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Jomana ALRwashdeh

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Assessment of the rangeland ecosystem restoration efforts on soil properties and socioeconomic factors in Jordan

Primary Supervisor: András Sabők

Research Assistant

Independent Consultant: Dr Vince Láng

General Manager AgriDron Ltd / Discovery Center Nonprofit Ltd

Benjamin Bukombe

Researcher Discovery Center Nonprofit Ltd

Author: Jomana ALRwashdeh

U5HQWB

Institute of Environmental Sciences/Department of water management and climate adaption

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Contents

1. Introduction

1.1. Background

Rangelands are the most prevalent type of land cover on earth and are categorized as part of the drylands that consist of arable land, savannas, semideserts, grasslands, shrublands and genuine deserts. Drylands cover 41% of the earth's land surface with 2 billion people living there according to estimations (FAO, 2019). In addition, rangelands play a significant role in climate change mitigation, biodiversity, cultural values, supplying services for food and fuel, flood control and carbon sequestration since they can store a massive amount of carbon (Bikila et al., 2016). Rangelands store more than 30% of terrestrial belowground carbon stock in addition to the amount stored in aboveground biomass (Wang et al., 2018). These systems and the people that live in them are extremely vulnerable to ecological and social instability due to the scarce and highly unpredictable resource availability. For instance, 10–20% of drylands deteriorated, furthermore, Indicators of human development and well-being in dryland populations are significantly behind those in the rest of the world (D. Briske, 2017).

Rangeland degradation refers to the gradual destruction of rangeland ecosystems leading to declining biodiversity and productivity and can take place in any climatic zones (D. Briske, 2017). Soil, water and vegetation are the most affected; the area of degraded rangelands in the world accounted for 20 and 73% according to estimations (Stavi et al., 2020). The degradation of the rangelands is similar to the degradation of other land types except that in rangelands there are additional issues such as overgrazing or uncontrolled grazing (D. Briske, 2017).Other man-made activities, for instance, mismanagement of rangeland, natural causes, wildfire, long drought periods, wind erosion and water scarcity cannot be ignored (Hartman et al., 2016). These issues may affect communities that rely on these rangelands for their livelihood. The degradation of rangeland is a serious global issue that has been recognized for many years by scientists, therefore, it is a pressing need to start restoring deteriorated ecosystems and evaluate their impact on local natural resources (Wegner et al., 2018).

Such restoration practices should aim to protect watersheds, combat soil erosion, improve the production of forage and increase the potential sequestration of atmospheric carbon in soils and aboveground vegetation. It has been estimated that the carbon stocks in soils increase by 0.35-3 t C ha^{-1} yr^{-1} under different rangeland management (Bikila et al., 2016). Moreover, establishing on-site water harvesting techniques to retain overland water flow and introducing some soil bioengineering work so can lessen soil erosion. All these practices eventually lead to retaining all minerals and organic materials (plant residues) which enhances plant uptake, growth, and soil quality (Stavi et al., 2020; Wegner et al., 2018). Furthermore, the sink for the hillslopes is also playing an important role in ecosystem restoration, therefore, constructing flood dissipation systems since flash floods are very common in arid and semiarid regions, and these systems should be checked and maintained to prevent their failure.

1.2. Problem statement

Rangeland resources are the primary source of income for rural households. However, environmental and land stress such as overgrazing, cutting of woody vegetation, and low precipitation amounts are considered as sources of rangeland degradation (Blench, 1995) in the Badia region. In addition to, the political tensions in the area, for instance, the Gulf War in 1990 increased strain on the natural resources in the Jordanian Badia (Strohmeier et al., 2021). Therefore, rangelands shall be restored, and their ultimate benefits should be realized sustainably through promoting the formation of groups or cooperatives of rangeland users (Al-Karablieh, 2010). In the past few years, several restoration projects targeting ecological and socioeconomic aspects have been established in the Badia region. The ecological aspect is focusing on improving the productivity of the Badia rangelands by restoring the vegetation structure and composition. Furthermore, restoration practices aim to protect watersheds, prevent soil erosion, and produce forage for local livestock (Hobbs, 2007) .However, the effects of these restoration practices on soils and local remains unclear. Therefore, there is a need for more research focusing on evaluating restoration processes, their impact on soil properties and socioeconomic factors. This study combined field observation and remote sensing data to understand the interaction of rangeland restoration practices, local soil characteristics, terrain features and their influence on vegetation dynamics. Finally, the study evaluated the socioeconomic impact of the restoration activities in southern Badia.

1.3. Objectives

The aim of the study was to assess the efforts of rangeland restoration on soils and socio-economic factors in southern Badia in Jordan. Specifically, the study focused on rangelands in AlHusseiniya, AlHashemieh and AlQatrana districts and the following objectives were addressed:

1. The effect topographic and surface characteristics have on soil properties and vegetation indices.
2. To understand how restoration efforts affect soil properties.
3. To understand vegetation dynamics along soil property gradients.
4. To assess the effect of restoration efforts on socioeconomic factors in the investigated regions.

2. Literature review

2.1. Water harvesting techniques

Water harvesting technique (WHT) is using a device or technology to collect, store or otherwise increase the availability of intermittent surface runoff and groundwater to harness water for beneficial purposes (Beckers et al., 2013). This process naturally takes place when runoff from rainfall is gathered by the topography, for example, in a riverbed or at the base of a hillslope. Water harvesting is an effort to use or duplicate these processes.

Water harvesting techniques (WHTs) have been used and developed in arid and semiarid areas by local farmers to increase crop productivity and boost tree growth by increasing soil water storage, in addition, to minimizing soil erosion by water since fertile topsoil can be driven away resulting in soil degradation, reduce sedimentation, decreasing the effect of drought and minimizing the threat of desertification by lowering the runoff and increasing the infiltration. Furthermore, WHTs are cheap, simple, efficient and adaptable (Al-Seekh & Mohammad, 2009).

Water harvesting techniques are frequently categorized according to the source of the water they collect and are referred to as groundwater harvesting, runoff harvesting and floodwater harvesting (Beckers et al., 2013).In General, Water harvesting systems have four parts Catchments, where water is collected Appropriate catchments, are those where the surface and soil properties are such that runoff is produced frequently, i.e., where the infiltration rates are occasionally lower than rainfall intensities. Secondly, is Conveyance, Conveyor systems focus and direct runoff that has been collected from catchments to the storage facilities (Oweis, 2017).

The storage facility is the third part; There are many different types of storage facilities, including open reservoirs created, for example, by a dam or retaining wall, (sub-)surface cisterns and natural sediment bodies. Storage facilities serve as a buffer between the long dry months when water is needed and the brief rainfall and runoff events when natural water is delivered (Beckers et al., 2013). Finally, the target is the consumer of the gathered water. The targets can be either residential and drinking water, irrigation, husbandry, or both depending on the quality and quantity of the available water (Beckers et al., 2013). Contour embankments or contour bench terraces (Figure1) are mainly for harvesting runoff and soil erosion monitoring. Shrubs and trees are planted on the upslope side of the terraces, some disadvantages of this method require earthworks which can be done by heavy machineries, such as bulldozers, scrapers, and graders these machines remove the surface soil or A horizon to smoothen the space between the terraces which can degrade the soil, reducing germination vegetation and soil's seed bank. Using this method should ensure that storage capacity is for a minimum of 10 years for sediment accumulation (Stavi et al., 2020).

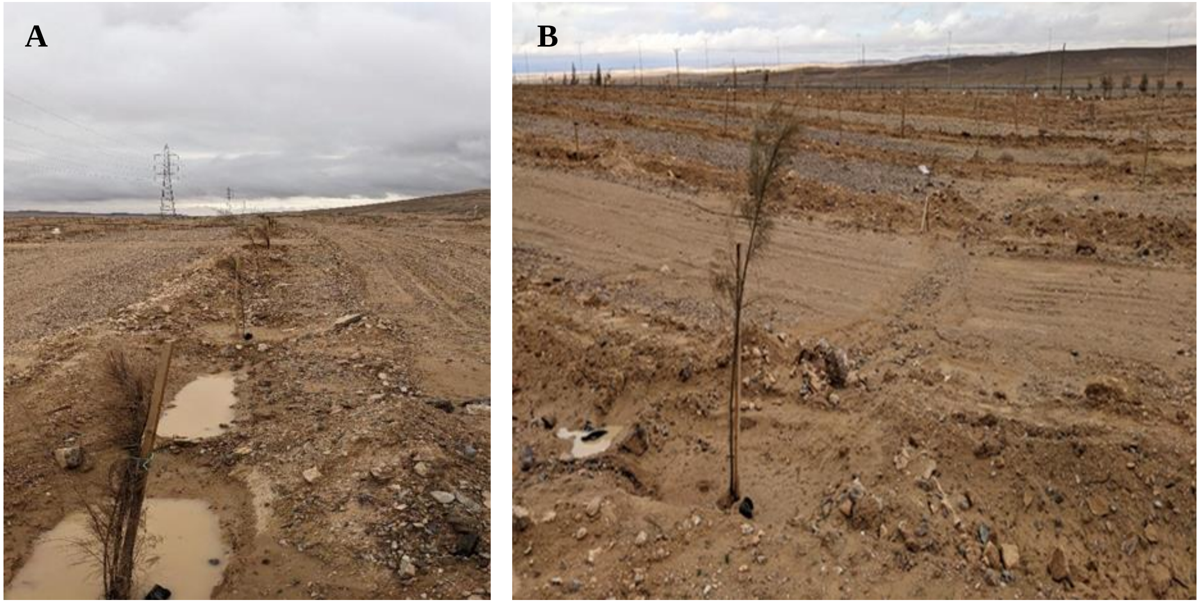

Figure 1. A and B represent contour bench terraces or contour embankments in AlQatrana, Jordan. (Photo by: Discovery Center team / 8 February 2023).

Traditional Stone terraces (Figure 2) are rarely used currently since it requires much physical effort starting from collecting the stones arrange them in a stable and uniform shape, according to studies stone terraces lower the runoff by 65%-85% and sedimentation by 58%-69%, mainly used in the hillslopes of mountainous arid regions (Al-Seekh and Mohammad 2009). This method is also utilized in the cropland fields not only in rangelands but due to the extreme removal of the stones to build them. It is estimated that the sheet and rill erosion have increased three-fold (Nyssen et al., 2007).

Figure 2. Traditional Stone terraces (Sluis, Kizos, and Pedroli 2014).

Rock contour berm systems (Figure 3) were established in the hillslopes of the rangelands in the southern areas of the United States through the mid 20 century for slowing runoff and minimizing erosion. It can be single, double or multi-line berms and the spacing between the stones is 15-30 cm (Stavi et al. 2020).

Figure 3. Single rock contour berm, Arizona, USA. (Stavi et al. 2020).

Pitting runoff harvesting systems are utilized in many drylands, for example, in Iran, Spain and croplands in western and eastern Africa with different pits depth and width dimensions, planted with different types of vegetation, such as maize, millet and sorghum (Jahantigh & Pessarakli, 2009; Stavi et al., 2020).

The micro-catchment technique includes the development of small structures or shallow basins in mild land slopes to collect and store overland flow (Ali et al., 2010), has been applied in many arid areas, such as restoration projects in the Jordanian Badia and planted in fodder shrub species to increase quality and quantity of forage such as A. halimus and Salsola vermiculata L (Stavi et al. 2020). The micro-catchment technique can also be used on steeper slopes with some adjustments like blocking them by constructing a series of counter-parallel bunds or agricultural terraces. The contour bench terrace is a prevalent style of agricultural terrace in the Petra region (Beckers et al., 2013).

