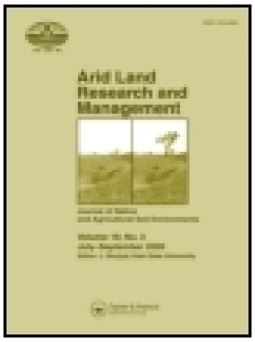

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Evaluating the influence of COVID-19 pandemic lockdown on Jordan Badia rangelands

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ABSTRACT
To explore the effect of COVID-19 pandemic lockdown on vegetation cover changes in Northern, Middle, and Eastern Jordan Badia rangelands, Landsat-8 (Operational Land Imager [OLI]) images were downloaded and processed to attain surface reflectance data for March and July 2018–2020. Normalized difference vegetation index (NDVI) was then derived from OLI-images, where the total area covered with water, bare soil, scattered vegetation, dense grasses and shrubs, and dense forests were estimated. Across the study period, 2019 had the highest rainfall (195 mm) and temperature (21.7 °C), while the lowest rainfall was recorded in 2018 (154 mm). The Northern Badia showed a consistently larger area of dense vegetation on average (407.4 km^2) compared to the Eastern (149.3km^2), and Middle (55.2 km^2) Badia. The total area covered with scattered vegetation in 2020 was higher than in 2019 and 2018 across the years and studied area, except in Middle Badia. Vegetation cover classes were inconsistent for Middle Badia in March, scattered vegetation was higher in 2019 compared to 2020. However, the total area covered with vegetation in July was lower than in March across the years and studied area. The curfew allowed the regeneration of shrubs and grasses in the study area, which helped in restoring the rangeland vegetation. COVID-19 lockdown served as a conservation grazing technique and provided a real case of restoring the degraded rangeland cover through managed grazing.

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Arid land; coronavirus; grazing; NDVI

Introduction

Rangelands comprise about 80% of Jordan's total land area (MoEnv 2015) and are characterized by arid and semi-arid climates. They are located in the Saharo–Arabian phytogeographic region and known locally as Badia (Al-Eisawi 1996). The lifestyle of

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nomadic pastoralism (Bedouins) is animal-oriented and involves forms of transhumance (Juneidi and Abu-Zanat 1993). However, over the last decade, Jordan rangelands have been exposed to land degradation and biodiversity loss (Al-Karadsheh, Akroush, and Mazahreh 2012). Frequent drought periods in recent years substantially increased grazing pressure of domestic livestock on the Badia. The large influx of Syrian refugees, climate change, industrialization, and salinization of aquifers increased desertification, reducing naturally available livestock fodder and forcing many of the Bedouins to abandon pastoralism and migrate to urban centers (Holechek et al. 2020; Sawalhah et al. 2018; UNEP 2016). The lack of balance between animal numbers and forage supply represents a potential threat for pastoralists especially in highly variable rangeland environments. High grazing rate can reduce perennial species diversity and lead to changes in species composition (Ash et al. 2011). Livestock grazing is the most common land use in arid and semi-arid rangelands and Jordan arid lands are not an exception. Therefore, understanding the effect of grazing on ecosystems is critical (Dara et al. 2020).

Rangeland health evaluations are fundamental for effective planning and supporting sustainability efforts in arid lands. Assessment of rangeland health considers soil and site stability, hydrologic function, and integrity of the biotic community (Pyke et al. 2002). High grazing pressure decreases primary production, reduces biomass, and perennial grass basal cover, consequently lowering the long-term grazing capacity of the land (Ash et al. 2011). Conservative stocking rates with year-round grazing can sustain land in a desirable state or facilitate the transition from a less desirable ecological state to healthier rangeland condition (Ash et al. 2011). Furthermore, conservative grazing systems sustain acceptable density levels of palatable plant species and reduce dead biomass in the pasture (Oñatibia and Aguiar 2019). Conversely, heavy stocking rates (intensive grazing) reduce density and frequency of plant species that are highly preferred by grazers and increase the density of non-preferred species which might be invasive in nature (Oñatibia and Aguiar 2019). Moreover, it has been documented that controlled grazing is not harmful to semi-arid and arid rangeland (Holechek, Pieper, and Herbel 2011). Conservative stocking involving 31–40% use of forage is the best optimization of forage production, livestock production, financial returns, and multiple-use values compared to other grazing intensities (light, moderate, heavy, and severe) in arid and semi-arid rangelands. However, both conservative (31–40% use of forage) and light grazing (15–30% use of forage) are now being widely applied in arid and semi-arid rangeland to reduce risk of drastic complete destocking during drought and to allow quicker recovery in post-drought periods (Holechek, Pieper, and Herbel 2011).

