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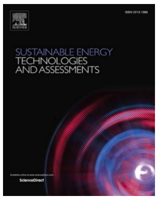

Environmental impacts of photovoltaic power plants in northwest China

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ABSTRACT

In the past decade, approximately 17 % of the world's photovoltaic capacity has been installed in China, especially in the northwestern desert areas. The impacts of the construction and operation of large-scale photovoltaic power plants (PPPs) on local ecological environments have become urgent scientific issues in regional environmental protection decision-making. To quantitatively evaluate the local environmental impacts of the construction and operation of PPPs in the desert oasis region, thermal infrared and multispectral sensors mounted on unmanned aerial vehicles (UAVs) as well as X-ray fluorescence spectrometers and soil sensors were used in this study to monitor a large PPP in Northwest China. We found that the construction and operation of PPPs can promote biological soil crust development and vegetation growth and can thus improve the soil texture and nutrition. However, the Ca, S and Cl concentrations were found to be 3, 5 and 1.7 times higher inside the PPP area than outside the PPP area, respectively. In addition, the soil salinization is also more severe inside the PPP area. In future studies, it is essential to further elucidate the impacts of PPP operations and agricultural on desert ecosystems.

Introduction

In the field of low-carbon energy development, solar energy is known as a renewable green energy type. Photovoltaic power plants (PPPs) are rapidly increasing in scale and number globally. In the past decade, China has installed approximately 17 % of the world's photovoltaic capacity [1]. China's solar energy resources are unevenly distributed and decrease from northwest to southeast [2,3]. The spatial distribution of PPPs in China also shows a downwards trend from northwest to southeast, and most of the northwestern region contains arid or semiarid climate zones. The solar power generation potential in arid areas is vast, both because of abundant land resources and because the solar radiation in these regions, especially desert regions, is much higher than that in other areas [4,5]. In addition to experiencing relatively high solar irradiance, these areas have fragile ecological environments and are extremely vulnerable to improper anthropogenic development activities and thus exhibit difficulties in the recovery process following disturbances [6].

Solar photovoltaic systems cannot be regarded as completely eco-friendly systems with zero-emissions [7]. In the context of the large-scale development of photovoltaic resources, to fully understand the ecological climate and environmental effects of PPPs, international researchers have begun to study the impacts of PPP operation on local, regional and even global ecological environment conditions; however, the obtained results are not consistent [8,9]. The installation of PPPs has changed the land use distribution [10]. The rainwater-concentrating and sheltering effects of photovoltaic panels have altered the soil moisture conditions, micrometeorology, and water resource utilization efficiency, thereby affecting ecosystem service functions [11–14]. The construction of a PPP significantly alters the surface disturbance of the soil, affects the balance between the photosynthetically active radiation and radiant flux, reduces the surface albedo, changes the precipitation distribution, and forms a heat island effect [9,12,15,16]. These changes

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Nomenclature

Abbreviations

BEC	Bulk electrical conductivity
DSM	Digital surface model
NDVI	Normalized difference vegetation index
ppm	Parts per million
PPP	Photovoltaic power plant
TIR	Thermal infrared
XRF	X-ray fluorescence
UAV	Unmanned aerial vehicle

Main notations

Ca	Calcium
Cl	Chlorine
Fe	Ferrum
K	Kalium
Nd	Neodymium
P	Phosphorus
S	Sulphur
Ti	Titanium
Mg	Magnesium
U	Uranium
V	Vanadium

critically impact the driving factors of the local microclimate, such as evaporation, wind speed, temperature, soil moisture, and soil temperature, on both temporal and spatial scales, thereby increasing the land degradation risk in fragile arid ecosystems [17]. Photovoltaic panels have a warming effect on the soil temperature in winter and a cooling effect on soils in the other seasons [15]. Desert areas have sparse vegetation and abundant wind and sand. Due to the dust and sand coverage, the solar module efficiency is significantly reduced. It is usually necessary to perform liberal applications of dust suppressant and water to clean the panels and prevent large amounts of dust or sand from affecting the PPP operation [18,19]. These chemicals are extremely toxic to the environment and may cause extensive negative effects on the local ecological environment in the long run [20].

Currently, there is a lack of relevant knowledge, preventing a comprehensive assessment of environmental impacts of large-scale PPPs. To minimize the environmental impacts of PPPs, it is important to understand the environmental costs generated by PPPs. The impacts of the construction and operation of large-scale PPPs on regional ecological environments have become an urgent scientific issue in regional environmental protection decision-making and research. Here, we performed a field study to measure the effects of a PPP in northwestern China on the soil and vegetation conditions. The experimental setup included soil sampling and unmanned aerial vehicle (UAV) flights from 2020 to 2021. We aimed to (1) comprehensively monitor the key environmental impacts associated with large-scale PPPs, (2) analyse the spatial differences in vegetation and soil conditions inside and outside the PPP and (3) assess the impact of PPP construction and operation on the local ecological environment.