The Macro catchment runoff harvesting; Systems that collect runoff from larger catchments, such as steep hillsides induced runoff that occurs in a hillside's higher regions may percolate or evaporate before it reaches cultivated or populated areas. Runoff loss can be significantly decreased by creating conduits (ditches or dikes) in the upper and middle portions of the slope. Water is typically delivered to agricultural areas using hillside conduit systems. The runoff is occasionally transferred to nearby wadis (an Arabic term for valleys or transient waterways) to supplement terraced wadi systems. Due to the quantity of outcropping bedrock in Petra, Jordan, (Figure 4) the locals discovered good conditions for runoff gathering, particularly for drinking water reasons. Here, a variety of intricately carved conduit systems for the runoff collected it and directed it to cisterns (Beckers et al., 2013).

Figure 4. Conduit systems in ancient Petra, Jordan. (Photo by: Discovery Center team /10 February 2023).

Hafirs (Figure 5) are open water basins that are semicircular and used for both animal and human usage, typically constructed at the base of plan-concave slopes using earth embankments. And occasionally in broad wadis or floodplains.

Figure 5. Hafir in AlHashemieh region, the southern Badia of Jordan. (Photo by: Discovery Center team /9 February 2023).

Contour ridge or furrow systems (Figure 6) are extensively utilized in the Jordanian Badia because of their low cost and reasonable cost of maintenance it has been reported that this method one of the most efficient methods in arid and semi-arid areas decreased the total amount of runoff by 73%, and enhancing growth of forages, for instance, saltbush protein-rich fodder and drought resistance species (Atriplex halimus L.) and grasses on the gentle and steep incline. Using single-blade, moldboard-plough or disk plough to make ridges or bunds with spacing 5m - 20m between lines (Al-Shamiri & Ziadat, 2012).

Figure 6. Contour ridges in the southern Badia of Jordan. (Photo by: Discovery Center team / 9 February 2023).

One of the simplest methods to restore degraded rangelands is to utilize plant residue, scrubs, branches and brushes as a barrier or a sink and make different structures out of these natural tools, the decaying process for such materials leads to an increase in soil organic carbon stock, increasing soil nitrogen content in case they contain leguminous twigs and shrubs. In addition, they offer cover for herbaceous vegetation so animals cannot feed on them, allowing them to grow and disperse their seeds and increase biodiversity. Logs also can be utilized on the hill slopes lines to monitor sheet and rill erosion (Stavi et al., 2020). Nylon meshes are mainly utilized in rangeland degradation in gentle slopes to effectively control water runoff and soil erosion and increase the productivity of herbaceous vegetation. It consists of nylon stripes with a 4 mm width woven strongly together. However, using such methods is expensive and has an adverse impact on the environment (Stavi et al. 2020).

Runoff harvesting systems should be appropriately planned, as restoration processes should eventually provide geo-ecological feedback and restore eco-hydrological functioning, boosting pasture productivity and maintaining rangeland carrying capacity (Stavi et al. 2020).

2.2. Rangeland soils

Rangeland systems and the ecosystem services they provide are critically dependent on the features and functions of the soil. Rangeland soils have a huge variety and are affected by three main functional groups of organisms, biological soil crusts, plants, species, spatial patterns, composition and the soil microbial community. Through their impact on soil structure, soil carbon, water, and nutrient availability (D. Briske, 2017) .Rangelands are highly vulnerable to changes in precipitation patterns, heat and atmospheric carbon dioxide. Therefore, healthy soils are the key to resilience under these varying conditions (D. D. Briske et al., 2006).

Vegetation cover is essential for preserving soil resiliency, Changes in the vegetation composition that are frequent on rangelands are greatly influenced by the soils (Bestelmeyer et al., 2003). Especially given how vulnerable rangeland vegetation is to soil deterioration. For instance, the woody plant increases soil aggregation stability, total N, mineralizable N, available calcium and surface soil C. Arid sites typically accumulate more carbon than wetter sites. However, this is highly influenced by the shrub species, soil bulk density (greater bulk density is associated with more carbon loss) and clay concentration (more clay content is associated with higher carbon accumulation) (D. Briske, 2017). Shrub encroachment in arid ecosystems may enhance soil surface water using a combination of hydraulic lift and decreased evapotranspiration (Gill & Burke, 1999). On the other hand, in some areas, shrub encroachment typically results in a patchier vegetation cover, which increases soil heterogeneity, decreases water penetration and increases plant interspaces' vulnerability to erosion, especially during droughts (D. Briske, 2017).

Topography also affects the distribution, size, and density of woody vegetation. South-facing slopes in the Northern Hemisphere are generally less covered in woody plants because they are warmer and drier than north-facing slopes (Bailey, 1998). Furthermore, upslope sections of the landscape may not support as many large-sized woody plants as downslope areas because runoff from slopes concentrates water and nutrients in downslope areas and increases incoming precipitation (Coughenour & Ellis, 1993).

Grass and woody plants have distinct adaptations to take advantage of the resources in the soil. In both life forms, the root mass falls exponentially with depth, however, woody plants often have larger roots at greater depths and greater maximum rooting depths. Deep, coarse soils that allow for easy percolation and nutrient leaching are preferred by woody plants. On shallow soils where bedrock or claypan layers limit taproot expansion, they are at a disadvantage. Many woody species have both deep taproots and shallow, laterally widespread root systems. This reflects a generalist approach to capturing soil resources that enables them to make use of infrequent little amounts of rainfall and the nutrients concentrated in the topsoil layers (D. D. Briske et al., 2006). Biological soil crusts are made up of cyanobacteria, lichens, mosses, fungi and algae that mix and combine with surface soils to form a cemented matrix (D. Briske 2017). Biological soil crusts have complicated and varying effects on soil stability and surface hydrology. They improve infiltration by increasing porosity and micro-topography, but they can also increase runoff because they secrete hydrophobic chemicals and plug soil pores when they become wet (Rodríguez-Caballero et al., 2013). In the majority of dry rangelands, biological soil crusts have long been recognized as essential elements of biogeochemical cycles. Ecosystem C cycles are influenced by autotrophic organisms found in crusts and the primary supply of N for many arid ecosystems can be N2 fixation by crust organisms (Pietrasiak et al., 2013). According to studies, biological soil crusts globally are thought to be responsible for about half of terrestrial biological N2 fixation and 7% of the net primary production of terrestrial vegetation (D. Briske, 2017).

Rangeland soils' microbial diversity is still not well understood, however, with recent developments in molecular and bioinformatics tools this is quickly changing. Despite low microbial biomass, recent studies have found unexpectedly high bacterial diversities (An et al., 2013). This diversity is described using DNA-based, culture-independent methods, such as profiling bacterial populations by sequencing the 16S gene. Site-specific factors often determine the makeup of soil bacterial communities, but Proteobacteria, Bacteroidetes and Actinobacteria are among the phyla with the highest abundance. Increasing C: N has also been seen to improve total bacterial richness (An et al., 2013).

Pore structure, mineral surfaces and water-holding capacity are local environmental factors that affect habitat quality and have an impact on microbial composition. While environmental conditions are unfavorable for their activity, dormant organisms in the soil can still be found using DNA-based methods. Yet, by focusing on the active members of the microbial community, RNA-based techniques offer a more practical approach. This is a crucial distinction to make in rangelands because short-term pressures like water scarcity or extreme heat can cause the active microbial community to differ significantly from the dormant, and thus the entire community (D. Briske, 2017). According to research by soil experts, drying soils decreases microbial activity while fast rewetting them boosts respiration rates. Rewetting dry soil could increase CO_2 generation by up to 500% over constantly moist soils (Fierer & Schimel, 2002).

2.3. The geography of Jordan

Jordan Or the Hashemite Kingdom of Jordan is a small country of about 89,342 km^2 (8.94 million ha) located in the west of Asia, it is a middle eastern country one of the so-called levant countries (Jordan, Lebanon, Syria and Palestine) and has been known for its stunningly beautiful scenery and archaeological sites. It's about 80 km east of the Mediterranean Sea between 29◦11 - 33◦22 north, and 34◦19 - 39◦18 east (Al-Qinna et al., 2011). According to the Department of Statistics, Jordan's population is about 11 million, with approximately 4 million living in the capital Amman. Jordan has 12 governorates which are Irbid, Ajloun, Jerash and Mafraq all are in the northern part of the country. Amman, Balqa, Zarqa and Madaba are in the middle and the southern governorates Karak, Altafilah, Ma'an and Aqaba.

There are three major rivers in the Kingdom: the Jordan River, the Zarqa River and the Yarmouk River and two seas the Dead Sea, which is the lowest point on earth almost 400m below sea level (N. Tarawneh, 2007), and the Gulf of Aqaba with about 180 km long (Al-Trabulsy et al., 2011).

The country has three physiographic Region: Highlands receive an ample amount of precipitation including snow and extend from the north to the south in the western part of the country, for instance, the northwest of the country with a sub-humid Mediterranean climate receives the highest annual precipitation (400-600 mm), almost 90% of the population is settled in the western part of the country (Mustafa & Rahman, 2018). Jordan's Rift Valley a small area to the west of the highlands is the second zone, and it is mostly used for agricultural production because of its high fertility and warm winter climate. The third region is the Badia with nearly (80%) of the country it covers the whole eastern part of the country and is an extension of the Arabian Desert, with average rainfall below 200mm (Al-Qinna et al. 2011).

2.4. The Jordanian Badia

The Jordan Badia covers almost 81.3% (72.660 km^{2}) of the Hashemite Kingdom of Jordan, the Badia is divided into three geographical areas: The northern Badia comprises 25930 km^2 (35.7%) the middle Badia with 9634 km^2 (13.3%) and the southern Badia accounts for 37096 km^2 (51%), and the climate it is arid with an average annual rainfall of 150-200 mm, the temperature fluctuates for the minimum reaches -5 ºC in the cold season and maximum 46 ºC in summer and the average temperature is 17.5 ºC (Al-Homoud et al., 1998). Badia is the home of Bedu (The nomadic), almost 116 tribes live there, Badia is not exclusively for Jordan it extends to neighbouring countries such as Syria, Iraq, and Saudi Arabia and covers 55%, 75% and 90% respectively, of their lands (Haddad et al., 2022). The majority of Badia people work in browsing and Livestock production, commerce, the armed force, and Agriculture, for instance, barley is the main rainfed crop, whilst wheat, forage, vegetables, and fruit (orchard) are irrigated (Al-Homoud et al. 1998). Agriculture in Badia generates about 90 million JOD (Jordanian Dinar) in annual revenue. Sheep account for the majority of the livestock in Badia, making up about 85% of the total. Al-Awasi sheep in particular, which are well-adapted to the Jordan Badia's habitat, fall under this category. By producing milk, meat, and wool, sheep and goats are significant sources of income (HFDJB, 2014)[1].

Jordanian Badia is home to various types of fauna and flora 220 vascular plants were recorded. Moreover, different other species were noticed for the first time, and several endangered animals were observed, for instance, Golden Jackal (Canis aureus), sand cat (Felis margarita) and Syrian wolf (Canis lupus). In the Heart of the eastern desert protected wetland named Al Azraq, the oasis contains freshwater pools and springs essential habitats for wildlife, especially migratory and resident birds, it is considered the main eco-tourism destination in Badia (Disi et al., 2004). For instance, in northern Badia 73 medicinal plants and herbs were reported to be used as a remedy for various ailments by the locals (Alzweiri et al., 2011).