Grazing intensity that is “cumulative effects grazing animals have on rangelands during a particular time period” as defined by Holechek, Pieper, and Herbel (2011) is typically used to measure the impact of livestock stocking rate on vegetation. Monitoring year-to-year changes in grazing intensity using traditional approaches is time-consuming, labor-intensive, and frequently hampered by a lack of adequate tools (Dara et al. 2020; Tadros et al. 2020). Remote sensing techniques provide a potential means to identify rangelands where surface property changes can be mapped and connected to land degradation (Al-Kofahi, Jamhawi, and Hajahjah 2018; Sawalhah et al. 2018;

Xie et al. 2019). For example, remotely sensed data from Landsat archives (1985–2017) together with ground reference data revealed previously unknown hot spots of heavy grazing during Soviet times (Dara et al. 2020). The study highlights the use of Landsat archives to map grazing pressure reliably across large areas and over long periods of time. Landsat datasets and Google Earth Engine were also employed by Xie et al. (2019) who developed a novel approach to mapping changes in vegetation cover at the pixel level (spatial resolution: 30 m) and identified degraded lands with an overall classification accuracy of 82.6%. In Jordan, a remote sensing approach successfully assessed land change/cover (overall accuracy of 80–86%) and was able to recommend monitoring of invasive plant species in the area such as *Prosopis spp*. (Tadros et al. 2020). Overall, Landsat 8 Operational Land Imager (OLI) is a viable tool to identify vegetation cover change and quantify degradation in Middle and Eastern Badia rangelands (Sawalhah et al. 2018).

After the outbreak of coronavirus disease (COVID-19), several countries adopted quarantine plans including traffic restrictions early in 2020 to reduce the spread of the virus (Chen et al. 2021). Jordan was among those countries that adopted the quarantine option, where large-scale city closures were imposed all over the country which effectively reduced the virus spread and controlled the national COVID-19 infection rates (Lau et al. 2020). Interestingly, imposed emergency protocols curtailed people's mobility and contributed significantly to improve the air quality in China (Chen et al. 2021). In Italy, the carbon footprint during the lockdown was reduced by 20% (Rugani and Caro 2020). It is expected that the natural environment has benefited from lockdown in many aspects. However, no study that we are aware of has assessed the influence of COVID-19 lockdown on vegetation cover, regeneration, or plant communities in open access rangelands.

Abed (2010) identified four movement patterns of stockowners in Jordan Badia rangelands, including one local pattern and three long-distance movements. The local movement pattern (77%) usually stays around cisterns and dams in the Ruwieshed region (northeastern desert) in winter and autumn. The long-distance movements begin to move to western areas until reaching Irbid governorate in late winter, and spend autumn there, and after that, they return to Ruweished. Among the long-distance movement East-West and North-South patterns account for 8–9% each, whereas East-South-North movement patterns account for 5%. The shutdown restricted the local and long-distance movements especially from southern areas (Karak or Tafila cities) to the northeastern region (Ruwieshed) and northwestern rangelands. However, the effect of COVID-19 lockdown on vegetation cover and distribution in Jordan rangelands is not known. In heavily grazed rangeland, like Jordan, it is commonly assumed that reduction in grazing pressure will result in more productive vegetation (Buttolph and Coppock 2004). We hypothesized that the lockdown significantly increased vegetation cover on rangelands compared to the same period of previous years. The normalized difference vegetation index (NDIV) is considered a valid indicator of vegetation cover (Prabhakara, Hively, and McCarty 2015). Bhavsar, Kumar, and Roy (2017) found that NDVI is the best vegetation index out of seven commonly used vegetation indices. Therefore, the objective of this study was to assess possible relations between COVID-19 pandemic lockdown and vegetation cover and