Materials and methods

Study area

The analysed PPP is located in Wujiaqu city in the Xinjiang Uygur Autonomous Region (Fig. 1). This PPP was built in 2013 and began operations in 2015; its total area is approximately 1.10 square kilometres, and it is located at the northern foot of Bogda Peak in the Tianshan Mountains on the edge of the Guerbantonggut Desert in the Junggar Basin. The region has a mid-temperate continental climate, with drought conditions, low temperatures, many hours of sunshine, large diurnal temperature differences, and drastic temperature changes. The annual average temperature ranges from 6-7 °C; the highest temperatures reach 40-42 °C; the lowest temperatures are −38-−43 °C; the average annual precipitation total is 200 mm; the annual evaporation is 2000 mm; and the sunshine duration is 2600∼3200 h/year. In the study area, precipitation is scarce, evaporation is strong, the climate is dry, the solar radiation is sufficient, water resources are scarce, and the soil contains large amounts of salt. The studied PPP is surrounded by sand dunes, and some of these sand dunes were flattened during the construction of the PPP. A small number of cotton fields are located in the surrounding flat and low regions. The elevation inside the PPP region is approximately 365 m.

The vegetation around the PPP mainly includes *Tamarix elongata*, *Agropyron desertorum*, *Suaeda glauca*, and *Cirsium segetum* as well as small distributions of *Peganum harmala*, *Festuca glauca*, *Nitraria tangutorum* and *Lycium chinense*. The photovoltaic panels have upper and lower layers with an inclination angle of 37°. The gap between the upper and lower layers in each photovoltaic panel is approximately 4 cm, causing rainfall to wash away the underlying saline-alkali soils due to gravity at the gap and forming a water area with a width of 3–4 cm. Moss is abundant in these stagnant areas, and the vegetation around the stagnant areas (under the photovoltaic panels) is dominated by abundant *A. desertorum* (Fig. 1). Gravel roads lead to the access point of the PPP.

Methods

Ground sampling and UAV flights were conducted to monitor the ground surface information inside and outside the analysed PPP (Table 1).

Using a combination of field surveys and monitoring techniques with multispectral and thermal infrared (TIR) sensors mounted on drones, surveys were conducted to record the surface temperature, vegetation status, and soil environment information inside and outside the Wujiaqu PPP in Xinjiang. The changes in the thermal pattern among different periods were monitored in the PPP, and the thermal effects of bare land, vegetation, and photovoltaic panels on the soil were explored. Through technical processing, including aerial triangulations, splicing and projections of the multispectral data collected by drones, a digital surface model (DSM) and the vegetation coverage, normalized difference vegetation index (NDVI), red, green, blue, near-infrared, red edge information of the PPP in 2020 were combined to obtain a multispectral spatial dataset. Two UAV flights were selected before and after manual pruning of vegetation within the PPP.

An Olympus Vanta handheld X-ray fluorescence (XRF) spectrometer was used to monitor the internal and external data at the PPP and collect the soil element concentration data in different positions on the PPP panels, on every 10 rows of panels, and at different orientations inside and outside the PPP. The Vanta analyser is a powerful, nondestructive-technique, handheld XRF device that provides rapid, accurate element analyses and allows the elemental compositions of alloys to be identified from magnesium (Mg) to uranium (U) and from parts per million (ppm) to 100%. A total of 744 samples were collected. The data were used to quantitatively evaluate the spatial variations in chemical element concentrations within the PPP station as well as their internal and external differences, thus revealing the possible impacts of the construction and operation of the PPP on the local ecological environment.

The temperature and humidity of the soil ground surface layer were monitored using an Acclima Sensor Reader Kit (SDI-12). The kit included a digital True TDR-315H soil water-temperature-bulk electrical conductivity (BEC) sensor with waveform capture. This instrument is an integrated time domain reflectometer that combines the ultrafast generation of waveforms and the digitization of functions.

The kriging interpolation method was used to interpolate the surface moisture data obtained through soil sampling. The ggplot2 package in