In addition, Badi holds natural resources including mineral deposits above and underground, adequate for overall development requirements, In terms of mineral resources Badia region, plays a significant role in supporting Jordan’s national economy, for instance, Basalt widely spread in

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[1] The Hashemite Fund for Development of Jordan Badia

northeastern Badia is covering approximately 70% of its land, as basalt has resistance to weathering, also to corrosive chemicals, therefore, it had been used for building ancient castles in the Region such as Qasr Alzraq and many more castles and forts, nowadays it's rarely used for construction. Furthermore, Scoria (Pozzolana) it's a potential component for the cement industry, it is added for two main reasons; as a corrective material for the iron content in the cement to produce Portland cement and as an additive material to standard Portland cement 10-30% by weight and producing Portland pozzolanic cement (K. Tarawneh, 2022), Zeolites are a group of hydrated alkali aluminotektosilicates and because of their unique structure, it has been used as soil amendments, gas and oil purifications and industrial and municipal wastewater treatment (K. Tarawneh 2022). Moreover, there are large quantities of bentonite, chalk, copper, diatomite, dolomite, gold, gypsum, oil shale, limestone, sand, silica, volcanic tuff, zircon, and phosphate all over Badia (Figure 7).

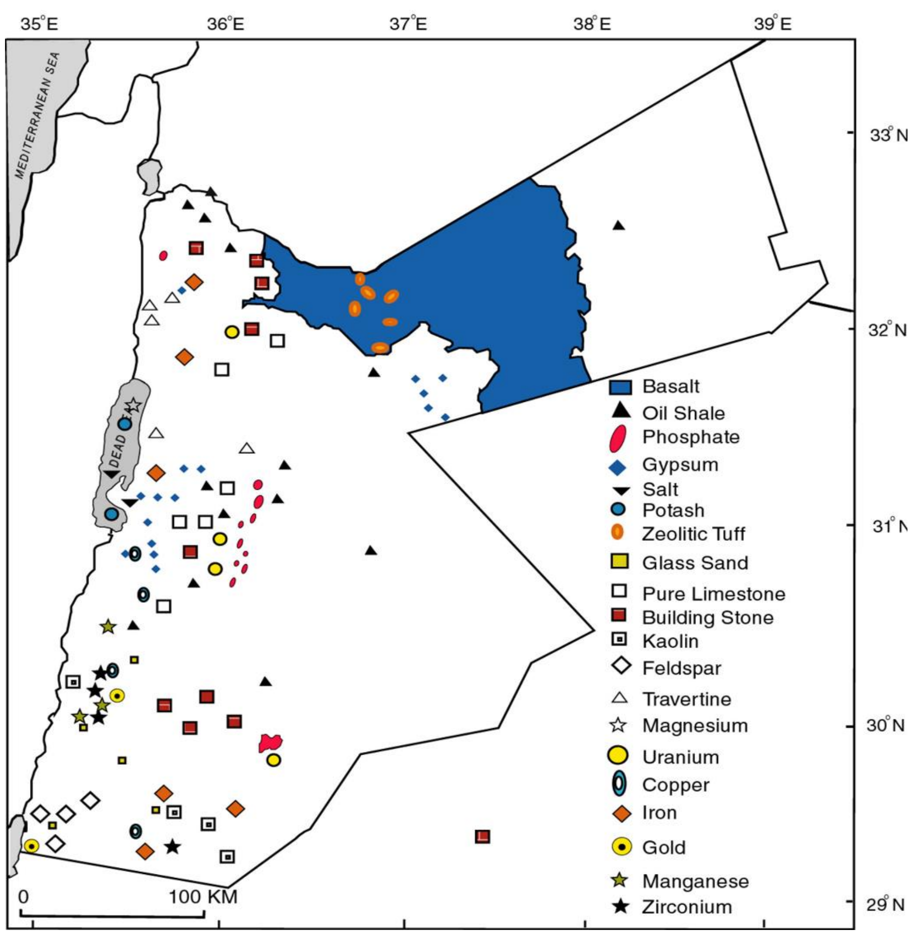

Figure 7. Distribution of minerals in Jordan. (Alnawafleh et al., 2013).

The Jordan Badia contains the Kingdom's principal surface water and groundwater basins, the total watershed area in the Badia is made up of 67,000km^2, Moreover, the most important basins are Al-Azraq basin (18,375 km^2) which provides water for agriculture and drinking purposes to adjacent areas and Al-Disi aquifer (7181km^2) which supplies drinking water to Amman through a water conveyor. In addition, 3500 groundwater wells are distributed throughout Badia. Hence, improving Jordan Badia's surface water and rainfall use is crucial and will have an impact on the region's overall development, since the total utilized and harvested water is 90MCM (million cubic meters) annually out of the total rainfall amount which is 5 to 7BCM (billion cubic meters) annually according to records (HFDJB, 2014). 95% of Jordan's population settles in fertile lands with an annual rainfall range above 200mm, this causes extra pressure on the resources and infrastructures there, accordingly, Badia development and utilization becoming top priorities and its consequences if it succeeds lead to positive impacts on the national economy and improving the living conditions for the Badia residents ~ 400,000 constitutes 6.5 of the Jordanian's population (Haddad et al. 2022).

2.5. The Badia Restoration Projects

In order to make the Badia region a desirable location for settling down, the Jordanian government began a project known as "Sedentarization of the Nomadic" in the 1960s. By providing Bedions houses, pastures, and digging artesian wells. The first Bedouins settlement projects were carried out in southern Badia precisely Tal Burma, in Al-Husseiniya and Al-A'arja in Al-Muhammadiya in 1961 as a cooperation between the Natural Resources Authority and the Federal Republic of Germany. Where 1000 donums (100 hectares) had been divided into agricultural units, 25 donums (2.5 hectares) each, for instance, Tal Burma divided into 40 agricultural units to grow fields crops and trees. 1975 the project came under the supervision of the Ministry of Agriculture. The ministry started to train some of the residents to be professional farmers, and although some of them faced many obstacles at the beginning, eventually they got used to it as they can be able to meet their families' necessities through regular wages, furthermore, social cooperatives were established and in 1967 artesian well was excavated 2km to the west of AlHusseiniya (HFDJB, 2014).[2]

[2] The Hashemite Fund for Development of Jordan Badia

The Badia Restoration Program (BRP) is another project which took place in the northeastern Badia region, In June 2005 the Governing Council of UNCC (United Nations Compensation Commission) granted $160.582.073 million to Jordan to restore and rehabilitate the damaged terrestrial ecosystems due to the influx of the of refugees with their livestock during the gulf war (1990-1991) ~ (1.8 million head of sheep, camels and goats). The main purpose of the Badia Restoration Program is to enhance the ecological productivity of the Badia ecosystems for wildlife and sustainable grazing, by returning the vegetation structure and composition, allowing the wildlife population to rebuild, and providing a base for sustainable grazing practices throughout the whole Badia area. 13-15 years were the full implementation phase to achieve the aforementioned goal (Ministry of Environment, 2010).

The Jordan Badia Ecosystem and Livelihoods Project (BELP), the world bank and the global environment facility granted the Jordanian government the sum of US$3.33 million. BELP is one of four projects which were held in the regional MENA Desert Ecosystems and Livelihoods program (MENA-DELP). The project's main objective is to capture and harness the value of the desert ecosystems to create opportunities for the Badia citizens and make their livelihoods more resilient amid climate change to optimize the flux of services and goods for sustainable development in the desert (World Bank, 2016). The project targeted three poverty Pockets in the Jordanian Badia, one in the northern Badia called Al Ruwaished in the Mafraq governorate and the rest in southern Badia, which are Al Jafr and Al Husseiniya in the Ma’an governorate. For the implementation period started in January 2013 until June 2017 (around 4 years), the project partners were the National Agriculture Research and Extension (NCARE), the Hashemite Fund for the Development of Jordan Badia (HFDJB) and the Royal Society for the Conservation of Nature (RSCN) (Team 2018). The adaptive rangeland management and Alternative Livelihoods are the second project component which was held in two sub-districts in southern Badia AlJafr and Al Husseiniya for the sum of US $1.43 million (World Bank, 2015). The project was undertaken to establish two Hafirs for animal drinking and fodder, in addition, the foundation of three range reserves in 3 different locations with a total land area of 3000ha to be managed by the local communities in a Sustainable, biodiversity and friendly manner. The rehabilitation of 3000 ha in AlHusseiniya (653 ha) and AlHashemieh (854 ha) range reserves and the Bayar (1525 ha) range reserve in AlJafr.

In AlQatrana, a rangeland reserve known as Alhamath rangeland reserve was established in 2014 with a total land area of 2000 donums (200 hectares). In 2017, another rangeland reserve known as Glateh 1 had been established, and in 2019, this rangeland had been extended and known as Glateh 2, with a total land area of 2500 donums (250 hectares). The rangeland reserves were planted with Atriplex halimus L, by utilizing Contour ridge or furrow systems. The three rangeland reserves are managed by a local cooperative.

3. Material and methods

3.1. Study sites

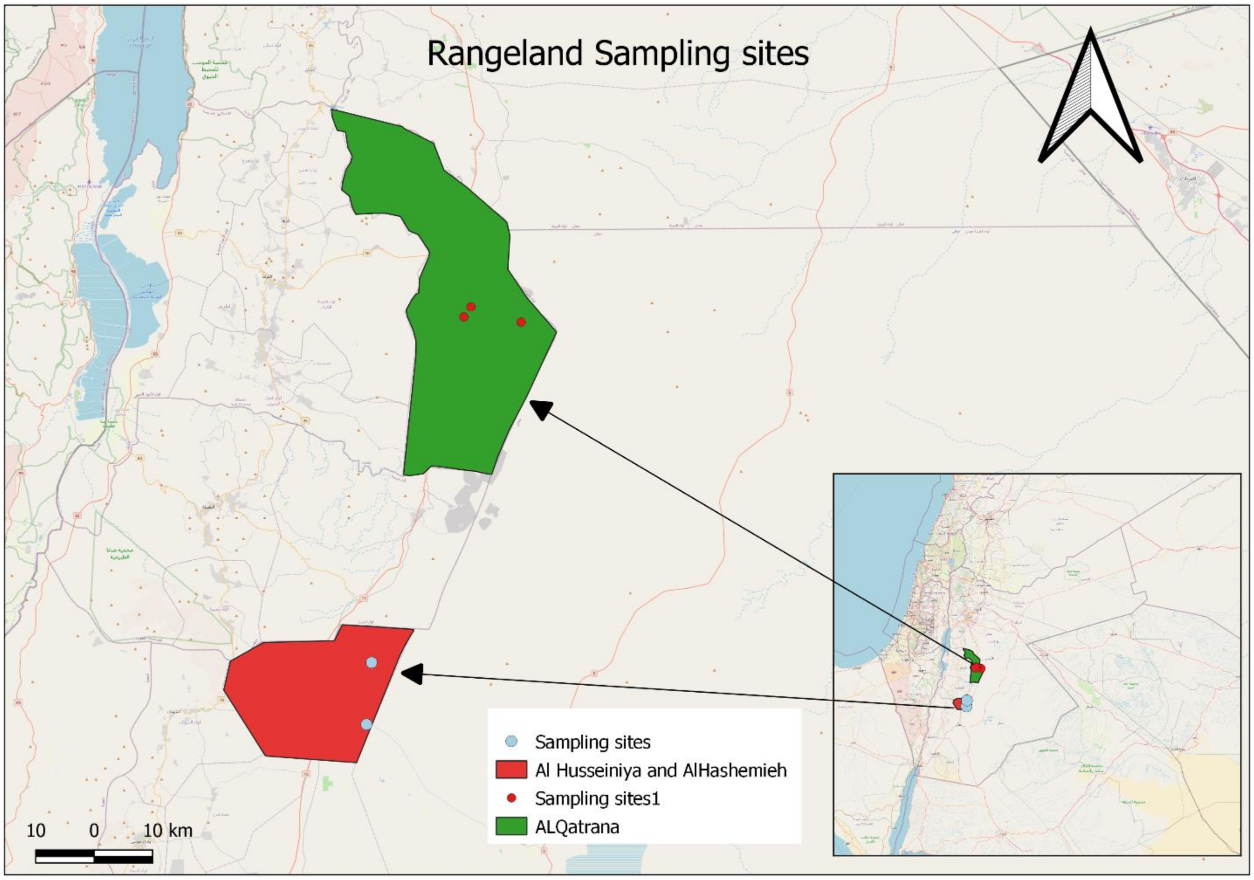

Figure 8. An overview map of the study area with sampling sites.

