10):

$$DD = (Y_4 - Y_0) - (Y_3 - Y_1) \quad (6)$$

The true counterfactual (Y_2) was not measured, but assuming unobserved characteristics were time invariant, the gap between the control and theoretical counterfactual was constant:

$$(Y_3 - Y_2) = (Y_2 - Y_0) \quad (7)$$

Therefore, the average impact can be simplified to:

$$DD = \ (Y_4 - Y_2) \quad (8)$$

I then applied a panel fixed effects (FE) model as presented by Khandker *et al.* (2010):

$$Y_{it} = \emptyset T_{it} + \delta X_{it} + \eta_i + \varepsilon_{it} \quad (9)$$

where Y was the outcome variable, T was the treatment, t was the time (before and after), η was the unobserved, time invariant individual heterogeneity and ε was both the treated and unobserved characteristics. The time invariant, unobserved characteristics (η) were differenced out, simplifying the formula to:

$$\Delta Y_{it} = \phi \Delta T_{it} + \delta \Delta X_{it} + \Delta \varepsilon_{it} \quad (10)$$

In addition to the panel FE model, this formula was applied to an Ordinary Least Squares (OLS) model to calculate the unbiased impact of the interventions.

Two assumptions are inherent in the double difference methodology: a) the treatment and counterfactual community were selected randomly, and b) there was no unobserved, time variant heterogeneity that could result in over or underestimation of program impact. First, the interventions sites were not selected randomly; particularly for the Vallerani interventions, watersheds needed to meet certain criteria. Therefore, to reduce any bias caused by the selection process, I used the Vallerani selection criteria during the counterfactual identification process. Second, I controlled for time variant heterogeneity by using MaxEnt to identify counterfactual sites with similar characteristics to the intervention sites and testing the initial conditions of the intervention and counterfactual sites. The descriptive statistic results suggest that MaxEnt properly identified sites with similar characteristics (Table 2). Therefore, I tested for initial, unobserved characteristics by running a "placebo" regression. Using only pre-intervention counterfactual and intervention data, I assigned each observation an identification number and, with the aid of a random number generator, selected half of the values from each group (Urbaniak & Plous, 2013). I assigned each group as pre- or post-treatment and ran an OLS model with the assigned before/after MSAVI II values. None of the values were significant, confirming that the initial conditions did not result in unobserved, time variant heterogeneity.

After testing the assumptions, I regressed the MSAVI II values against the intervention years and the type of intervention using a panel linear model package in R (Millo, 2017). First, I ran pooled Ordinary Least Squares regressions. Then, I checked for the robustness of the OLS model by using a FE model. The FE regression controlled for the household's unobserved and time invariant characteristics by focusing only on variation within each intervention site. Finally, I included the SPI in both the OLS and FE regression models as a continuous predictor variable to determine if drought influenced the vegetation cover.

4.9 Discussions with community focus groups

I conducted focus group discussions (FGDs) to understand how communities' depended on the ecosystem services, perceived changes in the rangelands and coped with drought. By meeting with multiple individuals at once, I was able to efficiently gather data and capture spontaneous responses. I selected four communities for the discussions: Bani Hashem (controlled grazing, IUCN), Qatraneh (Vallerani, NARC), Shaumari (protected, RSCN) and Jerba (none, IUCN). The implementing organizations identified participants for the discussion, but I requested the attendance of six individuals for each gender-segregated discussion group (i.e. 12 people per community). In Jerba and Bani Hashem, I conducted my focus group discussion alongside another study by IUCN and Resource Equity, an NGO focused on gender and land tenure issues. In order to prevent duplication of questions, I included relevant information from those discussions in my transcription notes rather than re-request similar information. At the start of every discussion, I verbally requested and received permission from participants to record the discussion, with the guarantee that answers would not be attributed to individuals. The taped conversations were transcribed into English and the notes taken throughout the discussions were used to supplement the audio recordings (see Appendix C).

The FGDs were semi-structured; I developed and followed a focus group guide while also allowing for unsolicited responses (see Appendix B). I validated my questions prior to the FGDs by running through guide with two ICARDA staff members, two Majidyya community members and 22 members of the Bani Hashem community. Based on their responses, the questions were modified to improve clarity. I did not ask participants directly about the project near their communities because staff from the implementing organizations attended the focus group discussions. Responses to questions specific to the success of the project could be biased if participants thought a certain answer would improve their chances of receiving additional funds or future projects. Therefore, I asked general questions about how they perceived rehabilitation.

I analyzed the FGDs using constant comparison analysis (CCA), an effective method when there are multiple focus groups for a single study (Onwuegbuzie *et al.*, 2009). This approach is normally applied in grounded theory analysis, where researchers develop theories based upon the qualitative data (Charmaz, 1996). My goal was to validate and build upon my eDPSIR framework, not develop a new theoretical model (Figure 2). Therefore, I considered this semi-grounded research, but still applied the CCA steps to categorize the responses and assess response saturation across communities. In order to facilitate the analysis, I used the MAXQDA software to deductively code responses (VERBI, 2018). Using the pre-identified categories from the eDPSIR framework, I assigned codes to each FGD transcript. Then, I separated the coded responses into similar groups, a process known as axial coding. Finally, I developed themes that encapsulated the grouped responses (Gläser & Laudel, 2013). I also weighted the response frequency using the number of participants to account for varying group size.

V. Results

5.1 Impact of rangeland rehabilitation strategies on vegetation cover

First, I applied the non-parametric Mann Kendall trend analysis test to assess changes in the MSAVI II panel data. Seven sites displayed significant, positive vegetation cover trends either during October-December or January to March. Three of those sites were controlled grazing interventions, and two of those sites had positive trends for both seasons (Table 4). Several sites had a negative vegetation cover trend, including Bani Hashem and Azraq, but none of the decreasing vegetation trends were significant. Thus, the controlled grazing strategy appeared to be the best strategy at improving vegetation cover upon initial inspection.

Table 4. Mann Kendall trend analysis of average Modified Soil Adjusted Vegetation Index (MSAVI) II from 2004-2018 for each intervention site, differentiated by early and late rainy seasons (n = 15 per site/season).

	Intervention	October – December		January – March	
		Tau	*2-sided p-value*	*Tau*	*2-sided p-value*
Arainba	Vallerani	-0.103	0.432	0.007	0.972
Mowaqer	Vallerani	0.062	0.642	0.324	0.013*
Qatraneh	Vallerani	0.099	0.454	-0.025	0.858
Ruwashid	Vallerani	0.274	0.035*	0.186	0.154
Bani Hashem	Controlled	-0.113	0.392	-0.054	0.694
Daba’a	Controlled	0.287	0.027*	0.425	0.001*
Wadi Al Botum	Controlled	0.117	0.372	0.356	0.006*
Wadi Rum (G)	Controlled	0.425	0.001*	0.568	$1.14*10^{-5}$*
Azraq	Protected	-0.159	0.225	-0.101	0.443
Qatar	Protected	0.002	1	0.059	0.692
Shaumari	Protected	0.140	0.284	0.287	0.027*
Wadi Rum (P)	Protected	0.264	0.042*	0.430	0.001*

** Significant at the 0.05 probability level.*

I then compared the Vallerani and controlled grazing MSAVI II values with the counterfactual sites by calculating a simple double difference (Equation 5). As previously mentioned, the protected sites and Wadi Al Botum were excluded from the impact evaluation as they lacked pre-intervention observations given my designated timeframe (i.e. 2004 – 2018). For both strategies, there was minimal or negative impact on vegetation cover (Table 5).

Table 5. Average impact of the Vallerani and controlled grazing strategies on MSAVI II based on the simple double difference calculation, differentiating between late and early rainy seasons (intervention n = 22 per season, counterfactual n = 22 per season).

Intervention	October – December	January - March	Overall
Vallerani	-0.003	-0.004	-0.003
Controlled grazing	-0.002	0.005	0.002

Using an Ordinary Least Squares (OLS) regression, I compared the MSAVI II values against years with and without the treatment. When all the years were pooled, rehabilitation did not significantly impact MSAVI II. I proceeded to run a pooled OLS regression, including the two rehabilitation strategies. In this case, both strategies had a significant impact on vegetation cover; however, they had opposite effects. Based on the t-values, the controlled grazing sites positively and Vallerani sites negatively impacted vegetation cover (Table 6). This suggests that controlled grazing is better at increasing vegetation cover compared the Vallerani technique. Reflecting upon the double difference results (Table 5), this outcome is logical and explains the lack of significance in the first pooled regression. Additionally, the overall p-value was significant for January to March, but not for October to November (Table 6). This difference can be explained by delays in the onset of the rainy season, a phenomenon reported in the literature and the FGDs (Al Qinna *et al.,* 2011; Bani Hashem and Jerba FGDs).

In order to test the robustness of the OLS results, I applied a panel fixed effects (FE) model. The FE model accounted for unobserved, time invariant characteristics and observed characteristics within each site. The FE model showed that controlled grazing only significantly affected the MSAVI II in January to March (Table 7). Similar to the OLS model (Table 6), the season is an important predictor of vegetation cover. Granted, the significant finding from the FE model was lost when the standard errors were clustered (Table 8). Upon closer inspection of the panel FE model results, the adjusted R-squared values were respectively -0.160 and -0.135 for October to December and January to March. Thus, rehabilitation strategies could not explain MSAVI II variance (Table 7). Therefore, factors beyond the intervention strategy should be included to improve the regression model.

Table 6. Pooled OLS regression of MSAVI II differentiated by intervention strategy for both seasons (intervention n = 22 per season, counterfactual n = 22 per season).

Season	Coefficient	Estimate	Std. Error	t-value	Pr (>|t|)
Oct-Dec	(Intercept)	0.133	0.006	20.99	$2.2*10^{-16}$ *
	Controlled Grazing	0.023	0.009	2.51	0.013 *
	Vallerani	-0.020	0.009	-2.28	0.024 *
Jan-Mar	(Intercept)	0.169	0.006	30.79	$2.2*10^{-16}$ *
	Controlled Grazing	0.067	0.018	3.80	0.0001*
	Vallerani	-0.041	0.013	-3.17	0.002*

October to December		***January to March***	
Adj. R-Squared:	0.001	Adj. R-Squared:	0.112
p-value:	0.183	p-value:	$1.8*10^{-6}$*

** Significant at the 0.05 probability level.*

Table 7. Panel fixed effects (FE) model regression of MSAIV II against the intervention strategies for both seasons (intervention n= 22 per season, counterfactual n = 22 per season).

Season	Coefficient	Estimate	Std. Error	t-value	Pr (>|t|)
Oct-Dec	Controlled Grazing	-0.001	0.003	-0.374	0.709
	Vallerani	-0.001	0.003	-0.314	0.754
Jan-Mar	Controlled Grazing	0.024	0.012	2.050	0.042 *
	Vallerani	0.002	0.010	0.189	0.850

October - December		***January – March***	
Adj. R-Squared:	-0.160	Adj. R-Squared:	-0.135
p-value:	0.907	p-value:	0.122

** Significant at the 0.05 probability level.*

Table 8. FE model coefficient test for both seasons (intervention n= 22 per season, counterfactual n = 22 per season).

Season	Coefficient	Estimate	Std. Error	t-value	Pr (>|t|)
Oct-Dec	Controlled Grazing	-0.001	0.003	-0.374	0.709
	Vallerani	-0.001	0.002	-0.482	0.630
Jan-Mar	Controlled Grazing	0.024	0.016	1.564	0.120
	Vallerani	0.002	0.008	0.241	0.810

** Significant at the 0.05 probability level.*

Admittedly, I should have applied the random effects (RE) model if I adhered to the Hausman test results (Oct-Nov: p-value = 0.298; Jan-Mar: p-value = 0.999); however, the RE model did not account for omitted coefficients. The RE model did correct for serial correlation, which was important because a Durbin Watson test showed that the regression residuals were positively, serially correlated for both seasons, a common issue with panel data (Oct-Nov: auto-correlation = 0.816; Jan-Mar: auto-correlation = 0.738). I did run the RE model for comparison; the results had the same significance levels as the FE model for both seasons. Therefore, I chose to present the FE model as it controlled for omitted variable bias.