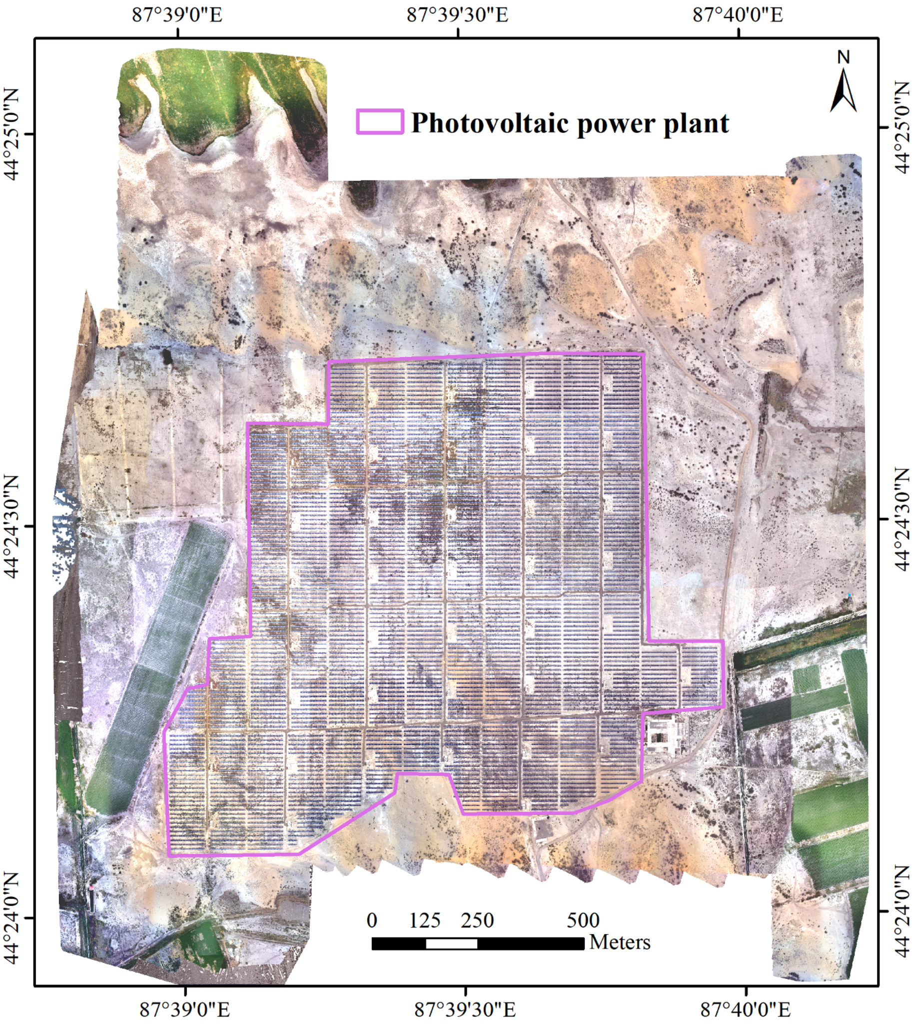

Fig. 1. Map showing the PPP analysed in this study.

Table 1
Flight and ground data acquisition schedule from 2020 to 2021.

Instrument	Year	Date	Samples	Height	Sensor	Note
UAV	2020	6.29–6.30	> 15,000 photos	150 m	Multispectral & TIR sensors	Before artificially eradicating some of the vegetation.
UAV	2021	9.28	> 8,000 photos	150 m	Multispectral sensors	After artificially eradicating part of the vegetation.
XRF Spectrometer	2021	9.28–9.30	744	0 cm	Silicon drift detector	The fence separates the photovoltaic power plant from areas outside the plant, and we monitored areas inside/outside of the plant.
Soil TDR	2021	9.28–9.30	690	−20 cm	Water-temperature-BEC sensors	Soil monitoring was performed in the same way as the X-ray monitoring above.

the R statistical program (R Development Core Team, 2017) was used to visualize the time series data. Linear regression and Pearson correlation analyses were performed to analyse the NDVI changes recorded before and after the construction of the PPP using the base library in R.

Results

Spatial pattern of vegetation

Two drip lines formed on the back and middle of each photovoltaic panel due to rain erosion (Fig. 2d). Abundant moss has grown in the drip line of each panel, while very little moss has grown in other areas. In addition to the moss growing near the drip line, vegetation growth is optimal near the panels, especially *A. desertorum* growth. The tamarisk growing outside the photovoltaic panel area reached a height of 3 m, and the height of some other vegetation reached approximately 1.5 m, thus reducing the solar radiation absorption potential of the photovoltaic panels. In September of each year, the vegetation between photovoltaic panels in the southern part of the PPP is artificially eradicated. The 2021 UAV flight experiments were performed after some vegetation was artificially removed (Fig. 2c).

Due to the shooting angle of the UAV and satellites, the vegetation hidden under the photovoltaic panels could not be photographed; as a result, the actual NDVI was larger than the NDVI values obtained through UAV and satellite monitoring. The NDVI data were derived from data collected by multispectral sensors mounted on drones. Farmland is affected by artificial seeding. The average NDVI of farmland in 2020 was 0.29, which is much higher than that inside and outside the PPP.