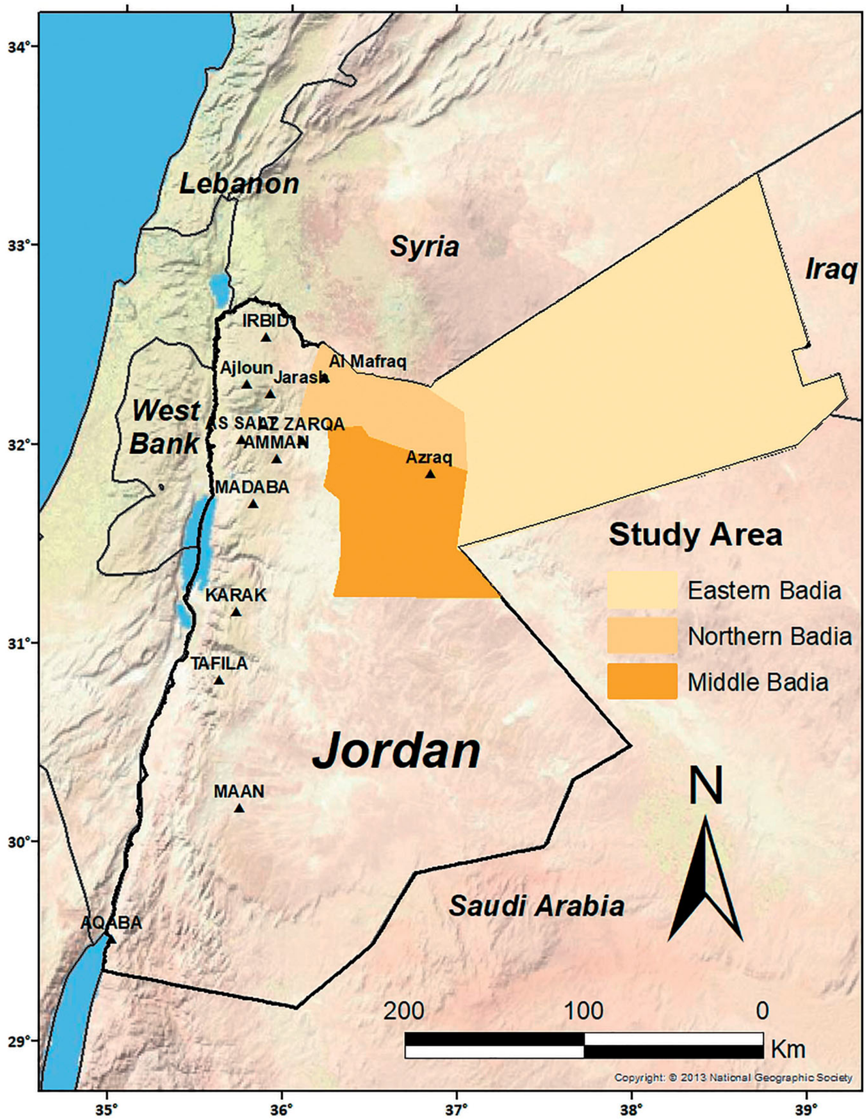

Figure 1. The location of the three study sites.

distribution in the Northern, Middle, and Eastern Badia rangelands using remotely sensed data from Landsat 8 OLI.

Materials and methods

Site description

Jordan is a small country, with limited natural resources and characterized by arid to semi-arid climate, located at 30.5852°N and 36.2384°E. The study area covered the Northern, Middle, and Eastern Badia rangelands with an area of 3141.1, 6236.4, and 24,667.6 km^2, respectively. Elevation ranges from 450 to 975 m above sea level. The total study area (34,045 km^2) covers about 38% of the country area (Figure 1). Mean annual

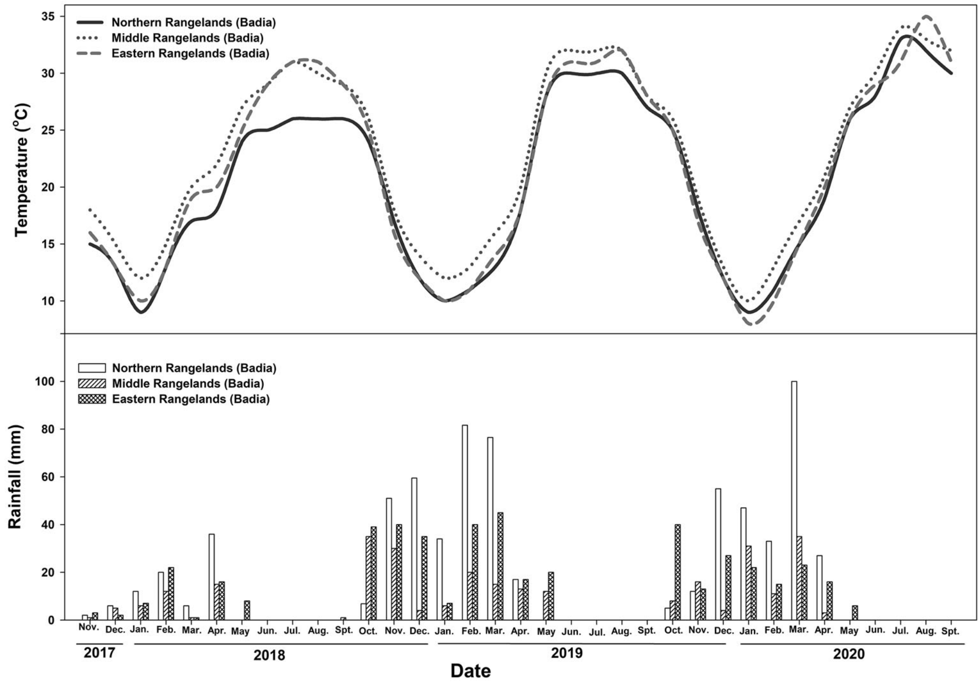

Figure 2. Mean monthly temperature and total rainfall in Northern, Middle, and Eastern Badia rangelands during the study period, 2018–2020.