5.2 Effect of rehabilitation strategies on ecological drought resilience

I proceeded to test whether rehabilitation interventions altered ecological resilience by incorporating the CDI and SPI drought indices. First, I visualized the effect of CDI and SPI on MSAVI II for the three rehabilitation strategies and combined counterfactuals from 2004 to 2018 (Figure 11). Overall, MSAVI II increased as the CDI shifted from exceptional drought to exceptionally wet for all strategies; however, upon closer inspection of the MSAVI II values, these changes were nominal. Unlike CDI, the relationship between SPI and MSAVI II did not have as clear a trend; Vallerani MSAVI II stayed constant and controlled grazing peaked in near normal conditions.

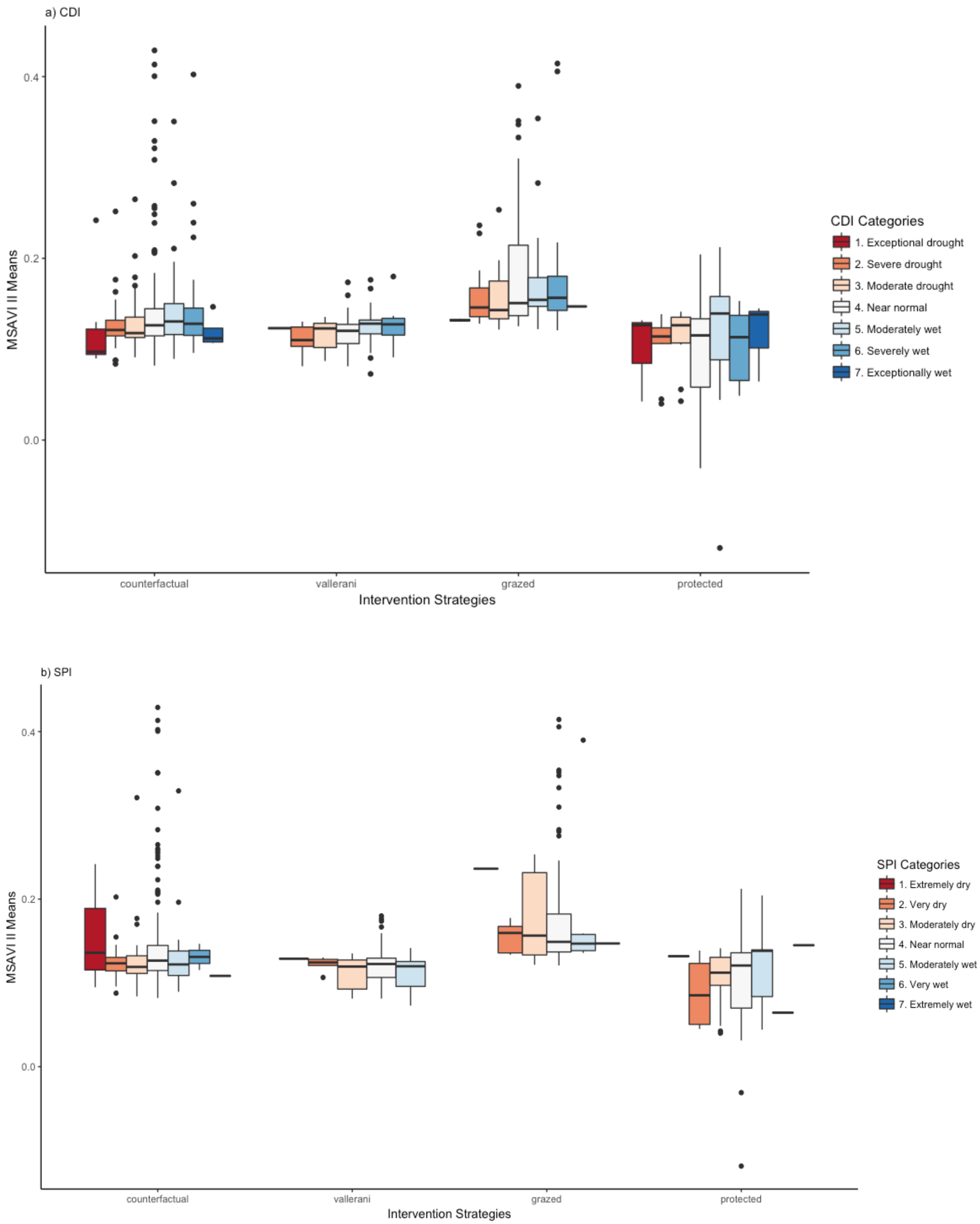

Figure 11. Effect of a) CDI and the b) Standardized Precipitation Index (SPI) on average MSAVI II values from 2004 to 2018 for the counterfactual and three intervention strategies, combining both seasons (counterfactual n = 360, Vallerani n = 120, grazed n = 120, protected n = 120).

In order to determine if rehabilitation improved the drought resilience of the system; however, I needed to identify changes before and after the interventions. Therefore, I visualized the effect of CDI and SPI on post-intervention MSAVI II (Figure 12). Counterfactuals were omitted as they lacked before and after data. Similar to Figure 11, the Vallerani MSAVI II increased as the CDI shifted from exceptional drought to exceptional wet events. This CDI trend was less evident for controlled grazing, which had high MSAVI II values even during severe droughts. As SPI moved from dry to wet, controlled grazing MSAVI II increased, with high outliers during near normal years. For Vallerani and protected sites, the influence of SPI varied. To determine if the differences visualized in Figure 12 were significant, I ran an unbalanced, three-way ANOVA (type II) test with post-intervention MSAVI II. The intervention strategy, season and their interaction significantly affected MSAVI II, but not CDI nor SPI (Table 9).

I proceeded to include SPI as a covariate in the double difference regression models. CDI was excluded due to multicollinearity issues with MSAVI II. The inclusion of the SPI did not alter any of the previous results, nor was SPI significant in any of the regression models. Thus, both SPI and CDI did not appear to significantly impact vegetation cover, suggesting resilience to drought shocks.

Table 9. Summary of the unbalanced, three-way ANOVA Type II results that analyzed the interaction of the rehabilitation strategy, season and a) CDI or b) 3-month SPI on post-intervention MSAVI II values from intervention sites (n = 238).

a) Variable	**Sum Sq.**	**Df**	**F value**	**Pr (>F)**
Rehabilitation strategy	0.160	2	38.67	$5.8*10^{-16}$*
CDI Categories	0.020	6	1.60	0.148
Season	0.028	1	13.56	0.0003*
Intervention: CDI Categories	0.019	9	1.01	0.437
Intervention: Season	0.020	2	4.94	0.008*
CDI Categories: Season	0.002	4	0.298	0.879
Treatment: CDI Categories: Season	0.009	6	0.711	0.641
Residuals	0.422	204		
b) Variable	**Sum Sq.**	**Df**	**F value**	**Pr (>F)**
Rehabilitation strategy	0.176	2	42.08	$3.13*10^{-16}$*
SPI Categories	0.025	1	1.18	0.279
Season	0.026	1	12.54	0.0004*
Intervention: SPI Categories	0.002	2	0.4431	0.643
Intervention: Season	0.021	2	4.93	0.008*
SPI Categories: Season	0.000	1	0.057	0.812
Treatment: SPI Categories: Season	0.001	2	0.176	0.839
Residuals	0.433	211		

** Significant at the 0.05 probability level.*

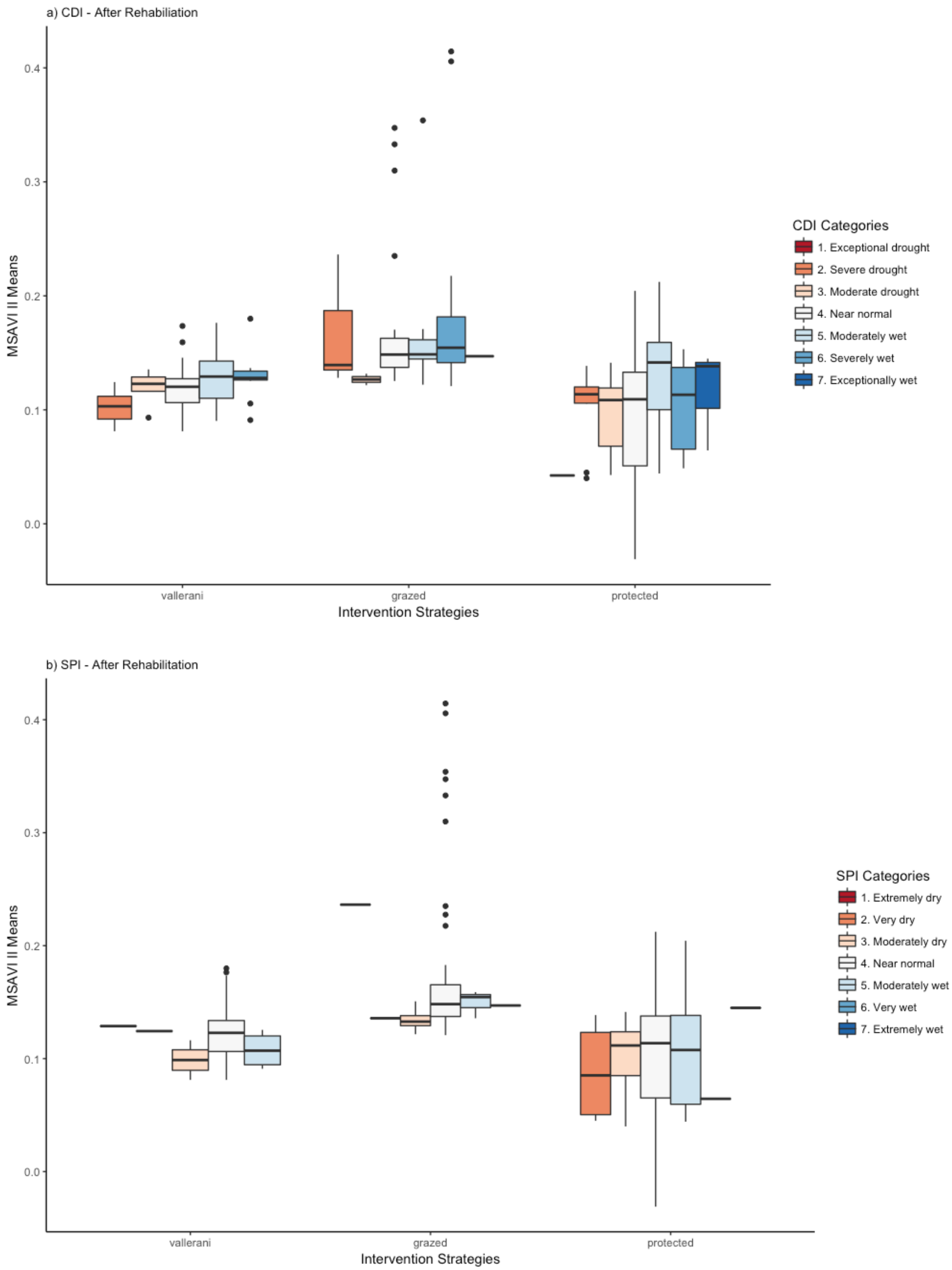

Figure 12. Effect of a) CDI and b) SPI on post-intervention MSAVI II for the three rehabilitation strategies (Vallerani n = 69, grazed n = 65, protected n = 104).