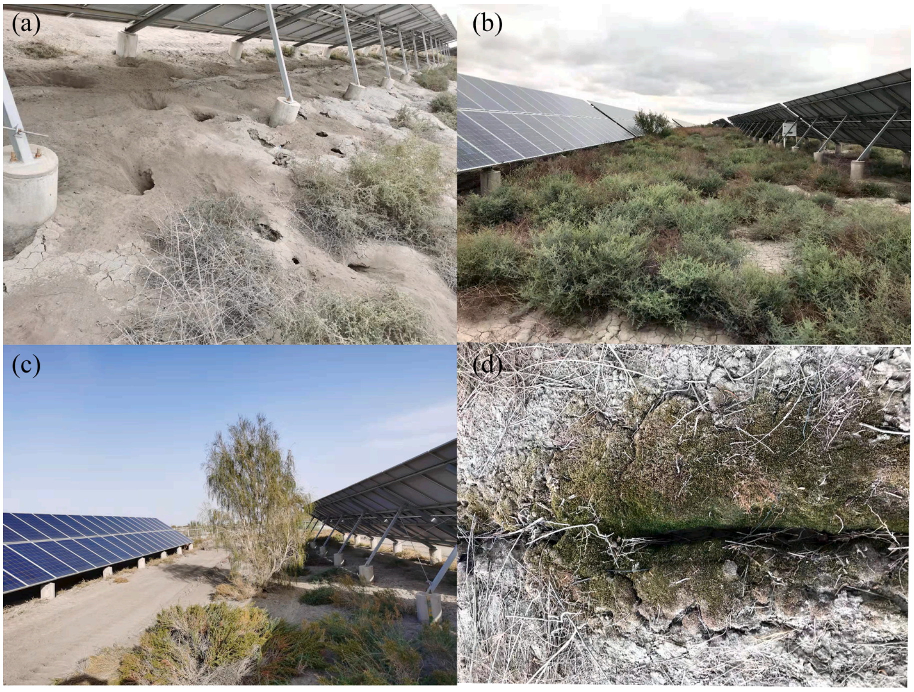

Fig. 2. Inside and outside of the analysed PPP: (a) calcified soil; (b) saline soil; (c) manual trimming; and (d) the drip line under a photovoltaic panel.

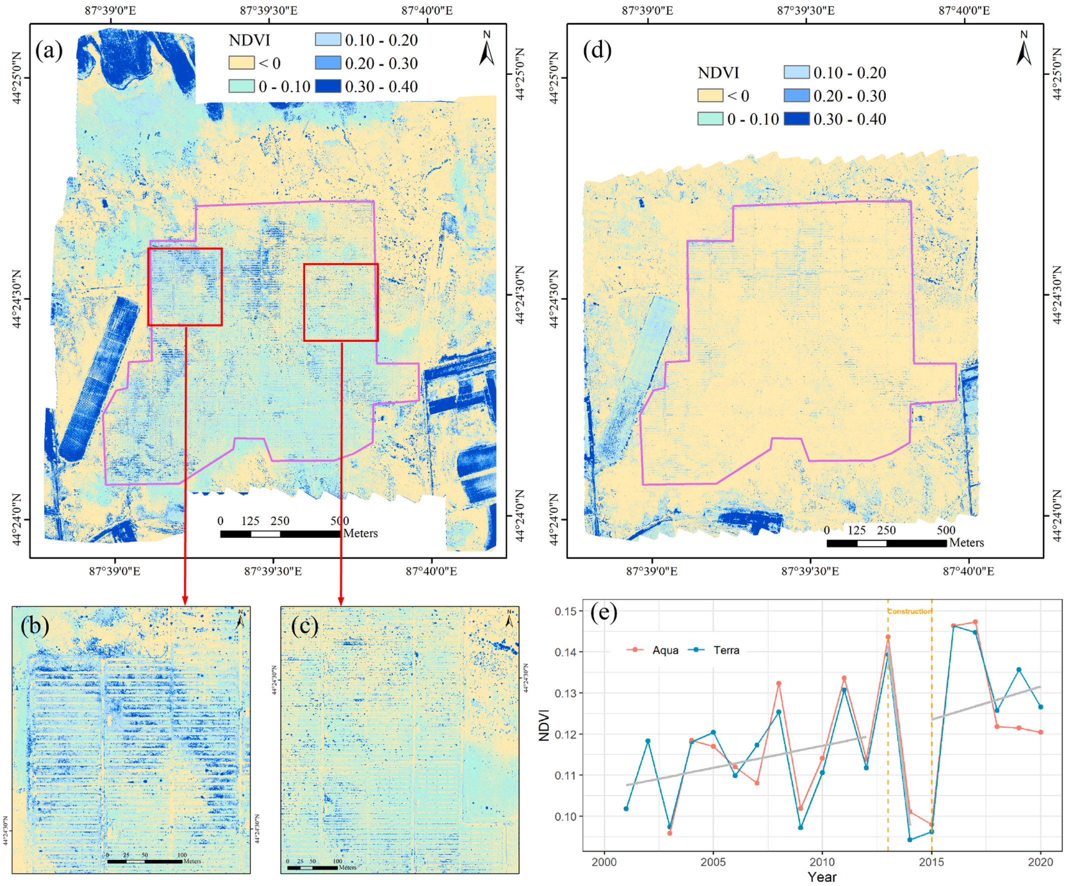

Fig. 3. NDVI spatial data inverted by multispectral sensors mounted on UAVs and moderate-resolution imaging spectroradiometer (MODIS)-derived NDVIs of the analysed PPP: (a) June 29–30, 2020; (b) NDVIs in dense vegetation areas (June 29–30, 2020); (c) NDVIs in sparse vegetation areas (June 29–30, 2020); (d) NDVI after the manual removal of vegetation (September 28, 2021); and (e) MODIS-derived NDVI from 2001 to 2020.

Therefore, without considering farmland, the average NDVI (0.05) of the PPP area is greater than that of the desert area outside the PPP (0.03) (Fig. 3). June is the growth period for vegetation both inside and outside the PPP, and September is the crop maturity and vegetation senescence period. At the same time, September is also the period in which the vegetation in the southern part of the PPP is artificially eradicated. The NDVI of the northwestern area inside the analysed PPP was significantly higher than the NDVI values in the other PPP areas. During this period, although the vegetation is greatly affected by human activities, the spatial distribution characteristics of the NDVI results obtained in 2021 were similar to those obtained in 2020, with the highest NDVIs corresponding to the northwest region of the PPP. By analysing remote sensing data derived from the Terra and Aqua satellites, the NDVI declined sharply from 2013 to 2015 as the ground vegetation was trimmed and the photovoltaic panels were installed. Even without considering the NDVI of the vegetation under the photovoltaic panels, the NDVI following the operation of the PPP was much larger than that recorded before the construction of the PPP.