precipitation ranged from 99 to 238 mm. Mean annual maximum and minimum temperatures ranged from 28 to 30 °C and 20 to 22 °C, respectively (Figure 2) during the three years analyzed in this study. The dominant grazing livestock species are sheep and goats (MoA 2013). Vegetation is composed of mostly halophytes grasses and forbs with an overstorey of scattered shrub patches (Amr, Modry, and Shudiefat 2011; Taifour, El-Oqlah, and Ghazanfar 2017). Table 1 shows the detailed description of the study sites.

Image acquisition, pre-processing, and classification

Satellite sensor data from Landsat OLI were downloaded and used to detect vegetation cover changes during the study period, 2018–2020. Images were collected for the months of March and July to detect the maximum and minimum vegetation cover across the study period (2018–2020). Badia rangelands are normally covered with grasses and shrubs in spring (March), but later in the season (June–October) the grasses die and only shrubs and trees remain green.

Cloud-free Landsat OLI images were downloaded from the Earth Explorer portal (USGS 2020). Surface reflectance climate data records (CDRs), level-2 images were used. The CDRs-level-2 datasets are atmospherically corrected and available free of charge from the Earth Explorer portal. In fact, those spaceborne images are a reliable Landsat source for change detection studies, especially for vegetation (Othman, Steele, and Hilaire 2018; Sawalhah et al. 2018). Radiometric and geo-referencing were then conducted using environment for visualizing images (ENVI) 5.0 software (Research Systems, Boulder, CO). The Fast Line-of-sight Atmospheric Analysis of Spectral

Table 1. Description of study sites.

	Study site		
Variable	Northern Badia	Eastern Badia	Middle Badia
Elevation (m)	600–975	480–915	450–670
Meteorological stations	Al-Mafraq	Al-Ruwaished	Azraq
Climate	Arid to semi-arid	Arid to semi-arid	Arid to semi-arid
Geology	Basalt	Basalt and limestone	Limestone
Soil type	Camborthids, Calciorthids	Camborthids, Calciorthids, Gypsiorthids, Torriorthents	Camborthids, Calciorthids, Gypsiorthids
Land Use	Limited grazing	Limited grazing	Limited grazing
Vegetation			
Plants grazed in March	*Calendula arvensis* L. *Achillea fragrantissima* Forssk. *Poa bulbosa* L. *Erodium acaule* L. *Filago desertorum* Pomel. *Hordeum spp.*	*Calendula arvensis* L. *Achillea fragrantissima* Forssk. *Allium stamineum* Boiss. *Anagallis arvensis* L. *Malva aegyptia* L. *Plantago ovata* Forssk.	*Phragmites australis* Cav. *Typha domingensis* Pers. *Panicum turgidum* Forssk. *Phragmites communis* Trin. *Aeluropus littoralis* (Gouan) Par. *Achillea fragrantissima* Forssk.
Plants grazed in July	*Atriplex halimus* L. *Anabasis setifera* Moq. *Tamarix tetragyna* Ehrenb. *Tamarix aphylla* L.	*Atriplex halimus* L. *Halopeplis amplexicaulis* (Vahl) Ung. *Suaeda fruticosa* Forssk. *Salsola rosmarinus* Bunge ex Boiss. *Tamarix spp.*	*Tamarix tetragyna* Ehrenb. *Vitex agnus-castus* L. *Ephedra foliata* Boiss. *Salix spp.* *Atriplex halimus* L. *Halopeplis amplexicaulis* (Vahl) Ung. *Anabasis setifera* Moq.

Hypercubes (FLAASH) algorithm in ENVI was used to normalize the different Landsat datasets. To cover the study area, four Landsat images were used in each scene (month) and were wrapped together using mosaicking tool in ENVI. In image mosaicking, pixel-based coordinates were used to place images in mosaics and the technique was performed to blend image boundaries (Sawalhah et al. 2018). Image derivative, NDVI, Equation (1) was calculated to detect the greenness of vegetation as in the equation below:

$$\mathrm{NDVI} = \frac{\text{near infrared} - \text{red}}{\text{near infrared} + \text{red}} \tag{1}$$

where near infrared and red are Landsat-8 (OLI) bands five and four, respectively. The NDVI classification scheme of Landsat OLI datasets included water surfaces, bare land, and different vegetation classes (Table 2).