I then applied a Spearman's correlation test to determine whether MSAVI II variance could be explained by CDI or SPI. For both the interventions and counterfactuals, vegetation cover was only weakly correlated to both drought indicators, albeit there was a difference between the indices (Table 10). For example, Vallerani MSAVI II values had the strongest correlation with CDI, but the weakest to SPI. Similarly, both the protected and counterfactual sites had weaker correlations to SPI compared to CDI. Although one might assume this is due to the presence of NDVI in the CDI, controlled grazing had a higher correlation with SPI than CDI (Table 10). Thus, although NDVI in the drought indicator might have affected the results, other factors appeared to be influencing the correlation. In order to ensure that outliers were not biasing the correlations, I re-ran the Spearman's test with the median MSAVI II values; however, all interventions' MSAVI II values were still only weakly correlated to both CDI and SPI. Therefore, drought did not appear to impact vegetation cover, regardless of the strategy.

Table 10. Spearman's correlation of MSAVI II means with CDI and SPI for post-intervention years from intervention sites (n = 238) and all years of the counterfactual points (n = 360).

Intervention Strategy	CDI	SPI
Counterfactual	0.134	0.090
Overall Treated	0.179	0.105
Vallerani	0.289	0.050
Controlled Grazing	0.152	0.197
Protected	0.210	0.086

5.3 Assessment of rangeland dependence, drought coping strategies and perceptions of rehabilitation

I conducted five focus group discussions in four communities, speaking to a total of 37 people (13 men and 24 women; see Appendix D, Figure B). I depended upon the implementing organizations to arrange the focus group meetings, so I did not always speak to both male and female groups in each community. Although the groups were gender segregated, in Qatraneh one woman joined the men's group and in Azraq one man was present in the female group. The transcribed results from each focus group were deductively coded and grouped into themes (Table 11; see Appendix C). The themes were clustered based on the eDPSIR framework (Figure 2): rangeland ecosystem services, drivers of degradation, impact on communities, coping strategies and response to degradation (Table 11). Within those clusters, I identified seven themes with response saturation across the groups and a weighted response higher than 1.75, an arbitrary threshold that I selected.

First, the FGDs highlighted the provisioning ecosystem services, primarily fodder for livestock. Second, natural drivers were most cited reason for rangeland degradation, although FGDs also recognized the role of human activities. Third, the loss of rangeland ecosystem services impacted income, resulting in economic hardship. Fourth, a common coping strategy to drought and rangeland degradation was to transition away from livestock-dependent livelihoods. The alternatives described by the groups differed, but intensification of agriculture was one option with implications on natural resource management and sustainable development in Jordan. Finally, all of the FGDs expressed interest in rehabilitating the rangeland and were aware of the historical or ongoing interventions.

Table 11. Frequency of themed responses from the five focus groups conducted in four communities (m=men, w=women, ES = ecosystem services, DR = drivers, IM = impacts, CS = coping strategies, RP = responses). The responses were also weighted based on the number of respondents to account for the varying group size (#/n).

	Azraq *(m, n=8)*		**Azraq** *(w, n=3)*		**Qatraneh** *(m, n=6; w, n=1)*		**Bani Hashem** *(w, n=12)*		**Jerba** *(w, n=8)*		**Total** *(w, n=24; m=14)*	
	#	**Weighted**	**#**	**Weighted**	**#**	**Weighted**	**#**	**Weighted**	**#**	**Weighted**	**#**	**Weighted**
ES. Provisioning ecosystem services	**4**	**0.50**	**6**	**2.00**	**5**	**0.71**	**4**	**0.33**	**2**	**0.25**	**21**	**3.80**
ES. Regulating ecosystem services	2	0.25	0	0.00	2	0.29	0	0.00	0	0.00	4	0.54
ES. Supporting ecosystem services	1	0.13	0	0.00	0	0.00	0	0.00	0	0.00	1	0.13
DR. Anthropogenic drivers	1	0.13	0	0.00	1	0.14	1	0.08	1	0.13	4	0.48
DR. Natural drivers	**6**	**0.75**	**3**	**1.00**	**3**	**0.43**	**2**	**0.17**	**2**	**0.25**	**16**	**2.60**
IM. Poor animal health	0	0.00	1	0.33	0	0.00	3	0.25	1	0.13	5	0.71
IM. Climatic changes	2	0.25	0	0.00	0	0.00	0	0.00	1	0.13	3	0.38
IM. Economic hardship	**1**	**0.13**	**2**	**0.67**	**8**	**1.14**	**5**	**0.42**	**5**	**0.63**	**21**	**2.98**
IM. Decreased rangeland dependence	2	0.25	2	0.67	1	0.14	2	0.17	3	0.38	10	1.60
IM. Negative effect on ecosystem services	**7**	**0.88**	**6**	**2.00**	**4**	**0.57**	**3**	**0.25**	**6**	**0.75**	**26**	**4.45**
IM. Pressure on social systems	0	0.00	0	0.00	1	0.14	2	0.17	0	0.00	3	0.31
CS. Buy livestock products	0	0.00	1	0.33	1	0.14	1	0.08	1	0.13	4	0.68
CS. Transition away from pastoralism	**7**	**0.88**	**4**	**1.33**	**2**	**0.29**	**4**	**0.33**	**5**	**0.63**	**22**	**3.45**
CS. Intensification of agriculture	0	0.00	1	0.33	2	0.29	0	0.00	4	0.50	6	1.12
CS. Alternative feed for livestock	3	0.38	0	0.00	3	0.43	0	0.00	5	0.63	10	1.43
RP. Interest in renewing the rangeland	**2**	**0.25**	**2**	**0.67**	**1**	**0.14**	**1**	**0.08**	**6**	**0.75**	**11**	**1.89**
Education of rangeland benefits	0	0.00	0	0.00	0	0.00	0	0.00	1	0.13	1	0.13
Interventions need improving	2	0.25	0	0.00	1	0.14	0	0.00	0	0.00	3	0.39
RP. Knowledge of intervention strategies	**3**	**0.38**	**1**	**0.33**	**5**	**0.71**	**2**	**0.17**	**1**	**0.13**	**12**	**1.71**
RP. Alternative livelihood options	0	0.00	0	0.00	0	0.00	1	0.08	0	0.00	1	0.08
Job creation for women	0	0.00	0	0.00	0	0.00	1	0.08	0	0.00	1	0.08
RP. Idealization of the past	1	0.13	1	0.33	0	0.00	0	0.00	1	0.13	3	0.58

VI. Discussion

6.1 Changes in vegetation cover

I defined rehabilitation success as the interventions' ability to shift the system from a degraded to improved state, as measured by vegetation cover (Figure 2). Using MSAVI II as a proxy indicator, the Mann Kendall results showed that vegetation improved for only seven sites between 2004 and 2018 (Table 4). Almost half of those sites were under controlled grazing management, accounting for half of the total number of significant values. Although pastoralists are regularly blamed for rangeland degradation, this result suggests that grazing benefits the ecosystem. Indeed, Behmanesh *et al.* (2016) argued that improper grazing management drives degradation, not grazing itself. A study in Senegal's dry zone similarly found that grazing increased vegetation production (Rasmussen *et al.*, 2018). On the other hand, Eldridge *et al.* (2019) claimed that grazing, even at a low intensity, negatively impacted the Australian rangelands and that aridity increased the magnitude of the adverse effects. Clearly, grazing management remains a contentious topic, but my results bolster the argument for controlled grazing. Thus, the GoJ should support the development of community-driven management plans that include rest periods, rotational grazing and stocking rates.

Only two Vallerani interventions exhibited a significant, positive vegetation trend (Mowaqer in January to March, Ruwashid in October to December), a surprising result given the approach is a proven technique that seems to increase the "greenness" of a site (Figure 13a). The poor MSAVI II signal could be attributed to the study methodology, intervention design or overall management. First, a major methodological limitation was that I averaged each site's MSAVI II values. Even if MSAVI II accurately captured the vegetation by accounting for soil noise, the bare interspace (i.e. the ground between the pits) may have masked changes within the contour lines by pulling down the overall average. Second, NARC did not apply any rehabilitation techniques to the interspace; however, there are options to boost plant cover between the pits. For example, scarification of the soil crust allows seeds from the soil bank to emerge or, if the native seed bank has been depleted, direct seeding (Louhaichi *et al*., 2014). Finally, the Vallerani sites were theoretically protected for two years prior to grazing; however, there was a lack of documentation to validate that grazing was properly controlled. Further studies should account for these potential issues to determine whether the Vallerani strategy was ineffective or if the perceived lack of change was due to improper analysis or management.

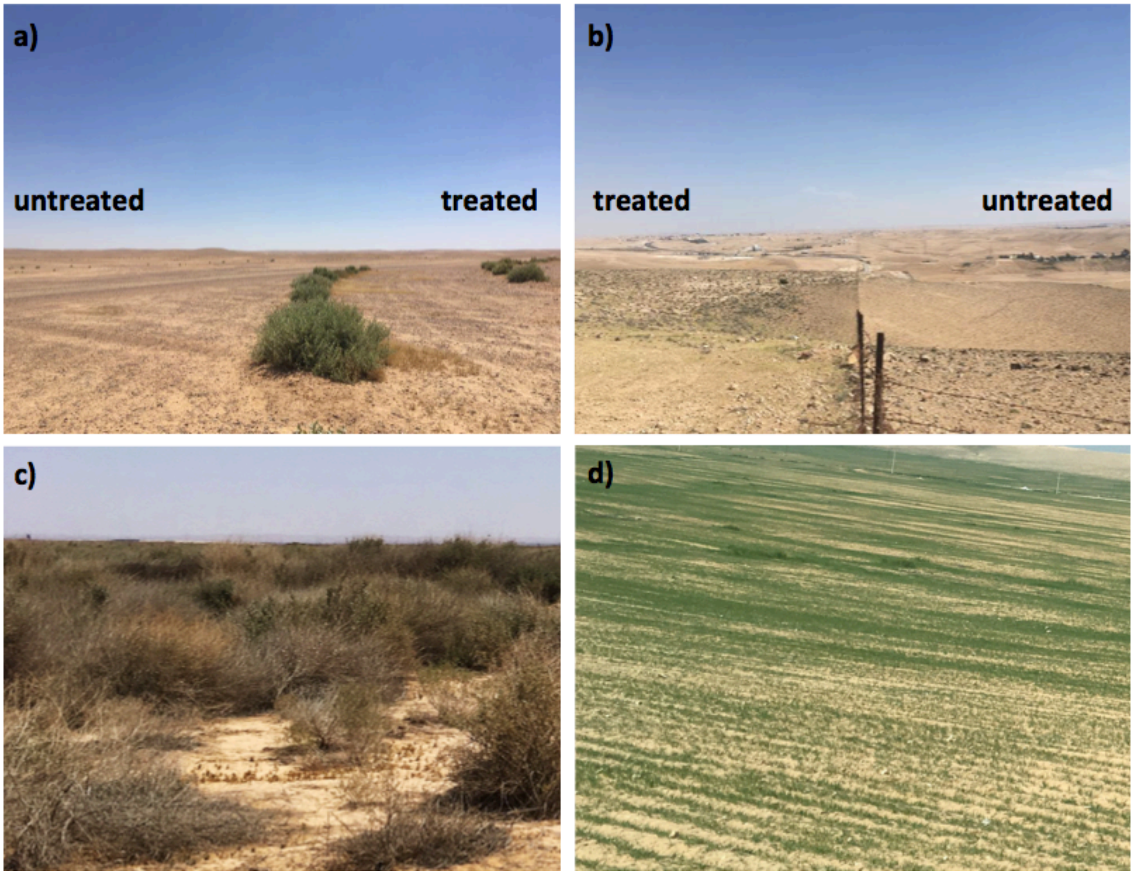

Figure 13. Examples of the analyzed land management strategies: a) Mowaqer Vallerani site (May 9, 2019); b) Daba'a controlled grazing site (May 9, 2019); c) Shaumari protected reserve (May 9, 2019); d) rainfed barley cultivation near the Jerba community (April 21, 2019).