Spatial patterns of soil chemical elements

Although the analysed PPP is located in a desert-oasis transition zone with sand dunes to the north and south, the soil type inside the PPP is dominated by *haplic Luvisols*. Through the monitoring conducted herein, we found that the calcium (Ca), ferrum (Fe), chlorine (Cl) and sulphur (S) concentrations were high in the study area and that there was little difference between the samples collected inside and outside the PPP (Fig. 4). These results suggest that the soil calcification state within the PPP is serious. The PPP is located on the edge of the Gurbantungut Desert in the Junggar Basin. Following the construction of the photovoltaic panels, the vegetation around the photovoltaic panels has grown well due to the shading, wind-sheltering, and water accumulation effects of the panels. The remaining Ca on the soil surface and the Ca released from plant decomposition transform to bicarbonate during the rainy season. As the conditions change, this bicarbonate deposits in the form of calcium carbonate in the middle and lower profile sections to form a calcium-accumulation layer. The salt accumulation caused by the rising

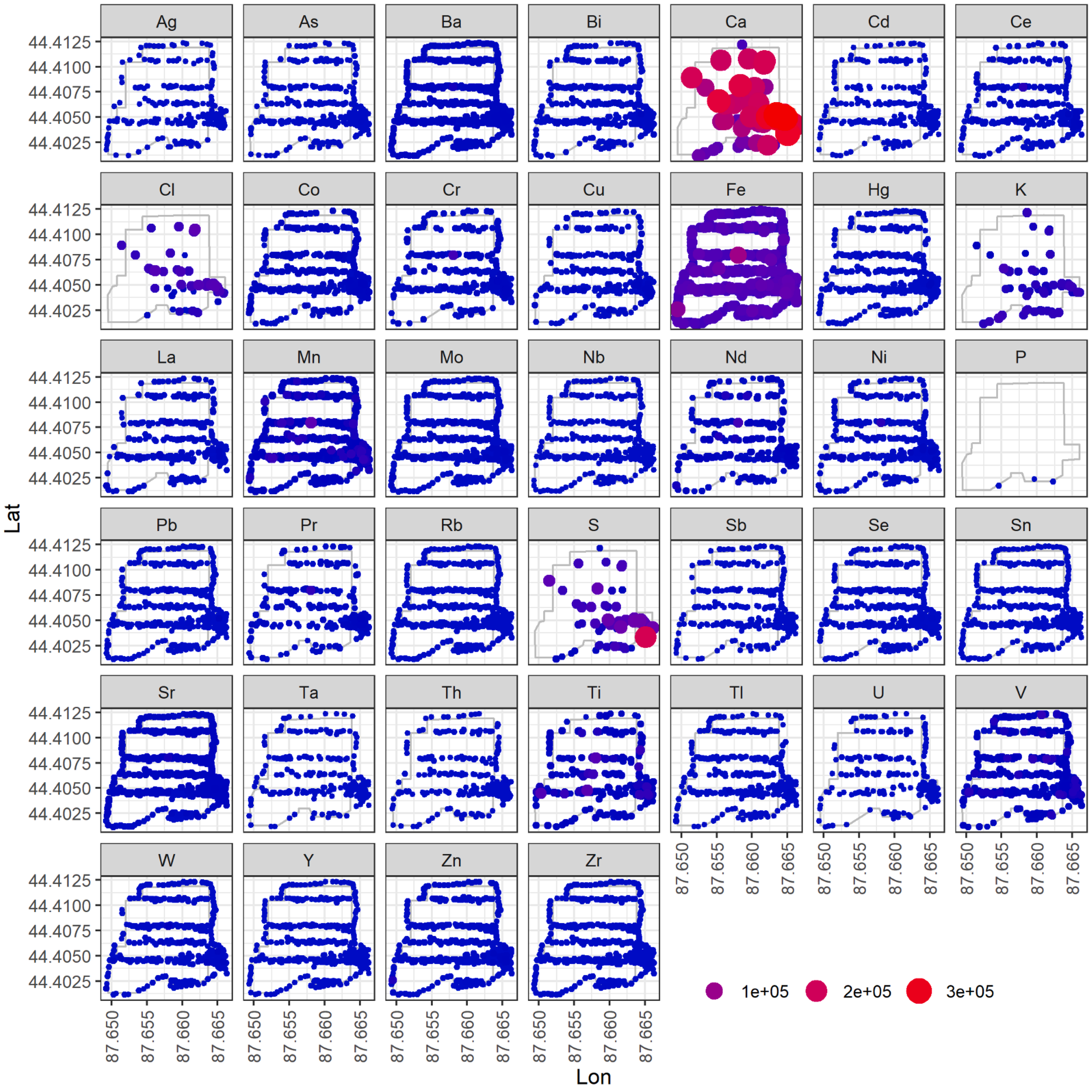

Fig. 4. Soil chemical compositions inside and outside the analysed PPP. The soil element concentrations are shown in units of ppm. The grey vector map delineates the construction area of the analysed PPP. The colour and size of each circle indicate the magnitude of the soil chemical composition.

groundwater capillaries has also aggravated salinization. Moreover, S has also appeared in the soil, which may be related to the cadmium sulphide contained in photovoltaic panels.