This study was conducted in the South Badia region in Jordan (Figure 8). Specifically, the sites were located in ALQatarna, Al Husseiniya and AlHashemieh. In our study, we focused on southern Badia as it occupies (51%) of the total area of the Badia region in Jordan and it has recently received attention from the international research community, making it an ideal site for this study. The climate in Badia is classified as arid and often described as a desert-like environment. This type of climate is characterized by a broad range of temperature variations, with summer temperatures exceeding 42 ˚C and winter temperatures falling below 0° C. The Mean annual precipitation (MAP) is 50 mm, the average evaporation is 341mm, and the humidity is 45% (NCARE, 2015)[3]. Rainfall season in Al Husseiniya and AlHashemieh sites starts in

[3] National Agricultural Research Center

December and lasts through March, while on rare occasions it may begin as early as October and extends to April. Early rainfall patterns (October and November) rarely have substantial depths or lengths and do not result in runoff. However, the rainfall season (April- May) is sometimes intense. When it occurs, it takes the form of thunderstorms and results in significant runoff. The impacts of climate conditions on agriculture, and rangeland, with significant effects on pastoral operations (HFDJB, 2014). The topography in Al-Husseiniya and AlHashemieh is classified as gentle sloping land with the major slope class, ranging from 0-5% covering more than half the area to the moderate slope class of 5-10%. Field information shows that the soil is stony to very stony clay loam and silty clay loam with weak fine subangular blocky structure, highly calcareous and saline.

The total area of the sites investigated in AlHusseiniya rangeland reserve (30.59507°N,35.88539°E) is about 653 hectares and AlHashemieh rangeland reserve (30.48696°N,35.89969°E) is about 854 hectares. These sites have received funds from international organizations such as the World Bank which funded the Jordan Badia Ecosystem and Livelihoods Project (BELP). According to field observation, some sites are bare soils (Figure 9).

Figure 9. Bare rangeland reserve in a restoration site in Al Husseiniya. (Photo by: Discovery Center team /9 February 2023).

AlQatrana site's topography ranges from 3-8% and is classified as having a moderate slope class. The site's soil is sandy clay loam to silty loam, and average rainfall amounts range from 70 to 80 mm. Unlike the two other sites, the restoration activities in AlQatrana (31.1164°N,36.0878°E) were successful (Figure 10).

Figure 10. Successful rangeland reserve restoration in AlQatrana. (Photo by: Discovery Center team / 8 February 2023).

The dominant vegetation in the rangeland sites is Atriplex halimus and it is saltbush natively growing in arid and semi-arid regions in the Mediterranean basin, and the western Asian region, including Jordan, in the eastern and southern parts of the country, on altitudes less than 900 m. Atriplex is mainly used as livestock forage Shrubs of A. halimus since it is providing feed that is high in nitrogen (3–4% of the dry mass). Moreover, it has a lot of protein (14–21% crude protein) found that compared to other fodder species, such as alfalfa, the crude protein content, digestibility, and nitrogen retention were higher (Bhattacharya, 1989). In addition, Atriplex is favored by the locals because of high water use efficiency and high salinity tolerance are associated with the C4 metabolism, and its capacity to generate substantial amounts of dry matter even in extremely dry conditions (Gharaibeh et al., 2011; Walker et al., 2014). A. halimus is a 3 m tall perennial shrub with branches growing from the base. Its bark is a grey-whit colour (Figure 11. A), and its leaves are 10-30 mm long and 5-20 mm broad (D. J. Walker et al. 2014). Vesiculated hairs on the surface of the leaf are a distinctive feature of A. halimus. These hairs release salt and absorb water from the air, and when they burst, they leave salt on the leaves' surface, (Figure 11. B) (Gharaibeh et al., 2011).

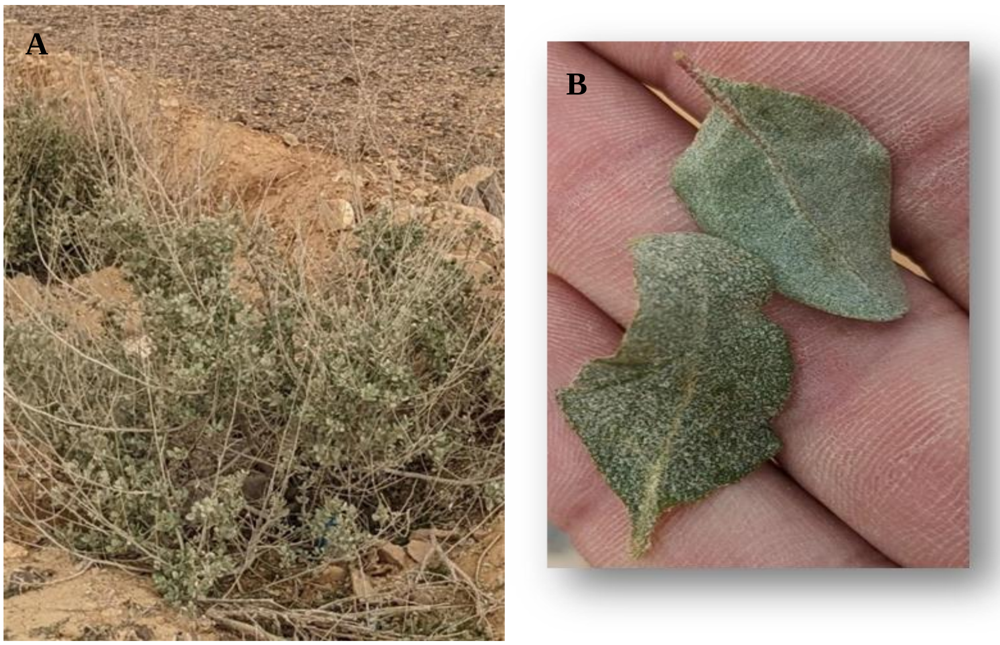

Figure 11. A. The Atriplex halimus shrub. B. Salts deposition on the leaves surface of Atriplex halimus. (Photo by: Discovery Center team /9 February 2023)

It grows on neutral or alkaline soils (pH 7.0-11.0), which are frequently saline (electrical conductivity, EC, of a saturated soil paste > 4 dSm^{-1}), in open, sunny locations. It is more active on loams and less active on sandy or clay soils (Walker et al., 2014). A. halimus occasionally draws water from below the vadose zone. It develops long, main roots and secondary roots that enable water absorption from deep soil layers (down to 5 m), while a dense network of small, shoot-borne roots may absorb moisture and nutrients after rain (Guerrero-Campo et al., 2006). A. halimus can resist temperatures as low as -10 to -12 °C, attributable to its moderate cold tolerance. A. halimus can withstand field temperatures below freezing (as low as -18 °C) corresponding favourably with the accumulation of soluble sugars, amino acids, quaternary ammonium compounds, and the ions Na^+ and K^+ in the leaves (Walker et al., 2008).

3.2. Data collection

3.2.1. Soil sampling and analysis

In February 2023, a field campaign was conducted to assess vegetation health, topographic features, and soil mineralogical characteristics of the investigated rangeland sites. Before sampling any specific site, detailed information was collected including: GPS coordinates and locations (rangeland name, sampling points along the contour lines, and between contour lines). Furthermore, sites were divided into reference and restored sites. Soil samples were taken in trenches developed as a water management practice and between trenches along the Catena slope.

A total of 11 homogenized soil samples weighing 1 kilogram each were taken from each sampling location in the top 30 centimeters of the soil surface. However, due to logistical issues, the soil sample was decreased to 200 g only.

From each soil sample, several soil parameters representing the chemistry and geology of the sites were measured using standard methods described in (MSZ EN ISO/IEC 17025:2005) at the SoilChem Agricultural and Environmental Analysis Laboratory (Nemzeti Akkreditáló Hatóság, 2019). The measured parameters include soil pH, exchangeable cations (Ca, K, Mg, and Na), humus and electric conductivity (EC), calcium carbonate content, gypsum, copper (Cu), zinc (Zn), and manganese (Mn). Furthermore, available nutrients were measured including phosphate (P), potassium (K), and nitrogen (N). Specifically, the soil pH was measured using the following protocol (MSZ-08-0206-2:1978 2.1. szakasz), pH determined by 1M potassium chloride (KCl) as (A. Wang et al., 2019) described.

Soil salinity was determined for each sample. Here, the term "soil salinity" refers to the overall salt content in the soil solution, which is the aqueous liquid phase of the soil and its solutes, and includes charged salts such as Na^{+}, K^{+}, $Mg2^{+}$, $Ca2^{+}$, Cl^{-}, HCO^{-}_{3}, NO^{-}_{3}, $SO_4^{-\,2}$, and CO_3^{-2} (Corwin & Yemoto, 2020). Soil salinity was measured based on soil Electric Conductivity (EC), using the following protocol (MSZ-08-0206-2:1978 2.4. szakasz).

Soil exchangeable cations (Ca, K, Mg, and Na) were measured using flame atomic absorption spectrometry – FAAS (Isaac & Kerber, 1971). Micronutrients such as Cu, Zn and Mn were measured using the FAAS method as described in the following protocol (MSZ 20135:1999 5.2. szakasz).

Calcium carbonate content was measured using the gas volumetrics technique (Ashworth, 1997). Humus in soil was determined using the spectrophotometry technique, which is easy and quick compared to other techniques for measuring soil organic matter (Javanshah & Saidi, 2016). Soil N has been assessed by measuring the two forms of nitrogen NO_3^- and NO_2^- and using the 2M KCl method (Mulvaney, 1996). Soil available K and P were determined using the following protocols (MSZ-08-0213-1:1978 MSZ 1484-3:2006 6. Fejezet) and (MSZ-08-0213-1:1978 ISO 15923-1:2013 F melléklet) respectively.

3.2.2. Social and economic data

In February 2023, we visited and interviewed the head of the Livestock breeder AlQatrana Agricultural Cooperative, who provided us with data about the livestock number in AlQatrana and the cooperative's primary activities. The following data were collected during the interview: number of active members, running projects, number of livestock managed by the cooperative and members of the cooperative, etc. The detailed information was then compiled and summarized for descriptive statistics.