Results

Weather data and vegetation cover

The mean temperature ranged between 10 and 14 °C in January–March and 28–34 °C in June–September (Figure 2). Northern Badia had slightly lower (3–8 °C) summer temperatures than the Middle and Eastern Badia, especially in June–August. Rainfall in the Northern Badia during the 2018 growing season (November 2017–May 2018) was 82 mm; the total rainfall there in 2019 growing season was 326 mm, and in 2020

Table 2. Normalized difference vegetation index (NDVI) value ranges of distinguished classes.

NDVI values range	Features
−1.0−0.0	Deep and shallow water
0.0–0.1	Bare soil and rock
0.1−0.2	Scattered vegetation (shrubs and grasslands)
0.2−0.6	Dense vegetation (shrubs, grasslands, and agricultural area)
0.6−0.9	Dense forests

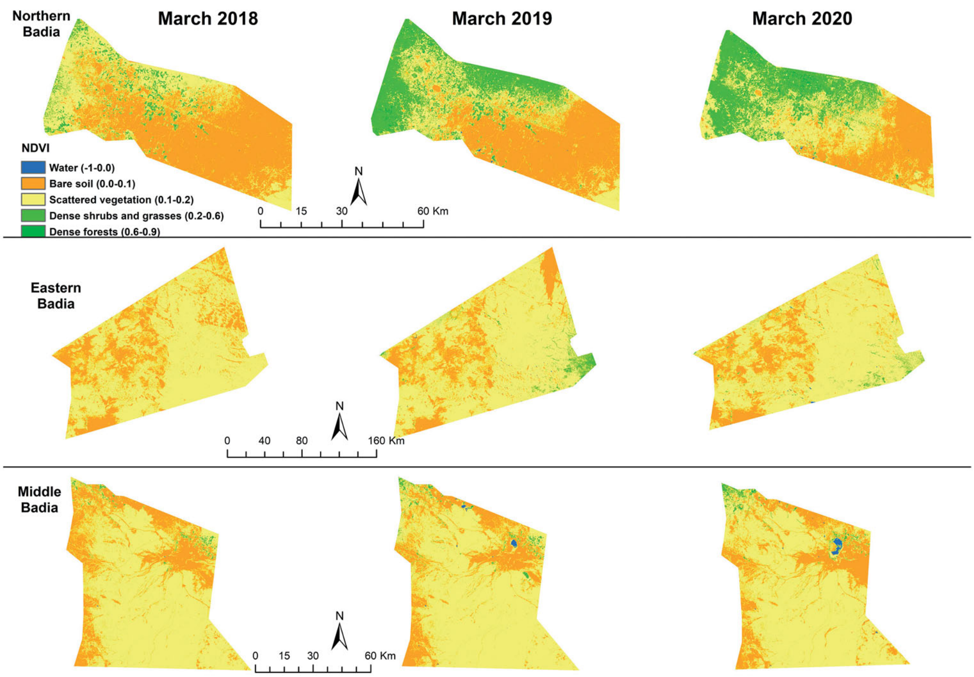

Figure 3. Vegetation cover (NDVI) maps and areas (km^2) in March 2018–2020. NDVI was derived from Landsat 8 (OLI) sensors data.

growing season was 279 mm (long-term average 208 mm) (Figure 2). In the Middle Badia, the total rainfall in the growing seasons of 2018 was 40 mm, 136 mm in 2019 and 108 mm in 2020 (long-term average 90 mm). The total rainfall for Eastern Badia during the 2018, 2019, 2020 growing seasons were 59, 243, 156 mm (long-term average 125 mm), respectively. Overall, the 2019 growing season had the highest rainfall for Northern, Middle, and Eastern Badia rangelands.

Vegetation cover classes (2018–2020) derived using Landsat 8 (OLI) are presented in Figure 3 and Table 3. The total area covered with scattered vegetation (NDVI 0.1−0.2), dense grasses and shrubs (NDVI 0.2−0.6), and dense forests (NDVI 0.6−0.9) in 2018 were lower than in 2019 and 2020 growing seasons (Figures 3 and 4; Table 3). In addition, Northern Badia had consistently higher area of dense vegetation (NDVI 0.6−0.9) than Eastern and Middle Badia across the growing season (March and July) and over the study period (2018–2020) (Figures 3 and 4; Table 3). In March, the total area covered with scattered (NDVI 0.1–0.2) and dense vegetation and forest (NDVI 0.2−0.6; 0.6 −0.9 for the 2020 growing season was higher than in 2019 and in 2018 for Northern

Table 3. Areas covered (km^2) by NDVI classes of Table 2 in March and July 2018–2020.