When analysing the differences between the concentrations of four chemical elements (Ca, S, Fe and Cl) measured inside and outside the PPP (Table 2), we found very small differences between the Fe concentrations inside and outside the PPP. However, the Ca, S and Cl concentrations inside and outside the PPP exhibited significant differences ($P < 0.05$). Much higher concentrations of these three elements were found inside the PPP, with values 3 times, 5 times and 1.7 times higher than those outside the PPP.

Spatial patterns of ground-surface soil conditions

The soil surface monitoring results showed significant spatial heterogeneity. The soil moisture contents in the northwestern area inside the PPP were higher than those in the other PPP regions, and the conductivity and moisture content showed similar spatial characteristics (Fig. 5). Soil electrical conductivity can generally reflect the soil fertility level and can therefore be used as an indicator of soil fertility and to estimate soil salt content. The average soil moisture content and electrical conductivity (11% and 635 μS/cm, respectively) inside the PPP were slightly higher than those outside the PPP (8% and 511 μS/cm, respectively). Although we sampled 690 soil temperature data points, the time span was too large, so we analysed only the data obtained by the TIR sensor. The TIR sensor acquired surface temperature data at a certain moment; however, the soil surface temperature must reflect an average obtained over multiple sampling times, and changes in the ground surface temperature can be easily affected by short-term weather. The ground surface temperatures derived using the TIR sensor in the PPP can be ranked in the following order: vegetation < photovoltaic panels < bare ground < gravel. The temperatures of the ground surfaces in front of and behind the photovoltaic panels were relatively low, forming two linear low-temperature zones. The temperature of the intersecting part of the low-temperature zone in each photovoltaic panel was also relatively low. By analysing the different surface temperatures inside, along edge and in the periphery zones of the PPP, we found that the photovoltaic panels had a shading effect. The internal temperature of the PPP was lower than the temperatures of the edge and periphery zones of the PPP; additionally, the surface temperatures of densely vegetated areas were lower than those of sparsely vegetated areas (Fig. 6). The spatial distribution of the surface temperature also shows that the vegetation coverage around the photovoltaic panel is higher than that outside the PPP.

Discussion

Impacts of vegetation condition

Due to the levelling of the ground, the construction of the PPP led to a sharp drop in NDVI; when the PPP became operational, the NDVI recovered rapidly, and the NDVI after this increasing trend with operation was higher than before construction. Regardless of the presence of farmland, the manual removal of vegetation, or the presence of vegetation under the photovoltaic panels, the NDVI values obtained inside the PPP were still higher than those derived outside the PPP. This shows that the operation of the PPP has improved the vegetation condition around the photovoltaic panels. The NDVI of the western part of the PPP was significantly higher than those of other areas in the PPP. The regional differences in NDVI within the PPP may be caused by subtle terrain differences.

When the photovoltaic panels are cleaned, it increases the water content of the shallow soil and provides additional moisture for vegetation growth under photovoltaic panels; this process is conducive to promoting the growth of vegetation under the panels and the restoration of the soil. In addition to the accumulation of rainwater from the photovoltaic panels, the panels had the advantage of the generation of condensation [21–23]. As an additional source of water for plants, dew may also positively impact vegetation in arid ecosystems [24]. Any slight increase in the water content is amplified, especially in arid areas, which may greatly impact plant growth and soil restoration [25]. In addition, many biological soil crusts were found under the two drip lines under each photovoltaic panel. The microtopography of condensed water is conducive to the occurrence of moss crust and reproduction [26]. Biological soil crusts promote the restoration of desert ecosystems, enhance soil stability, reduce erosion, facilitate carbon and nitrogen fixation, affect nutrient cycling and the spatial pattern of vegetation and critically affect soil erosion and terrestrial ecology [27]. The development and succession of biological soil crusts are crucial in the soil formation process and in the evolution of soil quality in desert ecosystems; thus, these crusts can be used as indicators to characterize soil quality changes in desert ecosystems [26,28]. PPPs affect the local temperature, humidity, and evapotranspiration conditions as well as other meteorological elements by redistributing radiation and moisture [29]. These microclimatic changes affect the local primary productivity, decomposition rate of organic matter, and carbon cycle and promote the growth of desert plants [30]. PPPs are thus likely to form relatively stable biological community systems, and vegetation coverage, biomass, and species richness have all been shown to increase in PPPs [2]. With these improvements to desert ecosystems, the numbers of some arthropods and soil microorganisms have also increased accordingly. Sites for PPPs can accommodate dryland flora and fauna species and provide sufficient space for natural ecosystems, thereby contributing to ecosystem stability [31].