3.2.3. GIS and remote sensing data analysis

To understand land surface properties and characteristics as well as their relationship with vegetation dynamics. a series of GIS and remote sensing data were used. First, high-resolution multispectral images (0.5m x 0.5m) data were collected from Pléiades satellite to assess the vegetation survival rate at each site. Second, a high-resolution Digital Terrain Model (DTM) (6 m x 6 m) was collected from NEXTMap® Elevation Data to assess land surface characteristics. Using an RGB band the number of plants was calculated per site as an indicator of plant survival rate. To do this, a grid of 20 m x 20m was drawn in the image and then digitalized the number of plants present in each grid. In the second part of the data processing, major topographic indices that are known to influence vegetation soil property dynamics were derived on a 20-meter resampled DTM derived from the high-resolution one. Topographic indices included in the analysis are topographic position index (TPI), slope length, slope steepness factor (LS-factor), relative slope inclination (slope), relative slop position, terrain aspect (aspect), and profile and plan curvature, terrain aspect, and valley depth. Furthermore, three indices representing surface mineral chemical characteristics (Xu et al., 2023) were derived from medium-resolution multispectral images from the Landsat mission. These mineral indices were used because they shape the chemistry of the local landscape and are part of the local pedogenetic processes. Surface mineral indices included are Clay Mineral Ratio (CMR), Ferrous Mineral Ratio (FMR), and Iron Oxides ratio (IOR) (Figure 12).

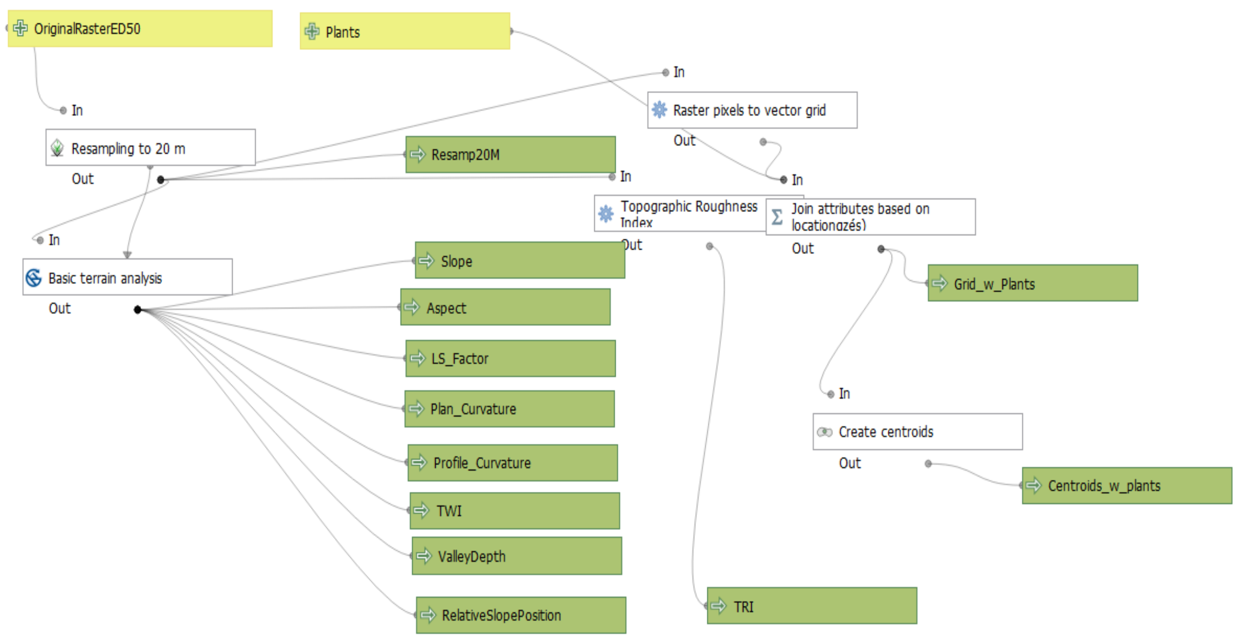

Figure 12. Model pipeline describing Land surface characteristics derived from Digital Elevation Model.

3.3. Data analysis

To assess differences in the distribution of soil chemistry (pH, total salt, humus, $CaCO_3$, P_2O_5, K_2O, NO_3^--$N^+NO_2^-$-N, SO_4^{2-}—S, Na, Mg) as well as differences between plant survival rate and the relative soil chemistry, collected data were analyzed for differences between trenches and within trenches positions as well between investigated sites. Summary statistics and data are presented as means per plot. For differences between investigated factors, an Analysis of variance was used. For this, the Shapiro-Wilk's test for normality test and Levene's test for homogeneity of variances were conducted. Where the tests showed that requirements of normality distribution and homogeneity were not met, the non-parametric Kruskal-Wallis test as an alternative to one-way ANOVA was used using R (Giraudoux et al., 2023). For a post-hoc pairwise comparison of significant differences in soil chemistry and plant survival rate between the three sites, and between positions in this case within trenches and between trenches positions the Dunn's test was conducted using the 'rstatix' package (Kassambara, 2021).

To assess the relationship between plant survival rate and land surface characteristics, a generalized linear regression model (GLM) was conducted using the glm function with family set to poisson. All statistics were conducted using R software (Team, 2009).

4. Results and discussion

4.1. Meteorological data

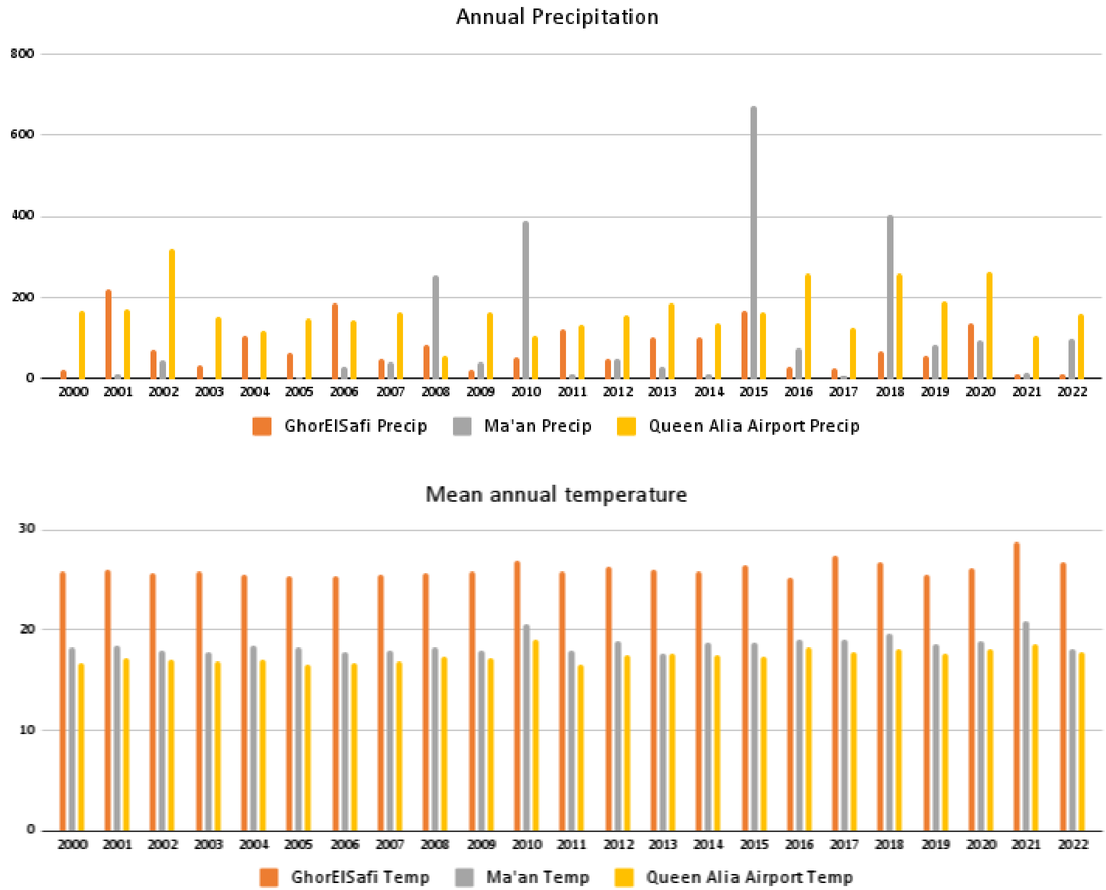

Figure 13: Distribution and patterns of annual precipitation and temperature for the three rangeland reserves investigated in this study (Arabia Weather 2023).

(Figure 13) shows the mean annual precipitation and mean annual temperature in meteorological stations near the study sites AlHashemieh, AlHusseiniya and AlQatrana for the past 22 years. Evidently, AlQatarna site had the highest mean annual precipitation compared to the AlHashemieh and AlHusseiniya sites. While the mean temperature was slightly higher in AlHashemieh and AlHusseiniya compared to AlQatarna.

4.2. Total elements concentration and distribution across the sites

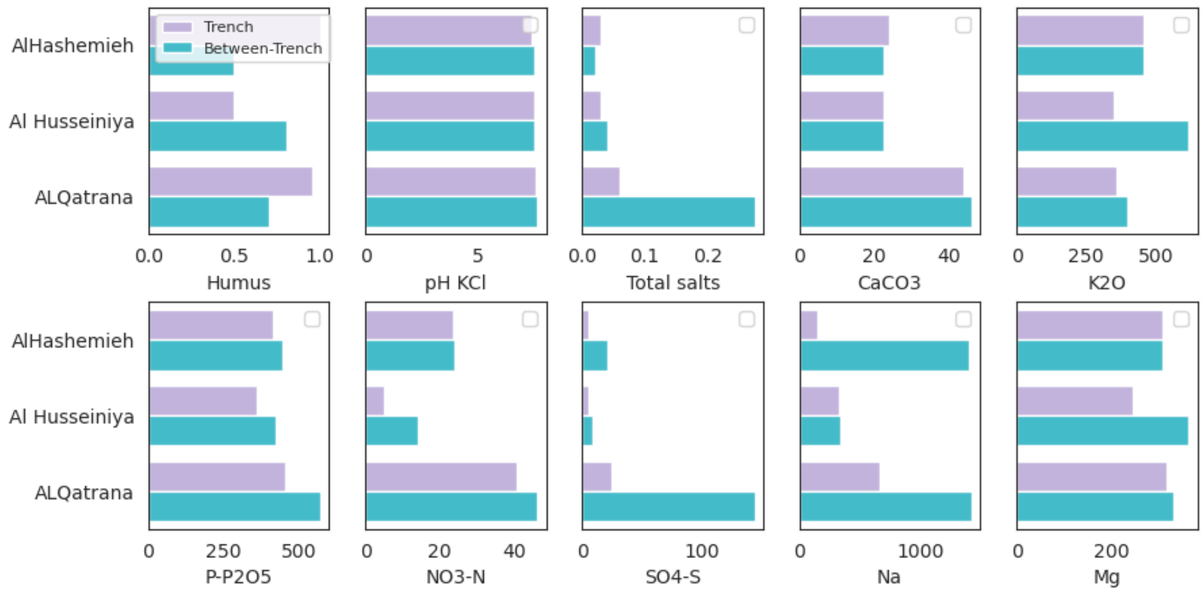

Figure 14. The distribution of soil total elements in the three rangeland sites grouped by sampling position.[4]

The figure represents the distribution of the elements in the three rangeland sites AlHashemieh, AlHusseiniya and AlQatrana, regarding the humus content ALQatrana and AlHashemieh in trench position had the highest value of humus with almost 1%, while pH values do not significantly differ between the three sites with an average pH value 7.5. AlQatrana site between-trenches position had 5 times higher total salts than AlHashemieh and AlHusseiniya sites. When compared to AlHashemieh and AlHusseiniya sites, AlQatrana site's calcium carbonate measurements were also higher in both positions in the trenches and between the trenches. Potassium (K) and phosphate (P) concentrations were found to be relatively high in all three locations, but AlHusseiniya site between the trench position had the highest value of K with 616.5mg/kg. Phosphate (P) concentration distribution was also nearly the same in all three locations and positions, with AlQatrana site between the trench having the highest concentration of P. The distribution of nitrogen concentration varied significantly between the three locations, with AlQatrana between trench having the highest concentration and AlHusseiniya trench having

[4] Note that one bar of the position is a composite of five samples mixed together before laboratory measurements.

the lowest. The sodium (Na) concentrations had shown significant variation, with 1690.776mg/kg in AlQatrana site and 1404.76 mg/kg in AlHashemieh site, and between trench position having the highest concentration of exchangeable sodium. In terms of gypsum content, AlQatrana site between the trench position had the highest concentration compared to AlHusseiniya and AlHashemieh. Unlike sodium, Magnesium was distributed fairly evenly throughout the three sites, with the maximum concentration being at the AlHusseiniya site between the trenches position (Figure 14).