Only two of the protected sites had significant, positive vegetation cover trends, which was expected. Most protected sites were established prior to 2004, so vegetation cover should have been stable. Wadi Rum was the only site with a significant positive change in both seasons, but this site was established in 2015. A boost in vegetation cover was anticipated in the years following initial protection. An unforeseen result was that the protected sites had lower MSAVI II values compared to other strategies (Figure 11 and 12). This result was particularly unexpected because I included the Azraq Wetland Nature Reserve, which has 1.5 million m^3 of water pumped into the system annually to maintain the ecosystem and, upon first glance, appears lush (Al Naber, 2016; see Appendix D, Figure C). Standing water can result in negative MSAVI II values, pulling down the average. Thus, I tried excluding Azraq and using the median values; however, the protected sites' MSAVI II values were still lower than the other strategies. Thus, protection itself, not the inclusion of the Azraq site or average values, negatively impacted vegetation cover. This finding was substantiated by Angassa *et al.* (2012) who found that protecting rangelands decreased vegetation cover and exacerbated degradation.

According to the Mann Kendall results, controlled grazing was the most effective strategy to increase vegetation cover; however, the trend analysis did not account for the timing of the intervention nor what would have occurred without the intervention. Therefore, I calculated the DD for the Vallerani and controlled grazing sites, which integrated the counterfactual data (Equation 5). Based on those results, I concluded that rehabilitation did not increase MSAVI II compared to sites without an intervention (Table 5). Similarly, a pooled OLS regression comparing MSAVI II over the years found that there was no significant impact; however, this could be attributed to the interventions' opposing effects.

When differentiated by rehabilitation strategy, the pooled OLS model revealed that Vallerani interventions had a significant, negative impact of vegetation cover, whereas controlled grazing had a significant, positive impact (Table 7). The controlled grazing results substantiated the Mann Kendall results; however, the trend analysis had identified two Vallerani sites with a positive change in vegetation cover. In comparison with other land management strategies; however, the Vallerani strategy appeared to be wholly ineffective. In addition to the reasons detailed above, there are two additional explanations for this result. First, the Vallerani technique is a form of active rehabilitation; a plow must dig the contour lines, removing any pre-existing vegetation. Controlled grazing, on the other hand, is passive and allows existing vegetation to remain, boosting the VI immediately following the intervention. Second, the quality of the planted native shrubs may have influenced the success of the intervention. Anecdotal evidence suggested that the MoA nursery, which provided the shrubs for all the NARC interventions, produced low quality shrubs with a poor survival rate. Similar to the previous recommendation, future research should distinguish whether the negative impact is a symptom of the quality of the Vallerani interventions or the strategy itself.

The FE model results, which looked at variation within each site, showed that only controlled grazing in the late rainy season had a significant impact on MSAVI II (Table 6). In this case, seasonality played an important role. Droughts are common at the onset of the rainy season, so controlled grazing would have a significant impact on vegetation cover in January to March when the rains began, but not in October to December (Al-Qinna *et al.*, 2011). This finding was substantiated during the FGDs; participants stated that the start of the rainy season is delayed. In contrast, climate change models for the Middle East predict that precipitation will increase in the early rainy season (i.e. autumn) and decrease in the late rainy season (i.e. spring;

Tabari & Willems, 2018). Although these findings are contradictory, they can both be true. My analysis focused on past interventions, so I adhered to the observations that rainfall decreased in October to December and increased from January to March, but future research should monitor how inter-annual precipitation shifts due to climate change.

The significance of controlled grazing in January to March was lost when the standard errors were clustered in a coefficient test, likely due to the positive, serial correlation (Table 8). Thus, the impact of controlled grazing on MSAVI II was not robust; however, the Mann Kendall test did show that MSAVI II increased for most controlled grazing sites. The lack of robust, significant impact could be attributed to the counterfactual identification process.

6.2. Land management in the counterfactual areas

Remote sensing cannot differentiate between sustainable and unsustainable "greenness". Due to a lack of land tenure data and fine resolution land cover maps, rainfed barely cultivation and irrigated agriculture areas may have been included as counterfactuals.[1] The likelihood of capturing rainfed barley and irrigated fields in the counterfactual identification process increased from 2004 to 2018 due to the expansion of agriculture into the rangeland (Al Karadsheh *et al*., 2012). Thus, counterfactual "green" fields may have masked the impact of rehabilitation, resulting in the false conclusion that rehabilitation did not improve vegetation cover.

Low intensity, rainfed barley is common throughout the rangeland despite this AEZ being unsuitable for cultivation, increasing household costs and accelerating land degradation (Taner *et al.*, 2004). In 2005, 39% of transhumant pastoralists cultivated barley on their own land, a figure that does not even capture pastoralists that rent land for barley production (Abu Zanat *et al*., 2005). Rainfed barely cultivation requires mechanical soil disturbance twice a year for land preparation and harvesting, increasing input expenditures (i.e. seeds, fuel, tractor, etc.). Additionally, winter barley is seeded early and the land is plowed prior to the first rains (Syouf & Duwayri, 1995). Thus, the soil lacks a crust when the rains begin, resulting in high rates of soil erosion. Water erosion is estimated to cause losses up to 5t $ha^{-1}yr^{-1}$ of soil across the rangelands, resulting in rilling and gully formation (Moreno de las Heras *et al*., 2010; Qaryouti *et al.*, 2014; see Appendix D, Figure A). ICARDA modeled surface run-off induced soil loss over a

[1] Urban areas could have also been selected due to a lack of fine resolution settlement data; however, I assumed that built areas would not produce "false positive" MSAVI II values and the sheer number of counterfactual points would minimize their impact on the average.

300-year return period for baseline, degraded and restored scenarios. The model estimated an average soil loss of 0.84t $ha^{-1}yr^{-1}$, 3.3t $ha^{-1}yr^{-1}$ and 1.27t $ha^{-1}yr^{-1}$ respectively (Haddad, 2019). Thus, rehabilitation is an important measure to mitigate soil erosion in the rangelands.

Wind and water erosion have immediate and off-site impacts. Localized soil loss decreases soil depth and fertility, impairing vegetation growth. Transported soil negatively affects air and water quality, natural water bodies and infrastructure. For example, soil lost via water erosion can result in dam sedimentation. As a water scare country, Jordan needs to capture and utilize every drop of water; however, sedimentation reduces reservoirs' storage capacity and increases maintenance expenditures (Annandale *et al.*, 2016). Despite the immediate and off-site costs associated with barely cultivation, the practice is widespread and growing (Badran *et al*., 2018). Thus, the cost of inputs and negative externalities, not just the measure of "greenness", should be incorporated into analyses of rangeland management options.

Irrigated agriculture is also encroaching into the rangelands, increasing the likelihood that the counterfactual site identification process captured this land use and similarly masked rehabilitation results. From 2007 till 2017, the total area under irrigation increased 46% across the country (DoS, 2007, 2017a). Molle *et al.* (2017) cautions that this figure is probably an underestimation since official figures do not include areas irrigated with "illegal water" from unregistered wells. The high MSAVI II values in years with exceptionally dry SPIs and the number of outliers in near normal SPI conditions supported the hypothesis that counterfactual points included irrigated agriculture (Figure 11 and 12). Although fine resolution land cover data should be used to substantiate this hypothesis, the FGDs did highlight intensification of agriculture as a coping strategy to drought (Table 11). Irrigated agriculture may improve household resilience in the short-term by ensuring stable yields and incomes; however, the negative consequences on groundwater are evident at the landscape and country level.

Agriculture accounts for approximately 60% of the total annual water consumption, most of which is sourced from aquifers, and drives over abstraction (MWI, 2016). In the Azraq water basin, groundwater abstraction was 215% higher than the safe water yield in 2011 (Al Naber, 2016). Groundwater recharge is influenced by immutable and transient variables. Immutable factors include the physical characteristics of the aquifer; beyond a certain depth, recharge is minimal and its groundwater is considered a non-renewable resource. For example, the Mafraq aquifer, which located in the northeast, is 350m below the surface, resulting in limited or no recharge (Closas & Molle, 2016). Transient factors, such as rainfall, also influence the amount of water available for recharge. Climate change models predict declining precipitation and rising temperatures, reducing groundwater recharge rates by 52% and 23% respectively (Al Raggad & Jasem, 2011). Depleting scarce water resources may have long-term consequences for the drought resilience of the already water-poor country.

6.3 Resilience to drought

Rangeland vegetation is influenced by rainfall, hence the incorporation of NDVI in drought indices (Al Bakri & Suleiman, 2004). The FGDs substantiated this claim, citing decreased rainfall and droughts as the major reason for a decline in rangeland ecosystem services (Table 11). One man succinctly summed up the importance of rainfall by stating, "if there is no rain, there is no spring" (Azraq FGD). Rehabilitation strategies aim to decrease reliance on rainfall by increasing native vegetation that is more tolerant to low precipitation and high salinity. Therefore, intervention sites were anticipated to be more resilient to drought than their counterfactuals.

I tested whether interventions increased drought resilience using a three-way ANOVA, Spearman's correlation test, and OLS/FE regression models. The three-way ANOVA results revealed that CDI and SPI did not significantly impact MSAVI II (Table 9). Similarly, 3-month SPI did not change the robustness of the OLS and FE regression models, suggesting that meteorological drought was not a variable that influenced vegetation. Additionally, neither SPI nor CDI were highly correlated to MSAVI II. Based on these results, one might conclude that the rehabilitation projects increased drought resilience; however, the previous vegetation cover results undermined this conclusion.

According to the Mann-Kendall results, the controlled grazing strategy had the most sites with a positive, significant increase in vegetation. Incidentally, the controlled grazing sites also had the highest correlation to SPI compared to all the other interventions, albeit only weakly, suggesting that when vegetation cover is present, rainfall impacts the rehabilitation outcome (Table 10). Thus, if interventions did not transform the ecosystem's state, drought would not significantly impact MSAVI II (Figure 2). Arguably, controlled grazing may be resilient to drought since regression models identified this strategy as a significant predictor for positive MSAVI II change and drought did not significantly impact MSAVI II; however, the vegetation cover findings were not robust. Therefore, I was disinclined to conclude that the ecosystem was more resilient to drought after rehabilitation.

The Spearman results also highlighted the importance of selecting a drought index that accurately reflects how rehabilitation strategies interact with different types of drought. Although MSAVI II was poorly correlated to drought overall, there were differences between the 3-month SPI (i.e. meteorological drought) and CDI (i.e. meteorological, agricultural and hydrological drought). Granted, comparing CDI and SPI correlations to MSAVI II could be misleading if the NDVI in CDI resulted in multicollinearity; however, the controlled grazing results suggested that this was not true. Controlled grazing MSAVI II values were more correlated to SPI than CDI (Table 10). Therefore, I cautiously interpreted the differences between the drought indices, particularly for the Vallerani sites. Vallerani sites' MSAVI II values had the highest correlation to CDI compared to other strategies, but the lowest to SPI. This result can be explained by the fact that it was a micro-water harvesting system; surface run-off has a larger impact than rainfall. Depending on the topography, the rainfall contributing to surface run-off could be spatially disparate. Therefore, SPI within the boundaries of the intervention sites did not necessarily correlate to the amount of water present in the system. Additionally, the Vallerani pits increased soil water storage, a factor captured in CDI, but not SPI. This finding highlighted that, when assessing the impact of drought, the chosen index should be suitable for the type of drought that has the most influence on the selected strategy.