Impacts of soil condition

In addition, the soil electrical conductivity and moisture content inside the PPP were higher than those outside the PPP, and the soil electrical conductivity and moisture content in the western region inside the PPP were higher than those in other areas inside the PPP. Electrical conductivity is an indicator of the salt content and fertility level [32], and the plants around the analysed PPP were mainly halophytes. This may indicate that the shading effect of the proposed PPP improved the storage of soil moisture and increased salinization. The surface water and groundwater in arid areas contain a considerable number of soluble salts. The construction and operation of the PPP will consume additional local water resources, resulting in the need to draw more groundwater from around the PPP in areas that already have limited water resources. Under the action of strong surface evaporation, these salts accumulate on the soil surface; as various soluble salts gradually accumulate on the soil surface or in the soil, soil salinization becomes severe [33,34]. The concentrations of three chemical elements (Ca, Cl and S) inside the PPP were much higher than those outside the PPP. We found that there is a layer of white salt crust on the surface of some soils in the photovoltaic power station, and the particles are fine and dense. This usually occurs in

Table 2
Statistics of several chemical elements with higher concentrations inside the PPP than outside (mean ± SD). The * symbol indicates significant ($P < 0.05$) differences between the chemical element concentrations of the soil collected inside and outside the PPP.

Element	Ca	Cl	Fe	K	Nd	P	S	Ti	V
Inside	167459±1828*	10077±136*	17848±599	6295±130	1168 ± 324	17±45	19562±260*	2308±577	2053±379
Outside	53426±575*	5965±205*	16705±645	9284±132	903 ± 285	109±41	4830±97*	2128±576	2142±377

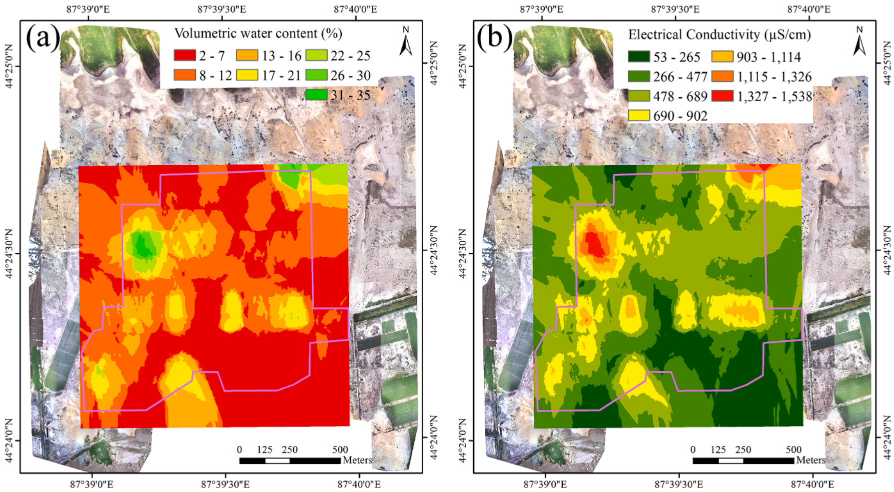

Fig. 5. Soil ground surface moisture and electrical conductivity measurements collected around the PPP: (a) the volumetric water content and (b) the electrical conductivity.

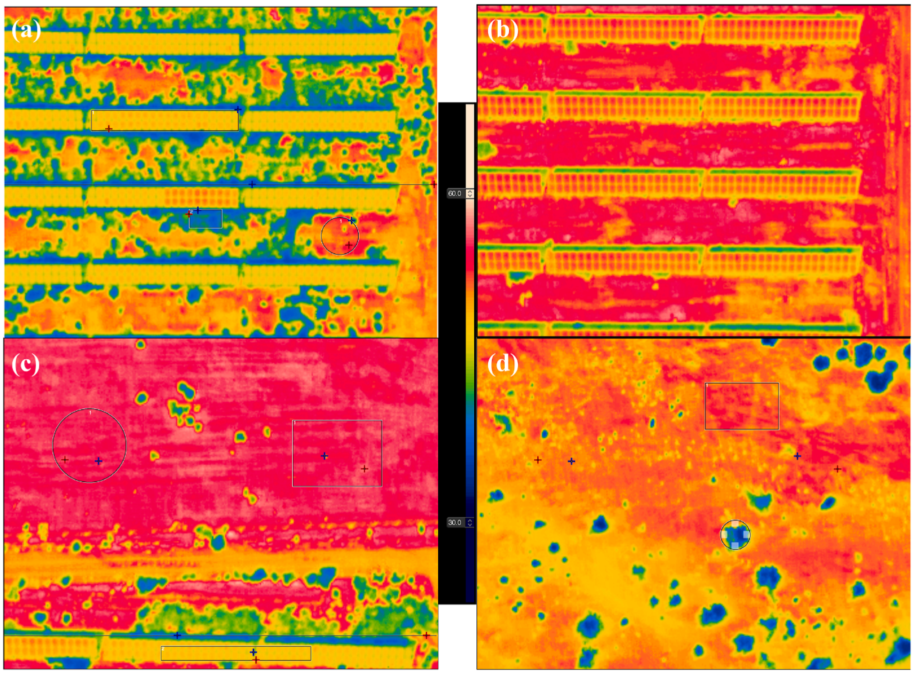

Fig. 6. Surface temperatures of different landscape types around the PPP: (a) dense-vegetation areas around the photovoltaic panels; (b) sparse-vegetation areas around the photovoltaic panels; (c) edges of the photovoltaic power plants (gravel floor); and (d) desert areas outside the PPP.