			Area (km^2)				
Study Site	Month	Year	Water	Bare soil	Scattered vegetation	Dense vegetation	Dense forests
Northern Badia	March	2018	1.1	1903.3	1047.1	180.6	9.0
		2019	2.6	1440.7	868.6	802.7	26.5
		2020	2.8	951.0	1139.3	999.4	48.6
	July	2018	1.6	2472.0	520.6	136.1	10.8
		2019	1.3	2032.1	942.5	151.9	13.3
		2020	1.3	1617.0	1333.1	173.7	16.0
Eastern Badia	March	2018	3.1	7190.0	17467.3	6.6	0.6
		2019	17.6	5935.0	18162.4	550.6	2.0
		2020	19.2	5593.0	18750.0	304.4	1.0
	July	2018	1.5	7482.7	17176.3	6.7	0.4
		2019	1.0	7462.4	17189.9	14.1	0.2
		2020	1.2	6363.9	18289.0	13.2	0.3
Middle Badia	March	2018	1.1	1714.9	4471.4	44.0	5.0
		2019	13.7	1484.8	4653.3	77.4	7.2
		2020	25.2	1601.9	4514.5	88.1	6.7
	July	2018	1.0	2523.2	3675.8	33.9	2.5
		2019	0.8	2293.4	3899.6	39.3	3.3
		2020	1.1	2005.7	4176.6	48.7	4.3

Badia (Figure 3; Table 3). For Eastern Badia, the total area covered with scattered vegetation (NDVI 0.1 – 0.2) in 2020 was higher than in 2019 and in 2018 (Figure 3; Table 3). Conversely, the dense NDVI classes (0.2 – 0.6; 0.6 – 0.9) for 2019 were higher in Eastern Badia than in 2020. However, vegetation cover classes were inconsistent for Middle Badia in March, while scattered vegetation (NDVI 0.1 – 0.2) class area was higher in 2019 compared to 2020; dense vegetation (NDVI 0.2 – 0.6) of Middle Badia in 2019 was lower than in 2020 (Figure 3; Table 3).

The total area covered with vegetation (NDVI 0.1 – 0.9) in July (Figure 4; Table 3) was lower than in March (Figure 3; Table 3) across the years and over the study area. In July 2020, Northern Badia had higher vegetation cover (NDVI 0.1 – 0.2, 0.2 – 0.6, 0.6 – 0.9) than in July 2019 (Figure 4; Table 3). Similar result was noticed in Eastern (NDVI 0.1 – 0.2, 0.6 – 0.9) and Middle (NDVI 0.1 – 0.2, 0.2 – 0.6, 0.6 – 0.9) Badia (Figure 4; Table 3).

Change detection

Change detection analysis for the study area showed changes in land cover classes in 2020 compared to that of 2019. The conversion of bare soil to vegetation (Figures 5) was noticeable; in both months (March and July), all vegetation cover classes increased in 2020 by 20–35% compared to 2019 in the Northern Badia. In fact, the cumulative vegetation cover area, in March, for all vegetation cover classes (scattered and dense grasses, shrubs, and forests) increased by 29% (from 1698 to 2187 km^2) and increased by 37.5% (from 1108 to 1523 km^2) in July (Figure 5). Although the percentage of change (2020 *vs.* 2019) was inconsistent across the vegetation cover classes in the Eastern and the Middle Badia, the cumulative vegetation cover for all cover classes increased in the Eastern Badia by 1.8% (from 18715 to 19055 km^2) in March and 6.4% (from 17204 to 18303 km^2) in July. Surprisingly, in the Middle Badia, cumulative