Issues with the counterfactual site identification process were also evident in the Spearman results. Previously, I suggested that the counterfactual sites captured rainfed barely; however, if this were true, CDI and SPI would be highly correlated to MSAVI II. Previous studies reported that barley yields were correlated to biomass; breeding programs in Jordan focused on prolonging elongation and increasing tiller number to improve yields (Wiegmann *et al.*, 2019). A 10-20% reduction in rainfall was estimated to decrease barley yield by 4-8%, which would result in a similar decline in biomass (Al Bakri *et al.*, 2011). Therefore, remotely sensed VIs should have been able to capture the impact of drought on rainfed barley. Instead, counterfactual sites were only weakly correlated to CDI and SPI. Thus, it was more likely that irrigated agriculture areas, not rainfed barley fields, were included in the counterfactual areas.

There is a broader policy question at hand: should the GoJ be focusing on drought adaptation strategies in the rangelands, an AEZ that is naturally arid? A recent assessment recommended concentrating drought mitigation measures in high rainfall areas (i.e. the northwest), arguing that those regions were more vulnerable than rangelands (Al Bakri *et al.*, 2019). The Jordanian rangeland is an (semi-) arid environment and the native flora and fauna have evolved to survive dry conditions; however, the drivers of degradation have undermined the natural capital of the system. Even if the anthropogenic drivers are removed, climate change and transboundary flow models predict that freshwater availability will continue to decline, placing pressure on the system (Rajsekhar & Gorelick, 2017). A degraded rangeland may be resilient to drought, but it is unable to support livelihoods and results in negative externalities. This may force pastoral communities to transition away from livestock and find alternate livelihoods; however, their presence is needed to maintain the ecosystem. Although overgrazing drives degradation, moderate, controlled grazing in is beneficial for ecosystem services. Brierley *et al*. (2018) provided evidence that pastoralism maintains vegetation cover in the rangelands despite climactic pressure, such as drought. Light to moderate grazing has also been linked to positive effects on water infiltration into the soil, indicating that the presence of livestock is essential for the eco-hydrological cycle (Wilcox *et al*., 2017). Thus, the GoJ should not exclude rangelands from national drought strategies on the grounds that it is naturally an arid environment, but instead identify rehabilitation strategies that have higher drought resilience.

6.4 Common coping strategies of pastoral communities

Individuals who participated in the FGDs linked the decrease in vegetation cover to a decline in rangeland dependence, highlighting the importance of native plants for livestock fodder (Table 11). They also stated that the loss of rangeland resources led to economic hardship due to the increased cost of fodder, reduced livestock health and diminished milk quality. Based on these responses, rehabilitation strategies were justified in targeting the system's lack of native vegetation, as it determined the carrying capacity of the rangelands and had cascading impacts on food security resilience (Figure 2).

In the face of drought shocks combined with a degraded rangeland, FGDs reported that individuals either intensify livestock production or transition away from pastoral livelihoods. These coping strategies are reflected in the population and agriculture censuses. In 2018, the Department of Statistics reported that only 9.7% of the population lived in rural areas compared to 17.4% in 2009 (DoS, 2009, 2018). Individuals migrated to urban centers in search of alternate sources of income. At the same time, the Agriculture Census found that the overall number of livestock has increased, highlighting the intensification of livestock production (Table 12).

The concentration of livestock in the hands of fewer owners is based on the concept of "economies of scale", that increasing the number of production units decreases unit cost. By owning more livestock, owners can afford to purchase imported feed or crop residues. One man in Qatraneh explained that in order to make a living from livestock, an individual must either own a minimum of 250 heads or have a secondary income (Qatraneh FGD). The goat and camel populations clearly reflect this observation. From 2007 to 2017, the number of goats increased 38% while the number of holdings only 6%. Sheep, on the other hand, undermine the "economies of scale" argument and contradict the FGDs; the number of owners rose 40% while the number of sheep only increased by 23%. Upon closer inspection, this trend may be driven by two governorates: Amman and Karak (Table 12). The capital is located in the Amman governorate, suggesting that sheep holders have access to jobs to supplement their income and purchase imported feed. In Karak, the number of owners increased 101% and the number of sheep by 85%, but access to a secondary income is not a compelling explanation. Regardless, the contradiction between the qualitative and quantitative data suggests that while populations perceive that livestock ownership is decreasing, pastoralism remains an important livelihood source for the governorate.

Irrigated agriculture was identified as an important strategy to mitigate drought by three FGDs, despite Jordan's limited water resources. One woman stated that when the rangeland can no longer support livestock, households begin pumping groundwater to produce vegetables (Jerba FGD). She stated that water costs ~4.5JD per hour, implying that she accessed water legally; however, evidence suggests that many farmers pump from illegal wells. The GoJ introduced policies to control groundwater abstraction, including well permits and fines; however, irrigated agriculture continues to expand and over abstraction persists (Al Naber & Molle, 2017). In the northern and middle rangelands, groundwater abstraction is approximately 2-3 times higher than official figures (Al Bakri, 2015). Therefore, agriculture intensification is a common drought mitigation strategy; however, in its current state, is an unsustainable practice and may not be a viable in the future. To promote sustainable agriculture, the GoJ should investigate other cash crops that are suitable for the AEZ and result in a smaller water footprint.

Table 12. Percent change of livestock (by category) and livestock holders from 2007 to 2017 for the country and governorates with selected interventions (adapted from (DoS, 2009, 2018).

District	**Camels**		**Goats**		**Sheep**	
	Heads (%)	*Owners (%)*	*Heads (%)*	*Owners (%)*	*Heads (%)*	*Owners (%)*
Amman	-6	-3	9	55	7	66
Aqaba	74	44	286	154	351	174
Karak	582	330	112	59	85	101
Ma'an	-57	-65	71	7	86	42
Mafraq	3250	1620	283	269	524	430
Zarqa	-24	87	33	5	56	27
Total	**5**	**1**	**38**	**6**	**23**	**40**

Employment outside the agriculture sector is important to reduce pressure on the natural resources; however, job opportunities may be limited due to the state of Jordan's economy. At the end of 2018, the unemployment rate was 18.7% and climbing (DoS, 2018). Thus, households are trapped in a vicious cycle; although they may not be able to afford feed for their livestock, if they sell their livestock they lose a valuable asset and may have difficulty finding an alternate source of income. Ex-pastoral households also simultaneously lose income generated from self-produced products while increasing expenditures to purchase meat and dairy products from the market. Although most FGDs stated that decreasing their dependence their livestock did not alter their consumption patterns, one woman did note that the quantity and quality of animal products purchased depended on fluctuations in the household budget (Bani Hashem FGD). In addition to household budget constraints, the purchasing power of the Jordanian dinar has dwindled, resulting in economic hardship and decreased consumption of livestock products. One study linked the urbanization of pastoral communities to increased risk of childhood stunting, anemia and non-ocular vitamin A deficiency due to decreased consumption of purchased meat and dairy products (Khatib & Elmadfa, 2009). Thus, the GoJ and other organizations should monitor the food security of rural, livestock-based communities and ex-pastoral, urban households given the current economic climate.

Organizations recognize that rangelands are socio-ecological systems; socioeconomic concerns must be addressed in conjunction with environmental rehabilitation. For example, the BRP strengthens cooperatives, establishes income generating opportunities, supports market promotion, invests in livestock extension services and expands veterinary services to improve the income of rangeland communities (BRP, 2010). These approaches are not limited to the BRP; IUCN trains community members in bee keeping and RSCN supports and markets locally produced products. These examples highlight that a multi-pronged approach is required to simultaneously improve pastoral livelihoods and alleviate pressure on the ecosystem by providing alternative income opportunities.

There was a major limitation to my qualitative results; the FGDs incorporated the perspectives and opinions of transhumant and agro-pastoral communities, but excluded the nomadic pastoralists. The selected interventions were implemented in coordination with settled communities, which was reflected in who was invited to participate in the FGDs. Although individuals that reside in mobile tents and caravans (as defined by the DoS and I assume to be nomadic pastoralists) represent only a small fraction of the population (i.e. 2% in 2015), this group is highly dependent on the rangelands and vulnerable to its degradation (DoS, 2015). Therefore, their voices should have been included. Additionally, FGD participants frequently blamed the nomadic pastoralists for the failure of the community-based resource management. In particular, Bani Hashem leaders requested fences and other forms of protection to exclude migratory pastoralists (Bani Hashem FGD). Thus, any government policy or intervention to renew the rangelands must incorporate the nomadic Bedouins' perspectives to improve their food security and likelihood of project success.

6.5 Opportunities and challenges with remote sensing

Remote sensing can actively monitor rehabilitation efforts across Jordan and the region, which could improve intervention outcomes (Al Bukhari *et al.*, 2018). Remote sensing is efficient, cost effective and scalable. Additionally, the technology is continuing to develop and improve. In 2015, the European Space Agency (ESA) launched two polar orbiting satellites called Sentinel-2. The two satellites provide images at a resolution of 10 meters every 2-10 days (ESA, n.d.). Sentinel-2 was not a viable option given my timeframe, but there is an opportunity to start using this higher resolution data for recent and ongoing interventions.

In order to advance remotely sensed rangeland monitoring, the most appropriate VI should be identified for Jordan. I selected MSAVI II for this study based on the literature; however, country-specific conditions can influence the accuracy of VIs. For example, a study in Iran found that VIs that adjusted for soil reflectance (i.e. MSAVI II) performed worse than the VIs that did not (Baghi & Oldeland, 2019). Therefore, before recommending remotely sensed VIs as a method to monitor and evaluate rehabilitation initiatives, a study should be conducted to compare VIs and select the one that most accurately reflects the aboveground biomass of the Jordanian rangelands.

A limitation of VIs is that they only capture aboveground NPP. This indicator does not include all the benefits linked with rehabilitation, such as biodiversity and the associated impact on animal nutrition. Biodiversity is positively correlated with more resilient ecosystem services (Perrings *et al.*, 2010). A meta-analysis of global restoration sites found that after the interventions, biodiversity increased by 44% and ecosystem services by 25% compared to the degraded landscapes (Rey Benayas *et al.*, 2009). In Jordan, rehabilitation projects report a similar upsurge in taxonomic biodiversity. In the Bani Hashem controlled grazing site, 36 indigenous species reappeared in the site after the intervention (UNEP, 2016). Additionally, ICARDA is currently implementing an experimental Vallerani site near the Majidyya community

(Figure 5). ICARDA actively planted *A. halimus, S. vermiculata* and *Ratama raetam*; however, volunteer plants have emerged within the pits and interspace. Although this finding has yet to be formally quantified, the field observation suggests that native seeds are dormant and, if the physical soil crust is broken, natural regeneration can occur and increase species diversity.

Native vegetation heterogeneity also has cascading impacts on livestock health. FGDs associated poor animal health and decreased product quality with the decline in rangeland vegetation (Table 11). A diverse diet is important to contribute to livestock's dietary requirements, including sufficient energy, protein, minerals and vitamins to maintain body weight, grow, reproduce and lactate (Corson *et al.,* 1999). For example, Awassi sheep fed only saltbushes (i.e. *A. halimus* out planted during Vallerani interventions) had worse outcomes compared to those fed barley hay (Awawdeh, 2011; UNEP, 2016). Therefore, the biodiversity benefits associated with rehabilitation may improve livestock health and product quality, even more than if they graze on the specific species that were re-introduced. Additionally, even if pastoralists grow rainfed barely as fodder in the rangelands, these cultivated areas are homogenous, restricted to a short growing season and susceptible to climate shocks. Ruppert *et al.* (2015) reported that annual plants (i.e. grasses such as rainfed barley) are 27% less resistant to drought compared to ephemeral and evergreen perennials (i.e. native shrubs). Therefore, implementing strategies should promote functionally diverse, perennial vegetation to improve the temporal availability, nutritional quality and stability of rangeland fodder.

These tangential benefits of rehabilitation may not be captured if monitoring relies solely upon remote sensing. At a resolution of 0.8m, Peng *et al.* (2018) found that hyper spectral VIs could detect plant species diversity; however, large scale monitoring efforts use coarse resolution images to cover a greater area (i.e. the 30m Landsat 7 data). Transitioning to Sentinel 2 or other higher resolution satellites may overcome this limitation; however, in the meantime, field studies should complement remote sensing results and quantify benefits that might otherwise be overlooked.