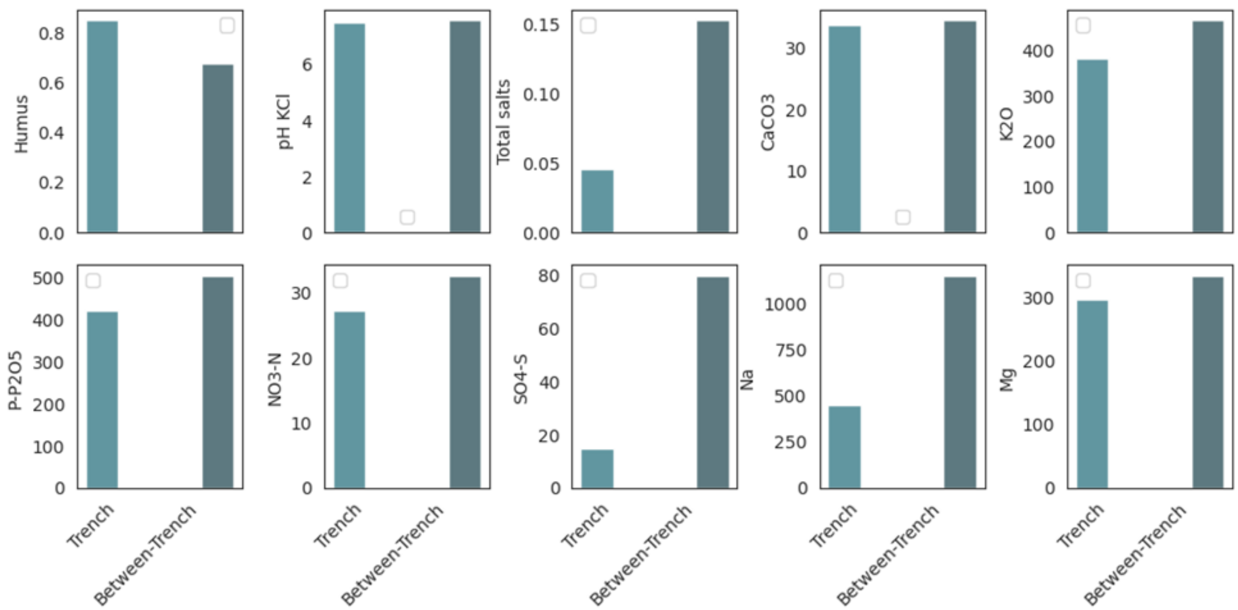

Figure 15. The distribution of the soil total elements by position[5].

The figure demonstrates the distribution of all soil elements between trenches and in trenches positions. For example, humus concentration is higher in the trenches position compared to the between the trenches position, while pH values had not significantly changed between the trenches and in the trenches positions. In contrast, the total salt percentage showed higher salt accumulation between trenches positions. As for the carbonate content, it had been found that the concentration of CaCO3 does not significantly alter between trenches or in trenches positions (Figure 15). Potassium (K), phosphate (P) and Nitrogen (N) concentrations were all found to have relatively the same concentration both in trenches and between trenches positions, gypsum

[5] Note that all data for the AlHusseiniya, AlHashemieh and AlQatrana are combined.

content was 4 times higher in between trenches position compared to in trenches positions. Between trench positions, the position had the highest concentration of Sodium. Regarding magnesium concentration, it was found that there is no significant difference in Mg concentrations between trenches compared to trenches positions (Figure 15).

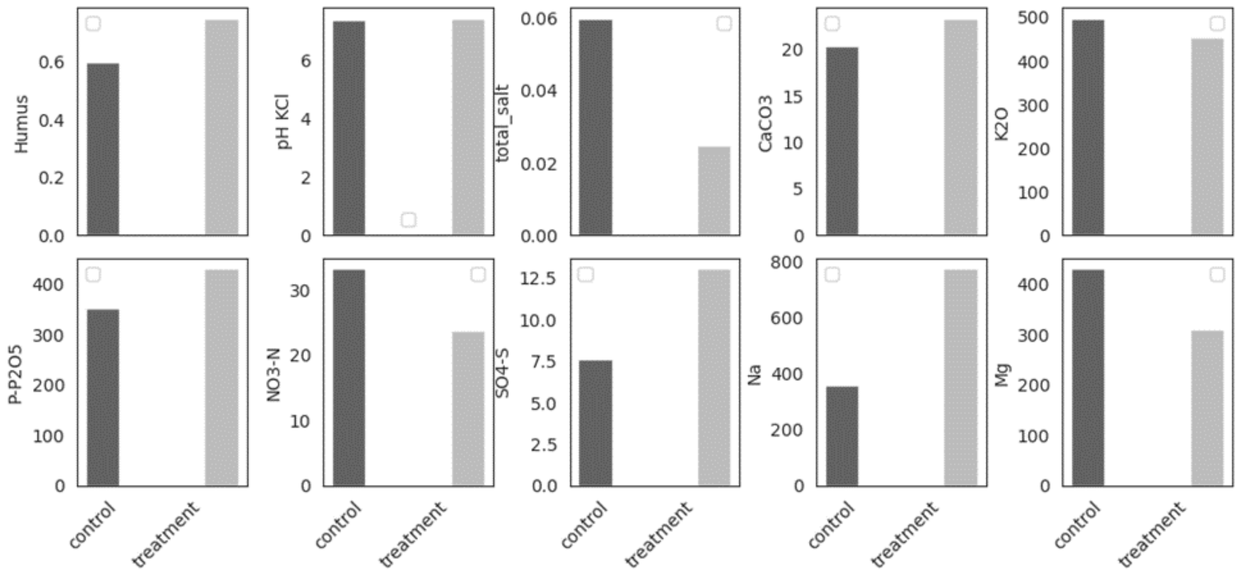

Figure 16. A comparison of the total soil elements between reference and restored sites.[6]

The figure illustrates the distribution of all elements between restored and the reference sites. As compared to the reference sites, it was found that restored sites had higher humus concentrations. However, neither location's pH values had dramatically changed. It was found that the reference areas had significantly accumulated more salts compared to the restored areas, regarding the carbonate and gypsum content it is found that the restored sites have more $CaCO_3$ and gypsum.

Whereas P concentrations were higher in restored sites, potassium (K) and nitrogen (N) concentrations were higher in the reference sites. Evidently, the sodium concentrations were 2 times higher in the restored sites than it is in the reference sites, unlike Mg which had the highest concentrations in the restored sites (Figure 16).

[6] Note that "control" sites represent reference sites and "treatment" represents restored sites.

4.3. Terrain surface characteristics

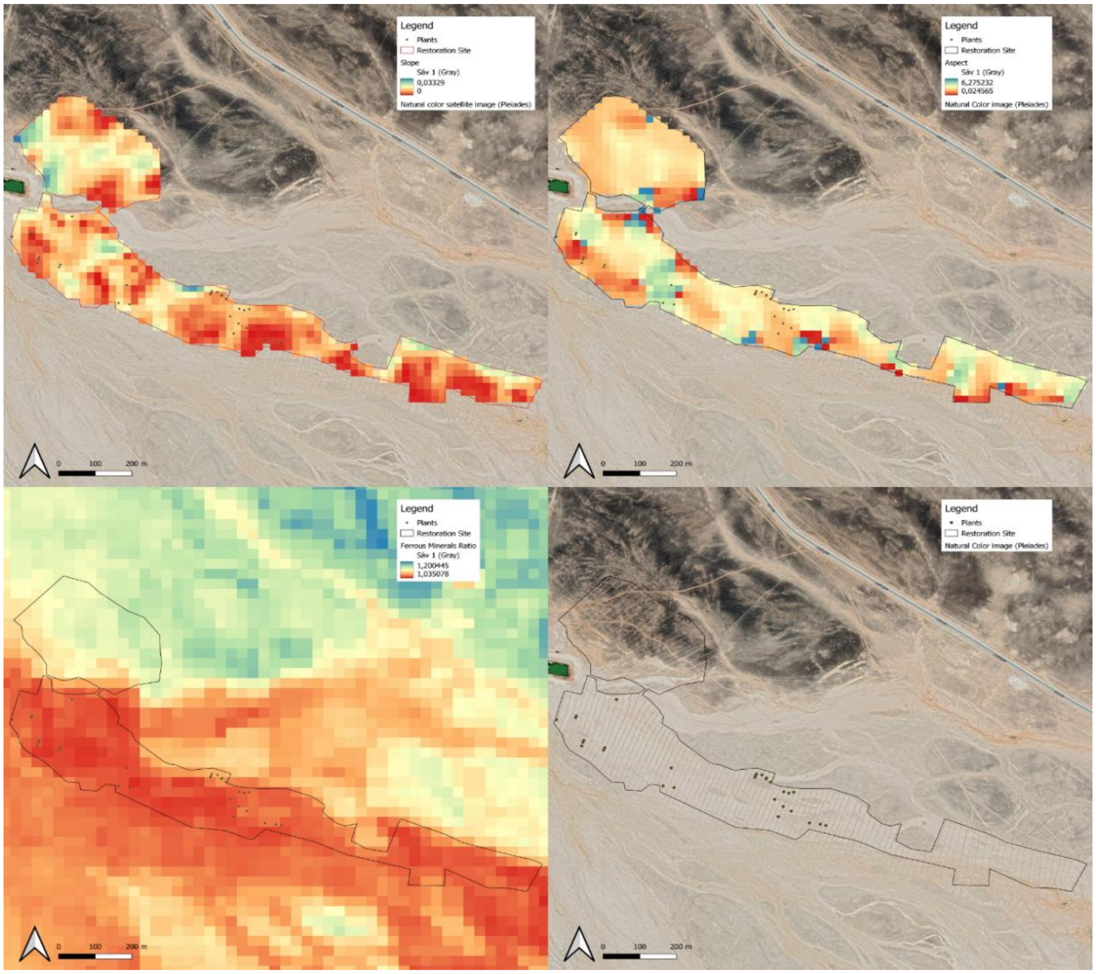

Figure 17. Topographic indices for AlHashemieh site which include slope, aspect, FMR (Ferrous mineral ratio) and plant counts.

When comparing surface characteristics derived from the digital elevation models and satellite images, the data shows that mineral and surface characteristic features significantly differed between the three investigated sites. Ferrous mineral ratios, and clay mineral ratios were higher in AlQatrana, compared to AlHashemieh and AlHusseiniya (Figure 17-19). Furthermore, plant survival rate followed the same trend with higher plant survival rate in AlQatrana compared to its counterparts AlHashemieh and AlHusseiniya (Figure 17-19; Table 1).