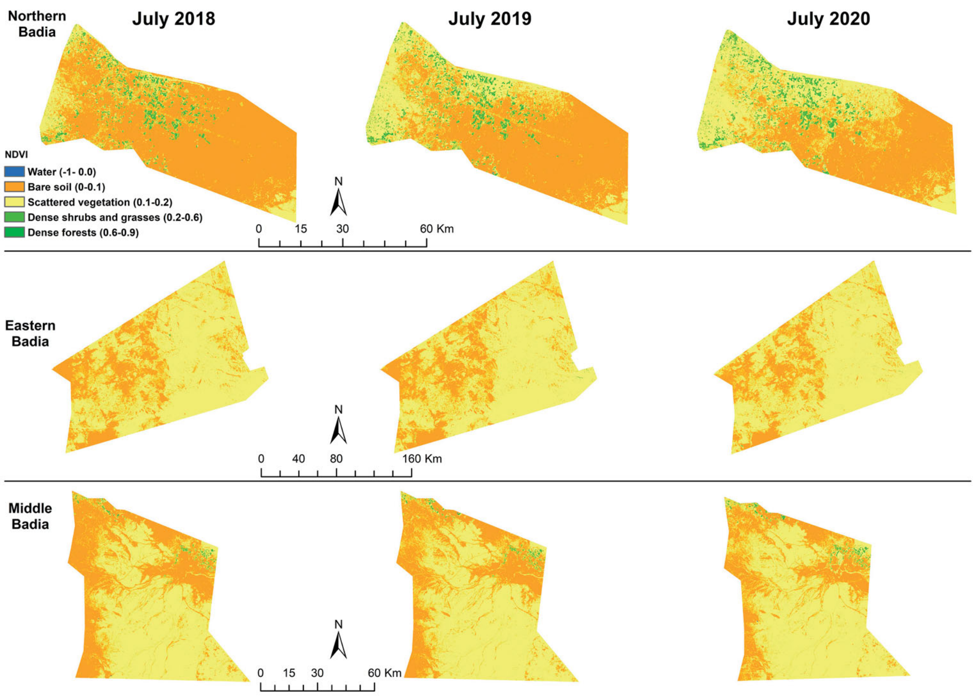

Figure 4. Vegetation cover (NDVI) maps and areas (km^2) in July 2018–2020. NDVI was derived from Landsat 8 (OLI) sensors data.

vegetation cover decreased by 2.7% (from 4738 to 4609 km^2) in March and the total area increased by 7.3% (from 3942 to 4230 km^2 in July. Overall, the total area covered with vegetation (scattered and dense vegetation, grasses, shrubs, and forest) was higher in 2020 compared to 2019 across the Badia (Northern, Eastern, and Middle) and over the growing seasons (March and July), except for Middle Badia in March. This could be explained by the nature of the Middle Badia location which covers the location and the path of herders (movement route) moving from southern areas to the northeastern areas (Abed 2010). In addition, there are herders living there and this reduces the effectiveness of the imposed lockdown and the restrictions on the vegetation restoration in this area.

Discussion

The reduction in grazing pressure in arid regions improves vegetation production, especially in areas that usually experience heavy grazing like Jordan Badia rangelands, and in such areas controlled grazing is an effective conservation practice. The lockdown episodes due to COVID-19 pandemic served as an excellent natural model to simulate the effect of controlled grazing on arid regions. The total vegetation cover in 2018 was lower than in 2019 and 2020 across the Badia rangelands over the growing season, March and July (Figures 3 and 4, respectively). This can be attributed to the total rainfall in 2018 which was significantly lower than during the next two growing seasons (Figure 2). For example, the total precipitation in Eastern Badia was 59 mm in 2018 and

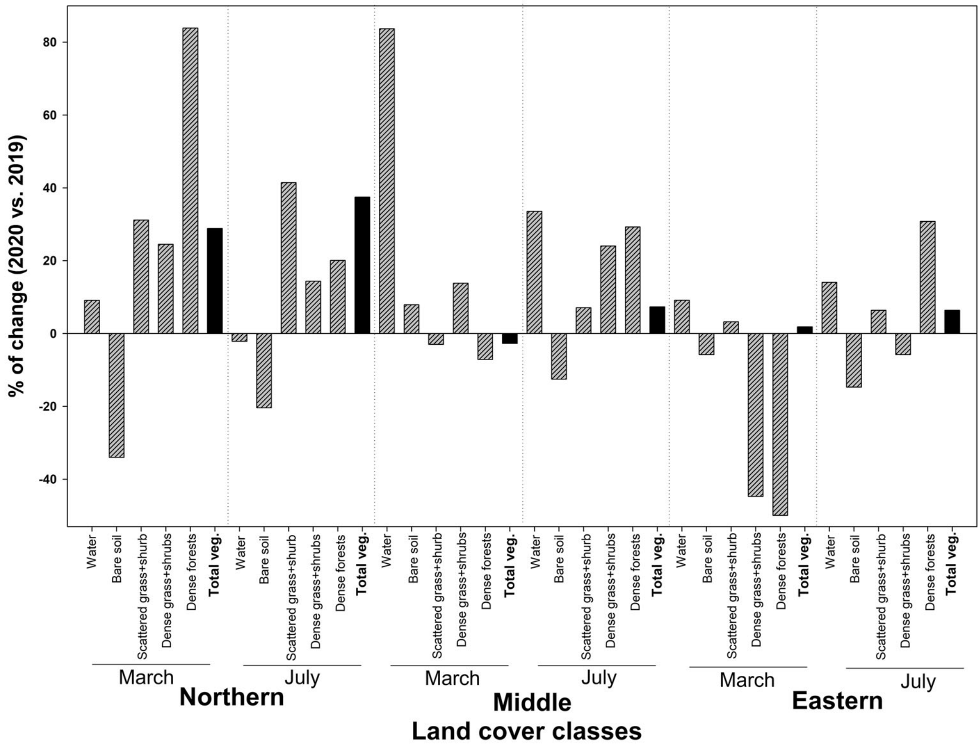

Figure 5. Percent change (2020 *vs.* 2019) of water, bare soil, scattered and denses vegetation (shrubs and grasses), dense forests, and cumulative vegetation cover for all vegetion cover classes (scattered and dense grasses, shrubs, forests). Change detection analysis was derived from Landsat 8 (OLI) sensor data.