6.6 The argument for rehabilitation

The FGD responses highlighted the importance and potential of rehabilitation efforts in Jordan. Communities perceived the interventions positively and expressed their support of the projects. Even the Jerba community, the only group without a recent intervention, mentioned a MoA rangeland reserve that operated in the 1980s and indicated an interest in engaging in a similar project. Individuals also provided critical feedback, recommending that rehabilitation initiatives be better coordinated, funded and targeted (Table 11). These positive and critical responses emphasize that one of the key ingredients for rehabilitation success is present: community engagement (Marques *et al*., 2016). Although the FGD sample size limits my ability to generalize, the participants' responses suggest that communities are motivated to participate in future projects to improve the rangeland ecosystem services.

Despite communities' motivation, rehabilitation interventions appear to be unsuccessful at improving vegetation cover and drought resilience compared to counterfactual sites. Based on this finding, decision makers may conclude that investments in Jordan's rangelands are not viable. In order to curb this reaction, Jordan's efforts must be compared to the global dryland restoration efforts.

Globally, dryland restoration interventions have poor success rates (Hardegree *et al*., 2016). When drylands experience a negative regime shift, such as desertification, reversing that change is difficult and costly due to the natural aridity of the system (Saco *et al.*, 2018). Additionally, the results of rehabilitation can diverge across sites despite using the same technique. Despite these challenges, the necessary tools, methodologies and data exist to provide science-based recommendations to policy makers and implementers. Models that use probabilistic forecasting (i.e. state and transition models) should be leveraged to understand how dryland ecosystems will respond under different management (James *et al.*, 2013). Additionally, remotely sensed "big data" should be harnessed for systematic, quantitative evaluations (Baylis *et al*., 2016; Ferraro & Pattanayak, 2006). The benefits associated with healthy rangelands outweigh the long-term costs of neglect, so research should aim to identify what and why certain strategies work to maximize the impact of rehabilitation investments.

VII. General Discussion

Relevant stakeholders in Jordan recognize the importance of reversing rangeland desertification and have taken active steps to rehabilitate the ecosystem. Unfortunately, my remote sensing results suggest that rehabilitation interventions did not increase the ecosystem's vegetation cover or drought resilience compared to other forms of land management. This finding; however, was based upon a single indicator: MSAVI II. Additionally, the counterfactual site identification process did not differentiate between sustainable and unsustainable practices. Rainfed barley and irrigated agriculture may have masked the benefits of rehabilitation by being equally "green" as intervention sites, but these practices have higher costs and negative externalities. Crop cultivation requires more inputs than pastoral systems; farmers must purchase seeds, hire tractors and, in the case of irrigated areas, pay for water. These immediate costs decrease the income of farmers, undermining food access. Negative externalities of rainfed barley include higher rates of soil erosion, resulting in dust-related health issues and dam sedimentation, while irrigated agriculture places strain on already scarce water resources. Both forms of land management may increase the VI; however, the short and long-term costs and externalities should be integrated into future analyses to give policy makers a more holistic overview of the benefits and trade-offs of different land management strategies.

More robust impact evaluations should also be conducted to provide better recommendations to decision-makers. Ideally, randomized control trials (RCT) can be conducted in the rangelands to control the counterfactuals and prevent unobserved, time variant heterogeneity. Baylis *et al.* (2016) also recommended RCTs to evaluate conservation policies. Although they highlighted barriers to applying RCTs design in conservation impact assessments that are pertinent to rehabilitation such as randomization limitations, confounding factors and spatial spillovers, the challenges do not preclude the benefits that RCTs could have on improving rehabilitation outcomes.

Despite the methodological limitations of this research, the results highlight one practice that can be implemented to improve the rangeland: controlled grazing. Although the significant impact of controlled grazing on MSAVI II was not robust, the strategy showed the most promise. This recommendation is not novel; the GoJ has been supporting initiatives to reintroduce *Hima* and return rangeland control to local communities. In 2001, this transfer of land rights was included in the Jordan Rangeland Strategy; however, the measure was never widely implemented due to a lack of consensus (MoA, 2001; Myint & Westerberg, 2015). IUCN has been promoting re-introduction of *Hima* for years and in 2014, HRH Prince El Hassan Bin Talal endorsed IUCN's *Amman Declaration on Innovating Hima* (IUCN, 2014). Granted, community-based natural resource management has had varied success, but a study by (IUCN, 2014) found that collective management of Jordan's rangelands resulted in more sustainable use compared to government reserves and open access areas. Hopefully this evidence supports the transition to decentralized management to control grazing; however, the government will still play an important role to evaluate the rangelands and enforce policies.

Remote sensing can be an effective and efficient method for the GoJ to monitor rangeland health. Even at a 30m resolution, MSAVI II captured sparse vegetation. With higher resolution satellite images and VIs proven to be effective for Jordan's rangelands, the GoJ can actively update stocking rates and respond to desertification (Al Bukhari *et al*., 2018). They can also single out sites where community-based grazing management is effective to identify best practices. Similar to any methodology, remote sensing should not be the sole source of data. Remote sensing results should be validated with ground observations and biomass sampling; however, it can provide initial information to direct cost and labor intensive field surveys to certain areas (Kilpatrick *et al.*, 2015).

Sustainable rural development in Jordan will be achieved by rehabilitating the rangelands. According to Scoones (1998), livelihoods are sustainable if they can cope with stressors and sustain capabilities without undermining the natural resource base. In the rangeland's current degraded condition, the ecosystem cannot support livelihoods in the face of drought and other shocks, as evidenced by pastoral households migrating to cities and seeking secondary employment. Given the state of the national economy and the frequency of coping strategies that require alternate livelihoods, the GoJ should closely monitor the food security of (ex-) pastoral households. Although there is a need to transition households away from livestock activities to alleviate pressure on the rangeland resources, Jordan cannot fully decouple its growth from the environment. Pastoral livelihoods and traditional management practices are important for maintaining the rangelands. Thus, sustainable development of both rural communities and the country depends upon finding a balance within the rangelands that ensures a functioning ecosystem and society.

VIII. Conclusions

The Jordanian rangelands and society are inextricably linked. In light of the degraded status of the ecosystem, this axiom has consequences for the food security and sustainable development of the country. The government and international community have invested in rehabilitation projects to revitalize the natural capital of the ecosystem, but the impact has been negligible. Therefore, identifying which rehabilitation strategies are effective and resilient to drought is essential to implement interventions that will have long-term impact.

My research cannot definitively conclude whether the rangeland rehabilitation interventions had an impact on vegetation cover and drought resilience due to issues with my counterfactual site identification; however, I recommend the following actions:

- Promote controlled grazing strategies, building upon the current momentum to re-establish the *Hima* system within Jordan.
- Conduct a robust impact evaluation to determine whether rehabilitation strategies are truly ineffective compared to other land management practices, or if improvements are masked by unsustainable practices (i.e. rainfed barley cultivation and irrigated agriculture).
- Monitor the rangelands using remote sensing techniques to provide real-time data that can facilitate immediate response to ongoing desertification.

These recommendations build upon the ongoing work and commitment from the government, national societies and international organizations. To further their efforts, stakeholders should leverage the available tools and knowledge to devise effective rehabilitation strategies to rejuvenate the rangelands to ensure food security and resilient livelihoods in the face of climate change.

IX. References

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X. Annexes

Annex A. Google Earth Engine Code

```
var roi= ee.FeatureCollection('users/point/Jordan');
var MIN_SCALE = 1/3;
var MAX_SCALE = 3;
var MIN_NEIGHBORS = 144;

//USGS L7 Phase-2 Gap filling protocol, using a single kernel size.
var GapFill = function(src, fill, kernelSize) {
 var kernel = ee.Kernel.square(kernelSize * 30, 'meters', false);
 var common = src.mask().and(fill.mask());

// Find the pixels common to both scenes.
 var fc = fill.updateMask(common);
 var sc = src.updateMask(common);
 var regress = fc.addBands(sc);
 regress = regress.select(regress.bandNames().sort());
 var fit = regress.reduceNeighborhood(ee.Reducer.linearFit().forEach(src.bandNames()), kernel,
null, false);
 var offset = fit.select('.*_offset');
 var scale = fit.select('.*_scale');

 // Find the secondary scaling factors using just means and stddev
 var reducer = ee.Reducer.mean().combine(ee.Reducer.stdDev(), null, true);
 var src_stats = src.reduceNeighborhood(reducer, kernel, null, false);
 var fill_stats = fill.reduceNeighborhood(reducer, kernel, null, false);
 var scale2 = src_stats.select(".*stdDev").divide(fill_stats.select(".*stdDev"));
 var offset2 = src_stats.select(".*mean").subtract(fill_stats.select(".*mean").multiply(scale2));
 var invalid = scale.lt(MIN_SCALE).or(scale.gt(MAX_SCALE));
 scale = scale.where(invalid, scale2);
 offset = offset.where(invalid, offset2);

 // Apply the scaling and mask off pixels that didn't have enough neighbors.
 var count = common.reduceNeighborhood(ee.Reducer.count(), kernel, null, true, 'boxcar');
 var scaled = fill.multiply(scale).add(offset)
    .updateMask(count.gte(MIN_NEIGHBORS));
 return src.unmask(scaled, true);
};
var source = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
            .filterDate('2017-01-01', '2017-04-15')
            .filter(ee.Filter.lt('CLOUD_COVER', 10))
            .sort('system:time_start', true)
            .median();
           // .mean();
var source = source.select(['B4', 'B3', 'B2']);
var fill= ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
            .filterDate('2006-01-01', '2006-06-15')
            .filter(ee.Filter.lt('CLOUD_COVER', 10))
```

```
        .sort('system:time_start', true)
        .median();
var fill = fill.select(['B4', 'B3', 'B2']);
Map.addLayer(fill.clip(roi), {min:0, max:1, bands:['B4', 'B3', 'B2']}, 'fill')
Map.addLayer(source.clip(roi), {min:0, max:1, bands:['B4', 'B3', 'B2']}, 'source')
var result = GapFill(source, fill, 10);
Map.addLayer(result.clip(roi), {min:0, max:1, bands:['B4', 'B3', 'B2']}, 'result')
Map.setCenter(36.878, 31.367, 6);

//Calculate MSAVI II
var msavi2 = result.expression(
 '(2 * NIR + 1 - sqrt(pow((2 * NIR + 1), 2) - 8 * (NIR - RED)))/2',
  {
  'NIR': result.select('B4'),
  'RED': result.select('B3'),
 });
Map.addLayer(msavi2.clip(roi), {min: -10, max: 10}, 'msavi2');

// Calculate NDVI
var ndvi = result.normalizedDifference(['B4','B3']);
Map.addLayer(ndvi.clip(roi), {min:0, max:0.4, palette: ['CE7E45', 'DF923D', 'F1B555', 'FCD163',
'99B718', '74A901',
  '66A000', '529400', '3E8601', '207401']}, 'ndvi');
var viz = { min:-0.2,max:0.4,palette: ['CE7E45', 'DF923D', 'F1B555', 'FCD163', '99B718', '74A901',
  '66A000', '529400', '3E8601', '207401']};

//Calculate EVI
var evi = result.expression(
 '2.5*((NIR-RED)/(NIR + 2.4*RED + 1))',
{
  'NIR': result.select('B4'),
  'RED': result.select('B3'),
 });
Map.addLayer(evi.clip(roi), {min: -10, max: 10}, 'evi');

// Export the image, specifying scale and region (do for all three VIs)
Export.image.toDrive({
 image: msavi2,
 description: 'msavi_jfm_2017',
 scale: 30,
 maxPixels:1e13,
 region: roi
});
```

Annex B. English Focus Group Discussion Guide

Hello everyone, thank you for being here today. You were identified as a well-informed representative of the community to participate in these discussions, so we appreciate your attendance.