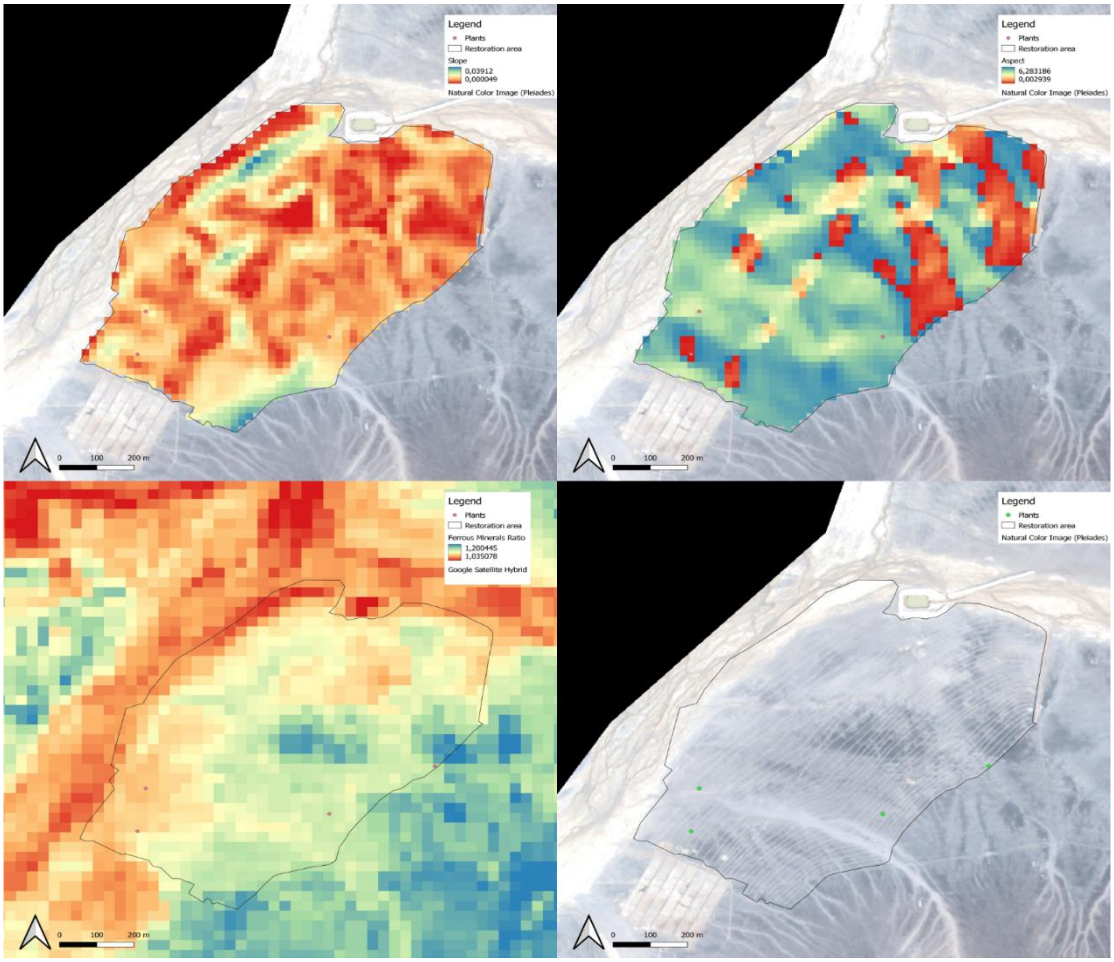

Figure 18. Topographic indices for AlHusseiniya site include slope, aspect, FMR (Ferrous mineral ratio) and plant counts.

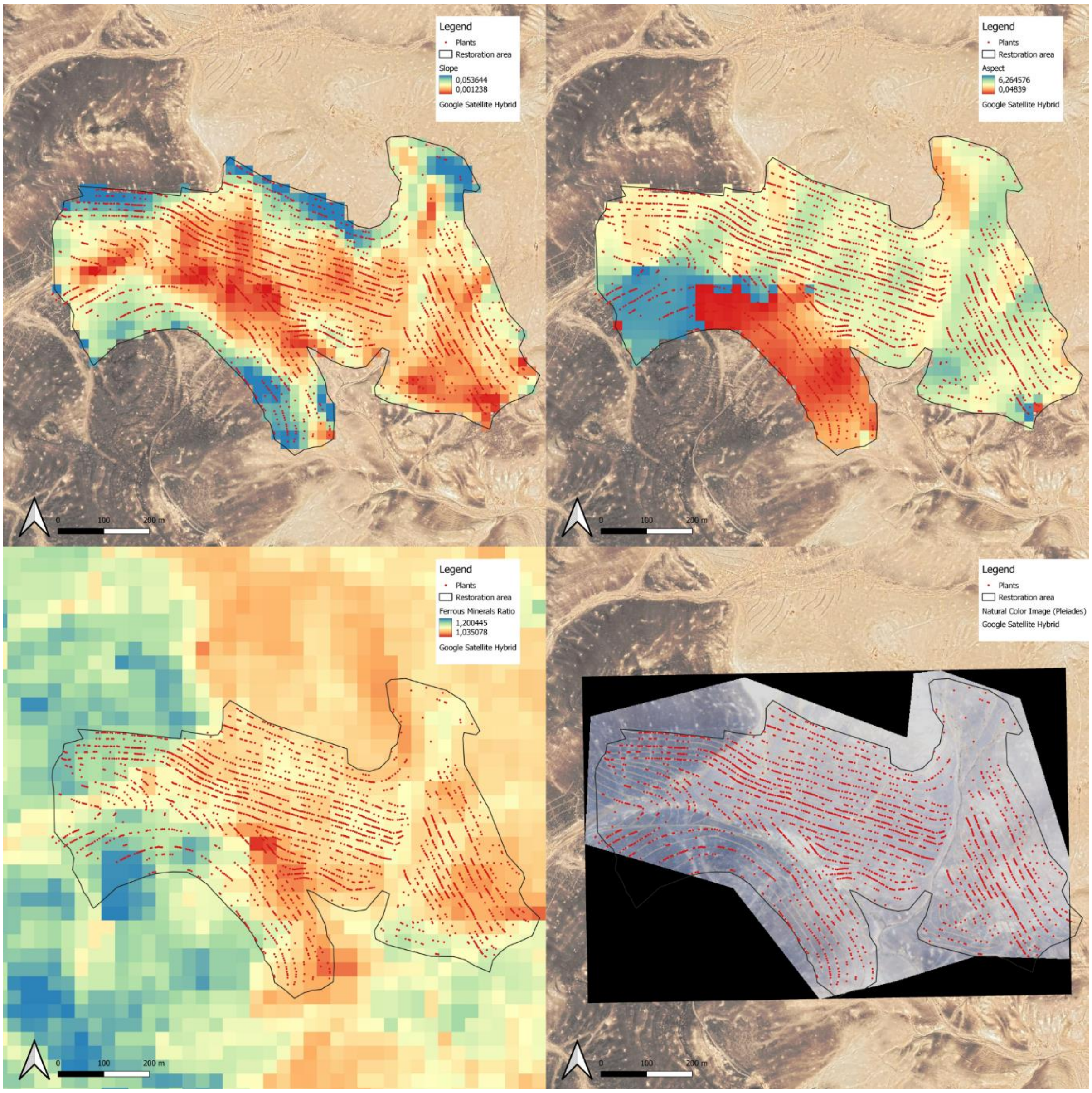

Figure 19. Topographic indices for AlQatrana site include slope, aspect, FMR (Ferrous mineral ratio) and plant counts.

Table1.Statistical results of the Generalized linear model used to assess the relationship between land surface characteristics and plant survival rate. Note that for independent variables data was normalized.

Variables	Coefficients	std err	z	P> |z|	[0.025	0.975]	R2
Elevation	-53.5797	1.949	-27.484	0.000	-57.401	-49.759	0.79
Relative Slope	7964.6743	1092.547	7.290	0.000	5823.321	1.01e+04	
Valley Depth	164.5006	16.521	9.957	0.000	132.121	196.880	
Aspect	9.5758	17.765	0.539	0.590	-25.243	44.395	
TWI	24.1623	30.240	0.799	0.424	-35.107	83.432	
Slope	6.026e+04	1.2e+04	5.005	0.000	3.67e+04	8.39e+04	
Plan Curvature	2.038e+04	1.36e+04	1.498	0.134	-6279.684	4.7e+04	
LS Factor	-2936.4708	810.315	-3.624	0.000	-4524.659	-1348.282	
Profile Curvature	-8511.8895	1742.175	-4.886	0.000	-1.19e+04	-5097.289	
TRI	-616.6628	89.363	-6.901	0.000	-791.810	-441.515	
CMR	963.1719	2109.316	0.457	0.648	-3171.012	5097.356	
IOR	1.417e+04	679.431	20.862	0.000	1.28e+04	1.55e+04	
FMR	1.614e+04	2076.261	7.774	0.000	1.21e+04	2.02e+04	

The findings from the generalized linear model (GLM) revealed a strong relationship between surface mineral characteristics, topographic data and plant survival rate (Table1). For example, the data shows a significant decrease in plant survival rate with elevation. In contrast, slope-related features such as relative terrain slope, valley depth and terrain aspect and plan curvature showed a positive relationship with plant density rate (Table1). Furthermore, indices representing surface minerals such as clay mineral ratio (CMR), iron oxides ratio (IOR) and the ferrous mineral ratio (FMR) revealed strong positive effects on plant survival rate.

4.4. Social and economic contribution of the rangeland restoration

Data from the interview shows that the cooperative in AlQatrana site was established in 2014 and the total number of members is currently 145 who have joined the cooperative since its establishment. Most of the members are livestock breeders and local people living in AlQatrana region. Each member is required to pay a one-time 150 Jordanian dinars (JOD)~ (200 Euros) to join the cooperative (Table 2). Note that AlQatrana region has the highest number of livestock in Jordan (Figure 20).

Since its founding, the cooperative has taken on several projects, such as establishing the three rangeland reserves with the assistance of the National Agriculture Research and Extension (NCARE), which was in charge of the scientific aspect of the rangeland reserves, including selecting the appropriate locations and topography, soil analysis, and establishing 8 construction of improved water storage structures (hafirs). Furthermore, the management of three reserves is carried out successfully and focused on sustainability, by preventing overgrazing through hiring guards who allow only the members of the cooperative to graze in the range land reserves. Also, there are legal sanctions against those who breach the restrictions. In case of drought events like the years 2020 and 2021, the cooperative took the responsibility to irrigate these rangeland reserves, with mobile water tanks once per month, the total capacity of the tank is 14m^3 and costs 25JOD ~ (33 Euros)/ tank, additionally, these rangeland reserves have given residents 12 full-time jobs. As a result, ALQatrana rangeland reserves have been described as one of the most successful rangeland reserves in Southen Badia.

Table 2. Data about the cooperative.