243 mm in 2019. In addition, the highest cover (NDVI 0.6 − 0.9) in Northern Badia site compared to the Middle and the Eastern site could be in part due to weather conditions. The mean temperatures were slightly lower, and the total rainfall was higher than in the Middle and the Northern Badia (Figure 2). Therefore, climatic fluctuation was likely the primary driver for vegetation changes. This finding agrees with previous studies that showed that precipitation is the primary factor affecting annual change in forage production if grazing is not heavy or severe (Holechek, Pieper, and Herbel 2011).

In this study, we assessed the vegetation cover in March and July. In March, the annual grasses achieved the maximum growth level as well as the evergreen and deciduous shrubs and small trees. In July, the grass life cycle ends and thus plants die. At that time (July), only evergreen shrubs and small trees are available for grazing. This might explain why vegetation cover in July was lower than in March across the study period, 2018–2020.

Multi-temporal Landsat images were used in order to classify vegetation cover and distribution in Northern, Eastern, and Middle Badia during the last 3 years including the COVID-19 lockdown period, March–July 2020. Landsat 8-NDVI data were used to estimate vegetation cover changes before (2018–2019) and during the lockdown period (in 2020). Therefore, we believe that the hypothesis was met where the COVID-19 lockdown period (March–July 2020) improved the vegetation cover in the Badia rangeland.

This can be deduced from the fact that the total rainfall in 2019 was significantly higher than in the 2020 growing season across the studied rangeland sites. Conversely, the cumulative vegetation cover for Northern, Eastern, and Middle Badia for 2019 was lower than in 2020 across the growing season, except for the Middle Badia in March (Figure 5). Traditional rangeland management in the Badia region used to employ a system that resembles the lockdown conditions, known as *Hima* (meaning "protection" in Arabic). The sites under *Hima* conditions for one year or more show improvement in the biodiversity and support better fodder production. In this system, the communities can conserve the rangeland and regulate their use (UNEP 2016). Ash et al. (2011) similarly emphasized that intensive grazing limits the primary production, biomass, and grass basal cover, and thus lowering the long-term grazing capacity of the land. Conservative stocking rates supports more desirable ecological state of the region and healthier rangeland condition.

After the outbreak of corona virus pandemic in Jordan, the government has applied sudden actions to prevent the spread of the disease, including a national lockdown, social and economic restrictions. However, this extraordinary lockdown in the country (March–July 2020) has improved vegetation cover in the Badia rangelands, including the northern and middle regions. The curfew restricted the local and long-distance movement especially from southern areas to northeastern and northwestern rangelands. At that time, livestock holders used their own dry forage to feed their stock. In addition, fodder prices forced the stockowners to sell part of their flocks to buy fodder. Some livestock holders depended on the open lands surrounding their residence, where minimal checkpoints existed such as in the Eastern Badia. Managed and controlled grazing proved to be a solution to improve vegetation cover in the rangelands in arid countries. Therefore, decision makers need to consider managing the livestock movement through issuing and implementing regulations to protect the wild flora and improve the vegetation cover in Badia rangelands.

Conclusions

The improper exploitation of natural resources leads to the destruction of vegetation and soils. The situation becomes worse where environmental factors are not favorable such as higher temperatures with limited and fluctuating rainfall in arid to semi-arid areas. The vegetation cover densities are under pressure from arid climate and the grazing intensity in these regions. The imposed COVID-19 pandemic lockdown in Jordan improved the vegetation cover densities in the Northern, Eastern, and Middle Badia rangelands as indicated by the comparison of NDVI values before and after the lockdown. However, the environmental factors especially rainfall amounts were less in the last growing season which favors the idea that the improvement in vegetation cover was mainly caused by the protection of rangelands from intensive grazing. Therefore, the ancient rangeland protection protocol '*Hima*', and more recent approaches such as monitored grazing or exclusion policies for rangeland management showed effectiveness at large scales in arid to semi-arid rangelands. Our results showed that controlled grazing could be an effective system to improve and rehabilitate degraded Badia rangelands and maintain better vegetation cover and sustainability of the rangelands.

Disclosure statement

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