ICARDA: My name is Sarah and this is my colleague Mira. We work for ICARDA Amman office, an international organization that focuses on agriculture and rangelands. Mira will be leading our discussion today and I will be taking notes.

IUCN: My name is Sarah and I work for the ICARDA Amman office, an international organization that focuses on agriculture and rangeland research. I will be leading our discussion today with the help of Enas, a colleague from the International Union for the Conservation of Nature.

RSCN: My name is Sarah and I work for the ICARDA Amman office, an international organization that focuses on agriculture and rangeland research. I will be leading our discussion with help from my RSCN colleagues.

We are here to discuss how the rangelands have changed in the past 20 years and how that has impacted you and your community. We will also collect information on the impact of drought on your household. We will be taking notes throughout the discussion. I expect our discussion will last around an hour. Before we start, here are a few rules:

1. We would like to hear from everyone.
2. Please allow everyone a change to share their opinions and experiences

We will be recording this group, but everything you say will be anonymous – do you agree? Any other questions or concerns? Great, let's start.

1. Can you all introduce yourselves by sharing information about your daily work and if your household owns livestock (number, type, etc.)?
2. What does your household get from the rangeland?
   For example:
   a. *How long can you graze your livestock in the rangeland?*
   b. *Do you collect medicinal herbs?*
   c. *Do you or someone in the community keep bees?*
3. Have you noticed a change in what you get from the rangeland over the past 20 years?
4. How has your dependence on the rangeland changed in the past 20 years?
5. How does drought affect your household?
   For example:
   a. *How did you feed and manage your livestock?*
   b. *Did you water consumption change?*
   c. *Did you change the amount of food you consumed?*
   d. *Did you change the type of food you ate?*
6. Has the impact of drought changed in the past 20 years?
7. Have you noticed a difference before and after the project?

Thank you again for your time. Your answers have been very helpful. We will use this information to improve our Jordan rangeland research. Do you have any questions for me? If anyone would like to speak with me in private, I will stay here after we finish and I will also share my contact information. Thank you again for all your help.

Annex C. Transcription of Focus Group Discussions

Jerba (women) – April 17, 2019

Notes from the IUCN/Resource Equity FGD (relevant to my study)

The rangeland is open to everyone to use

From 1985 – 2011 they used the rangeland and managed it themselves

- In 2011, they replanted 50 dunums with native species

There used to be birds and medicinal plants, but not anymore

The cost of fodder has increased

Men mostly work in the army or the government

Women are teachers and are also involved in agriculture

The community would like to own more livestock, similar to before

- Despite the development of technology, they want to return to their cultural roots

Dependent upon wells – also invest in dams and *hafirs*

MoA should fence the 3,700 dunums for 2-3 years to allow native shrubs to recover

Generally each household has about 20-30 livestock

- Mix of goats and sheep, but more sheep

During drought years, they decrease the number of livestock

- Decrease in meat and dairy products produced
  - Generally, they are not using the wool, even though they know it is possible
- The barley and wheat production also decreases
  - Either irrigate the wheat or buy from the market

9-10 years ago, they could depend more upon the rangeland

Women collect herbs for home and the market

- Highlighted the importance of teaching children the different plants

They have request the development of more reservoirs from the MoA

--beginning of my FGD—

There are no bees and no one has tried to run an apiary

In the spring, they take their animals to an area far away (east) for two months for grazing

- Rainfall is low in the Eastern side – limited vegetation
- Return to the western area that previously lay fallow
  - Used to provide three to four months of grazing

The wheat/barley-cultivated fields are not communal grazing land – it is private land

- Sends a signal to pastoral herders
- Everyone knows their own rights to the land - even if left uncultivated, it is still private
- Owners have papers designating land tenure (name of the person)
- Herders will not graze their animals on the private land

People can rent/buy agricultural land from the owner

- After harvest, the goats and sheep will graze on the residues

If there is a drought or low rainfall, the barley yield is low

The changes in the rangeland are mostly due to the climate and decrease in rainfall

In the past, most of the income came from the animals and their livestock products

- They were considered “full” Bedouins

Regarding climate change, the rainfall has decreased, but the seasons have also changed

- In the past, the snow would come in January, but now it snows in April
- The rain is also delayed, but it continues later in the year (until May)

Dependence on the rangeland has decreased

- The rangeland is no longer sufficient to support the animals

Even 20 years ago, they didn't depend upon the rangelands
During droughts, households plant trees (i.e. olives and other species) and home gardens
- Some people plant vegetables in the desert and pay electricity to pump the water
  - 4.5JD for one hour of water pumping

Households are now more dependent upon agriculture than they were in the past.
- Historically, people planted more barley and wheat and only a few grew vegetables
- Now, people plant more vegetables using water from the community association well

In the past, the water used to be free – now they have to buy the water
- The springs where they sourced free water have dried up

Water is the most expensive part of agriculture production in the community
- Households don't always make a profit
  - Sometimes they do, but if input costs increase, they don't break even

There is a season for all the different vegetables, and periods where there are none
Syrians tend to take less salary, but now they ask for the raises so the payments are the same
[Side conversation about negative feelings about Syrians and the hope they return to Syria]
If there is a drought, the amount of meat and milk products decrease
- Due to the decreased number of animals or the need to purchase those products
- Previously they used to plant wheat, now they have to buy from the outside (market)

Traditional species of wheat were healthier compared to the ones they purchase on market now
In the past, they used to plant everything organically
- Everything used to be natural (they are talking about 50 years ago, not 20 years ago)

Now, lifestyles are unhealthy
- Kids are eating and seating
- Products in the food that are not natural

Bani Hashem (women) – April 18, 2019
Notes from the IUCN FGD (relevant to my study)
The quality of the milk gets better in March
- More native vegetation later due to delayed rains

Women tend to take the animals out and collect the herbs personally
Decrease in the amount of sheep because the fodder was too expensive
Established the association eight years ago (2011/12) and elected leaders
Agreement with the tribal organization to protect the area

--beginning of my FGD—

Mix of participants – three households had between 15-20 sheep
The most benefit from the rangeland occurs in the springtime
- In good years, gather medicinal herbs from the rangeland
  - Chamomile specifically mentioned, but said there are many types

Two people in the community raise bees
- The association trained people on how to raise bees and two of them started a business
- They are producing honey and selling
- There may be others outside of the village with apiaries

Of course there are differences in the rangeland compared to 20 years ago
- The changes mostly depends upon the rain

Three/four years before rain was poor
20 years ago, the rangeland was better than now

The health of the animals was better when grazed on rangeland plants
Also, milk during the springtime (when the animals can graze natural) tastes better
One of the participants sold her animals because it was too expensive to pay for the feed
Used to be able to graze animals in the area
20 years ago, the rangeland provided feed for the animals from February to May (4 months)
Decreased the household expenses
Now, the rangeland can only support the animals for one month (2019 is an exception)
In the summer, the animals have to stay out of the rangeland
1980s-1990s, the rangeland was better due to the rain
The animals and the people depended more upon the rangeland
Decreased the cost of feed
Milk quality was better if the animals are feeding on grasses and shrubs
Animal health was also better – now, animals get sick all the time
The type of diseases are also compared with 20 years ago
Pollution is an issue - the stream used to be clean
Environmental pollution harms the livestock
Animals eat the plastic that people throw in the ground
When there is a drought, households decrease the number of livestock
Requires them to buy more milk products since they no longer produce the products at home
Buy based on the amount of budget available
There have been changes in lifestyle
The cost of food has increased - 10JD doesn't have the same purchasing power
The economic situation impacts the social life
Fewer gatherings since they can't afford to cover the costs of guests
Psychological pressure from the lack of income
Women want to do projects and have job opportunities
Participants highlighted the women who are producing yoghurts and other products
Women can help support the household budget
In their opinions, the protection has been a success for the individuals that have livestock
Allowed to enter a specific area for one month to graze

Qatraneh (men) – April 21, 2019
All participants owned livestock
Overall, the region has a huge value of livestock – more than 80,000 heads
Feed livestock with crop residues and barley
People also plant olives – all dependent upon groundwater irrigation
In 2013, the association was founded and responsible for the rehabilitation interventions
Desire to have associations across the Badia to organize investments
Projects are focused on protection
Results are successful, but there have been plant changes and regime shifts
Two areas of the project – one older and the other is new with total of 200 dunums
Salsolata and *Atriplex* species are planted in the Vallerani pits after the first rain
Generally, the region gets 80-100mm of rainfall
The association has a role throughout the whole project
Identify and develop the site, then an engineer comes in dig the pits
Land is designated by the government
[Solo woman} produces yoghurt, jameed and better from her own livestock
She sells homemade livestock products; generally milk quantity is highest in April

- There is no women's association, but she would like to form one
- The benefit gained from the rangelands varies greatly
  - In times of drought, they open it for 15-20 days
  - In good years, they don't have to buy any imported feed
    - Maximum, it can feed the livestock up to 4 months
    - On average, the livestock can graze for two months (based on rainfall)
- There are medicinal herbs in the rangeland, including chamomile and za'atar
  - The Hashemite Fund is investing in the local variety of za'atar
- They don't raise bees, but sometimes people bring their bees from the north
  - Lack of knowledge on how to raise the bees
- The greatest benefit from the rangeland is the decreased cost of imported feed
  - [Solo woman] stressed that they benefit from the grasses until April/May in good years
- 20 years ago, the rangeland was better
  - Seeds for the shrubs were available
- Now there are more droughts and fewer natural resources are available
  - Used to be more *Atriplex* and *Ratam*, but those are now gone
- People also would move more frequently in the past
  - When the spring started in the north, people would move north
- People are more sedentary now due to work and schools
  - People can now move their livestock wherever they want when they use imported feed
  - No longer depend on the wild plants
- People come from outside to use the pastures – anyone can come if it is government land
  - Forbidden for people to feed on the barley planted on private land
- If there are no guards, they can feed on the natural vegetation
- People are now planting vegetables in plastic houses
- The land needs support from the government
- Cement production destroyed the agriculture area due to the pollution
- The region is dependent on rain
  - If the rain is early, it is not ideal for the seeds, but the rangeland can still bloom
  - If the rain is late, the "spring" is less
- Last year there was a drought (2017) and that impacted the cost of feed
- There is a water source for the community developed by the government
- There is an old reservoir near the village, but they generally use the groundwater
- [Input from Mira Haddad –need to balance groundwater recharge with reservoir construction]
- Different breeds of animals receive different levels of subsidy
- In the spring the animals don't consume as much water
  - They can last for three days without water
- Water comes from Iraq, moves through Jordan and enters Saudi
  - Eastern regions don't benefit from the water that moves through Wadi Serhan
- During drought, food consumption doesn't change (neither the amount nor type)
- There is no milk produced during drought periods
- If they are not producing, they have to buy the product
  - That does change consumption a bit, depending the cost on the market
- Milk produced by animals consuming rangeland vegetation is greater those fed imported feed
- Possible to generate a living from 200 heads of livestock or more
- If the price of feed increases, there is a need for a second income
- The number of livestock has increased now, but the number of owners has decreased
  - If there is no other income, people sell off their livestock and find other work

The benefits derived from the Vallerani project are:
- Feeling of ownership
- Future rangeland vegetation – protect the seeds in the soil
- Wildlife returns to the area

Azraq Village (women) – April 23, 2019

Average of 14/15 heads of livestock per household, with a mix of goats and sheep
Use the milk and other products that come from the livestock
    Specifically milk, milk products, meat, wool and skins
Sell the products for an income
Most households keep sheep, goats and some cows
    House the animals in stables at the family farm
Benefit from the milk directly and also sell it to their neighbors
Goats provide the milk for celebrations, particularly *jameed*, which is in the national dish
In the past, the rangeland benefited by the people by:

- Providing the source of food for the household
- Mining the salt

Rangeland provided sufficient resources for their livelihoods
Overall production of agriculture and livestock decreased due to droughts/desertification
    Reduced from 2,000 heads to 200/300 heads *[check this]*
There has been a trend of decreasing rainfall
There are 1,900 families in the area
    Mainly from two different tribes (*Shishan* and *Bani Ma3roof*)
Desertification/drought dried up the resources so the ecosystem cannot support livestock
    Also issues of water and soil salinization
Nothing is green anymore - this change began in 1998
There is another side, similar to what the colleagues said before
People faced these challenges, but they also had access to other jobs
    No longer possible to live in the same way due to prices - switched to other jobs
    Shift to government jobs or they out-migrated to Amman, Zarqa or other countries
If they leave the agriculture, there is nothing keeping them there
There is another large problem - the groundwater
    There are no clear government policies that the farmers have to follow
Lack of awareness about what type of agriculture is suitable for the climate and soil
People plant what they want to plant – provided an example of olives (not good in Azraq)
Ignorance about the fact that even within the same region, there are differences
    For example, the woman and her neighbor can't plant the same things
We need to return to climate-specific thinking if we want a sustainable future
    We can't just think, I have income and food, etc. now
There needs to be a balance with nature
Think about the future, not just ourselves
Migratory birds might not return and the number fish in the oasis have decreased
    There is no awareness of how to balance environment with agriculture
Most of the past issues were due to the level of education
Working now to convince people to plant *Atriplex spps.*
    Good for the animals' health and milk quality
People should try this before rejecting this as an option

There is a difference between imported feed and the native species
People are now planting tomatoes in plastic houses
    Highlighted health benefits – i.e. for cancer
One woman says she leaves the greenhouse open due to the heat
Not everyone depends upon agriculture and percent that do is slowly decreasing
Even if they don't work in agriculture, they are affected
    The quality and quantity of food available changes
    If the climate changes, the food becomes more expensive, but income stays the same
Results in a decrease in spending for other part of life (example given: vaccines)
Everything in the past was healthy
    Diseases are more now than they were in the past
There is a need to return the environment to the previous state

Azraq Village (men) – April 23, 2019
Most households have between 100 – 300 heads
    The whole region has about 2,000 heads of livestock
Most of them are sheep, but there are also goats
In the spring, they benefit from the gasses and the watering holes (hafirs) fill up
    This year, the are benefiting more than other years
There is a diversity of different grasses that grow in the rangeland
    Wheat, grasses (species that are endemic to here) and poppies
    The quantity of grass is normally medium
Azraq used to be an oasis, which provided water and humidity
    Contributed to the microclimate
There used to always be grasses available in the rangeland
The surface water stayed until 1991 and then most of the oasis dried up
This was a result of the reduction of rainfall and the over abstraction of water
    There was also an increase in agriculture
Rainfall used to be more in the past
People depended upon the rangeland (due to the reasons mentioned before), but less so now
They don't grow the grass in the rangeland, but purchase imported feed from the market
The region is also highly exposed to drought
For 25 years, there hasn't been a rain like the one this spring – this year is an exception!
    New plants have grown and the seed production is high
    Don't expect that there will be another spring like this for many years
There have been multiple initiatives from the Ministry of Environment
- Protection of the rangeland – the protected areas are not enough for the people
- Building of reservoirs in the desert

Due to the drought, people are shifting away from agriculture and moving to the cities
    Also certain plants have gone extinct
Due to the decrease in plants, people also feed their animals crop residues
    Included olives, tomatoes and other agriculture products
Overall, the government is trying to help, but the:
    1. Impact of climate change is high
    2. Soil is becoming salinized
    3. Water supply is decreasing
    3. Government support is decreasing
The MoE is also building reservoirs in the desert

Rangelands, Rehabilitation & Resilience

Difficulty in implementing the initiatives because of the large area
- There was a suggestion to focus on discrete, small areas

The problem is not the grass, but the water
In the south, the rainfall has increased and there are more plants than in Azraq (the East)
- One participant described desertification, particularly where he lives

There are places in the south and north that are now more suitable for livestock
- This year the rains came earlier to the south – October/November
- The area that blooms is larger than the East

The rangeland must provide feed, but also water for the life of the animals
The livestock owners have a problem here
- They also need a water source within 40-60km

If the is rain, there is spring - if there is no rain, the spring doesn't come
When the rains don't come, people decrease the number of animals
- Return to the official watering sources in the Badia
- Nowadays, they bring trucks of water to the animals

If the family depends entirely on the livestock, the impact is greater
People switch their jobs to find opportunities in other sectors
There are positives and negatives
- Negatives – people leave the rangeland
- Positives – develop their different sources of increases

Bedouins used to shift their livestock outside the region and it was the main source of income
Now, most of the Druze (members of the *Bani Ma3roof* tribe) work in the cities
Ministry of Agriculture is not selecting appropriate places for interventions
- People should know the amount of water in order to select the best place

There are huge differences in the microclimates
Also issues with pollution
All the land around Shaumari [the nature reserve] should be like Shaumari
- It is an example of what could be in the future
    - Desertification and drought do not impact the protected area

The problem is in the rangeland – people use it without giving it a time to recover
- The rain that comes to Shaumari comes to the whole region

Require cooperation from the people
- Open the protected area for people to use

If there is investment in the rangeland, there will be benefits
There are no conflicts between the tribes in rangeland use

Annex D. Supplemental Figures

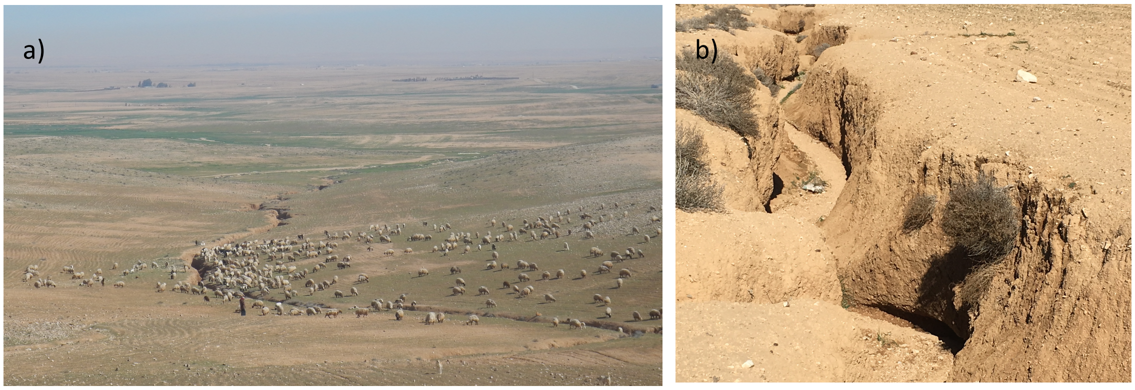

Figure A. a) Sheep grazing on rainfed barley fields (photo credit: Mira Haddad) and b) erosion downstream of barley fields near the Majidyya community, resulting in gully formation.

Figure B. a) Two Majidyya community members, with whom I validated my FGD guide, b) female FGD in Bani Hashem village, c) male FGD in Azraq village and d) female FGD in Jerba village.

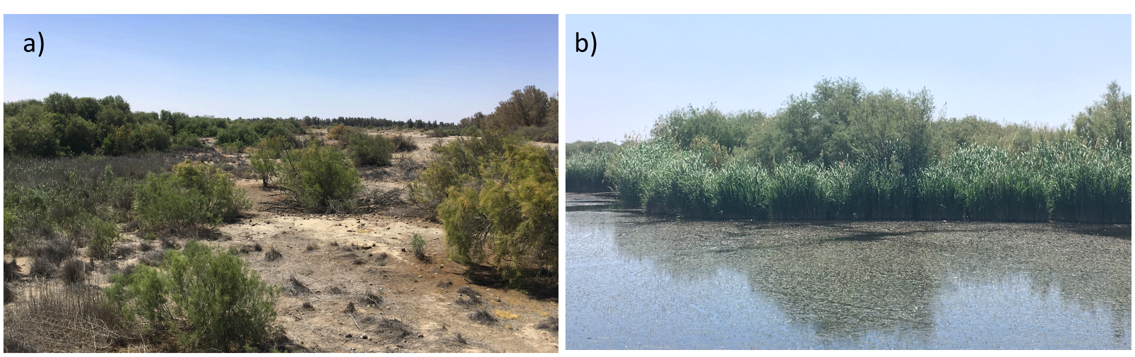

Figure C. a) Dry section of the Azraq Wetland Reserve and b) standing water in the same reserve (May 9, 2019).

Annex E. Resume

PROFESSIONAL EXPERIENCE

Graduate Research Fellow February 2019 – May 2019
International Center for Agriculture Research in the Dry Areas (ICARDA) Amman, Jordan

- Coordinate with internal and external partners to conduct focus group discussions with 40 stakeholders.
- Develop change detection maps to determine the impact of rangeland rehabilitation interventions.

Research Assistant, Department of Technological and Economic Change October 2017 – January 2019
Center for Development Research (ZEF) Bonn, Germany

- Generated comprehensive literature reviews and summarized findings to inform proposal development.
- Reviewed, edited and finalized papers, proposals and working documents for publication.
- Conducted spatial analyses using Geographic Information Systems (GIS) to assess land degradation.

Consultant August 2018 – September 2018
Food and Agriculture Organization (FAO) Amman, Jordan

- Liaised with national partners at the Ministry of Agriculture Research Center to meet project deadlines.
- Analyzed data, edited reports and developed promotional materials for a waste recycling in *Za'atari* camp.

Food Security Specialist at the Food and Nutrition Service September 2015 – July 2017
United States Department of Agriculture (USDA) San Francisco, CA (USA)

- Responded to emergency declarations by providing policy regulations, arranging food shipments and acting as an information conduit between relevant stakeholders.
- Created an innovative food inventory dashboard that was promoted and adopted nationally
- Monitored and evaluated the food distribution and Women, Infants and Children (WIC) state and tribal programs to ensure program compliance and efficacy, leading 5 of the program reviews.
- Provided ongoing technical support to 35 tribal organizations operating a food box program on Native American reservations by deciphering USDA regulations, training staff and coordinating logistics.
- Engaged with a Tribal Workgroup to map the nutrition programs and identify communities, particularly on reservations, with inadequate access to the federal food assistance programs.

Program Associate of International Operations March 2015 – August 2015
Global Communities Silver Spring, MD (USA)

- Supported start-up activities for a USAID-funded agribusiness investment project that totaled ~$21 million in Tanzania, Kenya and Malawi, which aimed to provide loans and training to small and medium business
- Coordinated operational logistics for seven programs, in addition to reviewing reports and evaluations.

English Teacher/Community Volunteer October 2012 – December 2014
Peace Corps Jordan Ma'an, Jordan

- Collaborated with a local NGO to host a nationwide leadership camp that trained 36 girls in nutrition, personal health and community volunteerism.
- Received two grants to implement projects that exposed 47 high school students to geography, critical thinking skills and basic scientific methods as a part of the greater workforce development initiative in Jordan.

EDUCATION

Universität Bonn, MSc. Agriculture Science and Natural Resource Management in the Tropics and Subtropics, est. 2019

Middlebury College, BA in Biology, 2012

American International School of Lusaka, International Baccalaureate Diploma, 2008

SKILLS AND PROFICIENCIES

Languages: Advanced Arabic (reading/writing/speaking) Basic German (speaking), Basic Spanish (speaking)

Trainings: GIS for Disaster Risk Management (United Nations University, 2018), Intercultural Competence (Center for Development, 2017), USA Appropriation Law (Financial Voyages, 2016) and Fresh Produce Safety (USDA, 2016)

Computer: MS Word, Excel, PowerPoint, Publisher, SharePoint, Google Earth Engine, GIS and R