Number of Members	Participation fees	Full-time job opportunities	Seasonal job opportunities
145	150 JOD~200 Euros	12	4-5

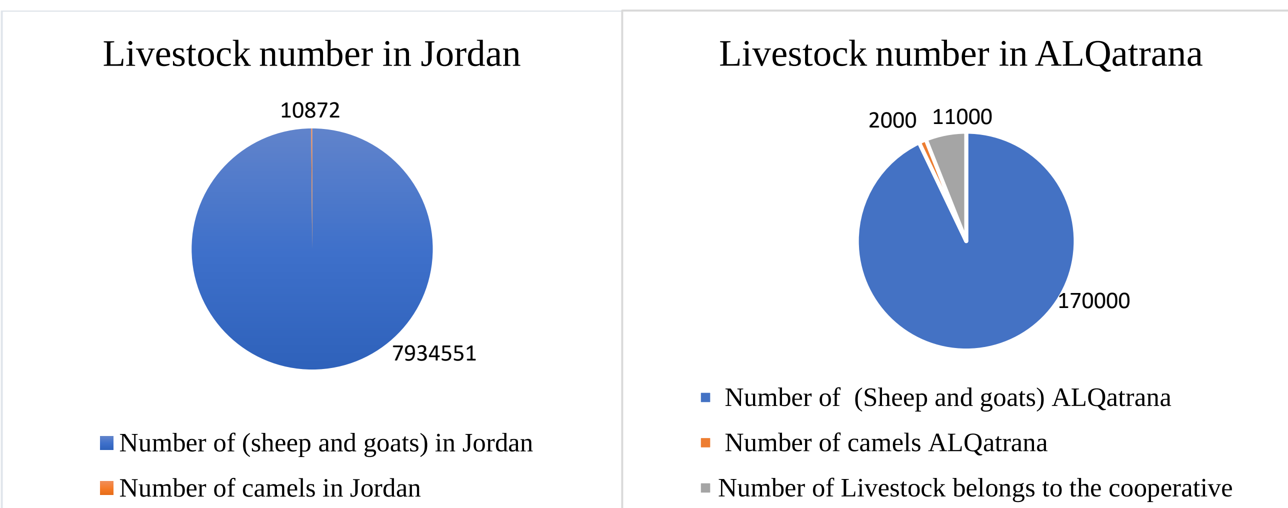

Figure 20. Illustrates livestock numbers in Jordan and AlQatrana. (Livestock Report, 2020) (Ministry of Agriculture 2020).

Moreover, the cooperative bought agricultural machinery and sheep, in addition to establishing the livestock market and providing the livestock breeders with the necessary medicines and vaccines for the cattle. The cooperative and NCARE are running an experiment for the first time by planting a new species of wheat imported from the United States, by utilizing a piece of land of approximately (12 donums) (1.2 ha), which was given to the Bedions under the project “Sedentarization of the Nomadic”, and the land is being planted with wheat upon the landlord's approval. It is claimed that the new specie has higher productivity, for instance, 110 kilos of seeds should produce 1 ton of wheat. The wheat is flood-irrigated, and urea is applied every 35 days and it’s expected to be harvested in May 2023 (Figure 21). The cooperative intends to launch more projects, some of which are already under construction, including a dairy product factory and an initiative to collect and purchase wool from livestock breeders, rather than be discarded, at modest prices for distribution to Jordanian textile factories.

For AlHusseiniya and AlHashemieh at least 28 cooperatives benefited from the project (Alternative livelihood activities) with 3,556 local cooperatives member benefiting from the project in southern Badia, it was expected that by the end of the project, the number of beneficiaries to reach 10,570 individuals yet by the actual end of the project the total number of beneficiaries from various activities was 30,768 men and women, the percentage of women participation or female beneficiaries is 41% (Setlur,Banu, 2016).

Figure 21. The experimental field which is planted with US wheat in AlQatrana. (Photo by: Discovery Center team /8 February 2023).

4.5. Discussion

Geochemical characteristics of the local soils

Observational and detailed soil analysis shows that the three sites significantly deferred in terms of geochemical soil properties, land surface characteristics and plant survival rate. The data shows that AlQatrana had the highest amount of total elements compared to its counterparts AlHusseiniya and AlHashemieh (Figure 14). Overall, sites in AlQatrana significantly showed the highest amount available nutrients such as N, P, S, and Ca carbonates as well as micronutrients such as Zn (Figure 14) followed by sites in AlHusseiniya and lowest in AlHashemieh. However, the differences in soil nutrients between sites in AlHusseiniya and AlHashemieh were not significantly different except for Na content (Figure 14). The data shows Na content was about three times higher in AlHusseiniya compared to the neighbouring sites in AlHashemieh. In contrast, Mg content was higher in AlHusseiniya compared to its counterpart AlHashemieh and AlQatrana. This data reveals that topsoil characteristics indeed reflect the chemistry of the local parent material and geology. This data is also supported by local factory mining phosphate rock for fertilizer production and dolomites for cement production in AlQatrana. Furthermore, this data is supported by a recent mineralogical study conducted in Badia which showed that the Southern Badia consists of major industrial rocks and minerals such as phosphate, oil shale, limestone, dolomite, chalk, marble, gypsum, diatomite (Alnawafleh et al., 2013). Furthermore, geological indices calculated from remote sensing data showed sites in AlQatrana have the highest amount of ferrous associated minerals which are essential for plant growth (Figure 19). Unlike macro and micronutrients, soil pH and soil organic carbon (SOC) were relatively the same across the investigated sites (Figure 14). This is likely for two major reasons. First, the high evaporation reported for the sites might be driving salts accumulation in the region resulting in similarly high pH in the topsoil of all study sites (Liu et al., 2021). Second, the relatively comparable SOC amount can be a result of the low amount of plant input in the soils of the investigated sites. This interpretation is supported by vegetation data collected during the field campaign showing that the long-term carbon input is indeed equally negligible.

Topographic positions as a driver of soil chemical properties

For all investigated sites, the data shows that the total elements content of the soil was highest in between trenches positions compared to within trenches positions except for humus content and the soil pH (Figure 14 & Figure 15). This was unexpected because in general trenches were built to support water harvesting and nutrient storage against runoff and erosion induced by overland water flow. However, the interaction of runoff and topography has induced the movement of topsoil material on the slopes (between trenches) exposing the original parent material rich in mineral nutrients and total elements through the soil rejuvenation process (McBratney et al., 2016). Existing studies have shown that eroding slopes can lead to soil rejuvenation through soil removal and soil redistribution (Wallbrink et al., 2002). This process can be critical to less vegetated landscapes like the ones investigated in this study. Generally, soils in the investigated region are less developed with the parent material being closer to the surface. When this less developed soil is washed away by regular flash floods and runoff, they expose new material rich in macro and micronutrients. This interpretation is supported by existing studies conducted in other regions showing that soil redistribution can lead to rejuvenation of soils in the upper slopes of the landscape (Vanacker et al., 2019).

The role land surface characteristics on plant survival rate.

The results of the GLM (Generalized linear model) showed a strong relationship between surface mineral characteristics, topographic data and plant survival rate (Table1). This is likely because of the role of topography in driving nutrient dynamics along the slope (Berhe et al., 2008). For example, the data shows a significant negative effect of elevation on plant survival rate. In contrast, slope gradients and terrain features such as valley depth showed a positive relationship with plant density rate (Table 1). There are two major reasons for this relationship. On the one hand, this is because of the available and total nutrients that generally decrease with altitude. On the other hand, slope gradients can induce movement of soil fluxes along slopes resulting in the loss of old and nutrient-poor soils and exposing new soils rich in nutrient content. The role of topography in shaping soils and plants has been reported in other studies conducted in other regions (Berhe et al., 2008; Doetterl et al., 2012, 2016; Vanacker et al., 2019). For example, the aspect of topography can significantly affect the distribution, size, and density of plants. South-facing slopes are generally less covered by plants because they are warmer than north-facing slopes (Bailey, 1998). Furthermore, upslope sections of the landscape may not support as many large-sized woody plants as downslope areas because runoff from slopes concentrates water and nutrients in downslope areas and increases incoming precipitation (Coughenour & Ellis, 1993).

This is also supported by the data (Figure 14 – 16) that show high nutrients on a bear, eroding and unprotected slopes (Between trenches) and low nutrients on old and stable soil protected by trenches. Furthermore, indices representing surface minerals such as clay mineral ratio (CMR), iron oxides ratio (IOR) and the ferrous mineral ratio (FMR) revealed strong positive effects on plant survival rate. Therefore, the higher survival rate observed in AlQatrana is likely a result of higher mineral nutrient content (Figure 14) compared to its counterparts AlHusseiniya and AlHashemieh. Also, the strong relationship between mineral indices and plant survival rate provides evidence that soil chemical characteristics are likely the main reason for differences observed in plant survival rates across the study sites. Furthermore, this data revealed that the role of soil chemistry on plant survival rate is likely mediated by the interaction of erosion and runoff processes and the topography of the landscape. However, this study did not take into account other factors such as the role of cooperatives in managing rangeland, external input and infrastructures to maintain rangeland and the plants. Adding such factors would likely improve the model results and the mechanistic understanding of the main drivers of plant success in the three sites.

6. Conclusion and recommendations

Rangelands are the most prevalent type of land cover on earth and are categorized as part of the drylands that consist of arable land, grasslands, and shrublands. The success of rangelands is often associated with available precipitation, potential evaporation and soil water. Consequently, the success of rangeland is often associated with management and restoration efforts with little attention on soils. Furthermore, the role of topography in these ecosystems is still understudied. There is little information on how rangeland management and restoration efforts combined with local soil geochemical characteristics influence the plants and plants survival rates. This study combined field observation and remote sensing data to understand the interaction of rangeland restoration practices, local soil characteristics and terrain features and their influence on vegetation dynamics. This study revealed that largescale survival rates of plants are mainly constrained by soil fertility driven by local soil geochemical processes and by water management practices. Furthermore, the data shows that due to flash floods on eroding slopes between trenches had higher total and available nutrients compared to their counterparts' trenches, suggesting the role of topography in nutrients dynamics in these arid regions. Altogether the findings of this study revealed an important but often ignored role of soil geochemistry and topography to understand the productivity, success, and functioning of rangelands ecosystems. Therefore, the soil geochemical properties and topographic features of the landscape should be taken into account while developing a rangeland restoration plan. For sustainable management of rangelands, the role of local cooperatives should be taken into account when planning and implementing restoration activities of rangeland reserves in arid regions.

7. Summary

Rangelands are important systems for understanding global ecosystems functioning and play a major role in supporting local inhabitants. The success of rangelands is often associated with other factors such as climatic factors, mainly precipitation and management strategies like water harvesting techniques. However, the role of soils and topography in these ecosystems is still understudied. There is little information on how rangeland management and restoration efforts interact with local soil geochemical characteristics to influence plant survival rates. This study combined field observation and remote sensing data to understand the interaction of rangeland restoration practices, local soil characteristics and terrain features and their influence on vegetation dynamics. Furthermore, the study investigated the socioeconomic aspect of rangeland restoration activities. The data revealed that largescale survival rates of plants are mainly constrained by soil fertility driven by local soil geochemical processes and water management practices. Overall, soils located on slopes between trenches showed higher nutrients (NPK, base cations, and micronutrients) compared to soils within trenches. Furthermore, sites in AlQatrana (rich in total and available nutrients) showed higher plant survival rates compared to sites located in AlHusseiniya and AlHashemieh (low total and available nutrients). These results suggest that due to flash floods on eroding slopes positions between trenches had higher total and available nutrients compared to their counterparts' trenches. This stresses the role of topography and erosion as a mediator of nutrient dynamics in these arid regions. Altogether the findings of this study revealed the important but often ignored role of soil geochemistry and topography to understand the productivity, success and functioning of rangelands ecosystems. Therefore, soil geochemical properties and topographic features of the landscape should be taken into account while developing a rangeland restoration plan. In addition, for sustainable management of rangelands, the role of local cooperatives should be taken into account when planning and implementing restoration activities of rangeland reserves in Badia.

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