saline-alkali soil dominated by Na^+ and Cl^-, which is closely related to the higher Cl concentration and electrical conductivity we observed. In the studied ecosystem, Cl ions rise to the surface with soil water, the water evaporates, and the salt remains on the ground surface, thus aggravating the salt damage of the soil. High chlorine concentrations cause excessively high salt contents in soils, thus affecting the normal absorption of water and nutrients by root systems [35,36]. Soil calcification is an inherent feature of arid regions with shallow groundwater, and the significant difference found in the Ca concentrations measured inside and outside PPP indicates that the construction and operation of the PPP aggravated the soil calcification situation in the study area. Among the 744 sampling points, P was detected at only 3; this result may have been related to the proximity of the studied PPP to farmlands. Although the region outside the PPP was much larger than the region inside, the number of samples was still too small to obtain a solid conclusion regarding the increased P concentrations due to agricultural planting. Through monitoring, we found large heterogeneities in the soil moisture measurements; these variations were related to the soil texture. The artificially trimmed soils had higher ground temperatures. In addition, the S concentrations inside the PPP were much higher than those outside the PPP; this may indicate that the sulphur present in the photovoltaic system has been transported to the soil.

Future perspectives

The growth of vegetation blocks solar radiation and thus affects the power conversion efficiency of photovoltaics, and the vegetation around PPPs can easily ignite. In the studied PPP, all the vegetation in front of the photovoltaic panels was removed at the end of September, exposing completely bare soils. This kind of vegetation removal is too straightforward. Although the cost of removal is relatively low when this process is used, the fragile desert ecosystems are instantly destroyed when all vegetation is removed. The rainwater accumulation and shading effects of the PPP promoted the healthy development of desert ecosystems [37]. However, the water consumed during the construction and operation of PPPs in desert areas also needs to be assessed in the future. While analysing the impacts of PPP operations on surrounding ecological environments, it should be kept in mind that surrounding farmlands may also have certain impacts on PPPs. To find a balance between PPP operation and ecosystem management, the development of photovoltaic agriculture may be a better choice [38,39]. This approach may require analysing the mutual environmental impacts of farmland and photovoltaic power plants in the future, which will provide a reference for the environmental impact analysis of photovoltaic agriculture. Moreover, the development of photovoltaic agriculture in arid areas has been shown to achieve many remarkable economic and ecological benefits, and the labour cost associated with clearing vegetation can be converted into the establishment of photovoltaic agriculture [40,41]. The implementation of photovoltaic agriculture will have a positive impact on China's poverty alleviation plan. In addition to creating jobs, it will significantly improve the living standards of people in impoverished areas in the northwestern China [42]. Strengthening the benefits of PPPs for the ecosystems in arid areas and reducing their negative impacts will improve their application prospects, with positive impacts on the planning, sustainability, policies and management strategies of large-scale photovoltaic systems and the ability to provide clean power production.

Conclusions

The impacts of the construction and operation of large-scale PPPs on local ecological environments have become urgent scientific issues in regional decision-making regarding environmental protection. UAV-mounted multispectral and TIR sensors, X-ray fluorescence spectrometers and TDR soil sensors were used in this study to monitor the inside and outside of a large-scale, land-based PPP. We quantitatively evaluated the spatial changes in soil properties inside and outside the PPP as well as their differences and revealed the possible impacts of the construction and operation of the PPP on the local ecological environment. The construction and operation of photovoltaic power stations is a double-edged sword. This study found that the operation of PPP has rainwater accumulation and shading effects, which promotes the healthy development of desert ecosystems, such as promoting biological soil crusts and improve vegetation growth, thus improving the texture and nutrition of the soil. However, the Ca, S and Cl concentrations were found to be 3, 5 and 1.7 times higher inside the PPP area than outside the PPP area, respectively. In addition, the soil salinization is also more severe inside the PPP area. It is thus critical to communicate the PPP operation and agriculture impacts on desert ecosystems in a homogenous manner among all future studies. Overall, the remote sensing and ground-based monitoring methods applied in this study can provide a better understanding of the contribution of the construction and operation of PPPs to arid region ecosystem indicators. These metrics can serve as benchmarks for other large-scale PPPs in arid regions.

Data availability

Datasets and R code related to this article can be found at https://doi.org/10.17632/fy3csfm7kv.1, an open-source online data repository hosted at Mendeley Data. Remote sensing data are available upon request to the corresponding author.

CRediT authorship contribution statement

Lihui Luo: Conceptualization, Investigation, Methodology, Data curation, Visualization, Writing – original draft. **Yanli Zhuang:** Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition. **Hu Liu:** Methodology, Writing – review & editing. **Wenzhi Zhao:** Methodology, Writing – review & editing. **Jizu Chen:** Investigation, Writing – review & editing. **Wentao Du:** Investigation, Writing – review & editing. **Xiaoqing Gao:** Conceptualization, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgements

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