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Canopy temperature: as an indicator of soil salinity (a case study in Syrdarya province, Uzbekistan)

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Asbtract. A shift in the temperature of the canopy may signify stress in the plants. In laboratory and greenhouse trials, using canopy temperature for the measurement salt stress in certain agricultural crops was thoroughly examined; however, its potential application in landscape-level investigations employing remote sensing methods has not yet been investigated at different time series. A satellite thermography for measuring the soil salinity of agricultural areas at the provincial level was the subject of our investigation. The research area was the irrigated, semi-arid, and salt-affected agricultural land appertain to Syrdarya province in Uzbekistan, which was mostly planted with wheat and cotton. The provincial soil salinity map was considered as a ground truth data and the moderate-resolution imaging spectroradiometer satellite (MODIS) data were perceived as an indication for canopy temperature in this study. We investigated the relationships between the soil salinity, the normalized difference vegetation index, and canopy temperature, using analysis of variance. The findings indicated a strong inverse correlation between canopy temperature and soil salinity, although this relationship changed throughout the experimental years. For cotton, the highest correlation was shown in September. In comparison to the other variables looked at, canopy temperature had higher computed F values. Our findings indicate that soil salinity may be detected at the landscape level using satellite thermography in regions where crops are being grown.
Keywords: satellite thermography, soil salinity, remote sensing, canopy temperature, vegetation indices, Syrdarya province

1. Introduction
One of the main causes of land degradation is soil salinization, which frequently coexists with increased soil erosion rates, improper agricultural practices, mining, overgrazing, and deforestation [1, 2]. Both human intervention and natural processes lead to soil salinization [3, 4]. Arid and semi-arid climate conditions are highly affected by salinity. Over 100 countries and all sorts of climates are

represented by the approximately one-third of all agricultural fields that are becoming progressively salinated. While data on the size of salt-affected lands varies, estimates indicate that close to one billion hectares are salinized globally, with 77 million hectares of it being due to human-induced (secondary salinization [5]). Up to two million hectares of land are becoming salinized each year, which significantly reduces agricultural productivity [6].

There are vast stretches of salinized terrain in Central Asia. Approximately 50% of the 7 to 8 million irrigated hectares in this region are salty, of which 30% have increased salinity levels. In fact, one of the key reasons behind Central Asia's declining agricultural productivity is soil salinity [7]. In Uzbekistan, soil salinity affects 51% of irrigated land to some extent [8]. Highly salinized lands cover roughly two million hectares, costing Uzbekistan over one billion USD yearly [9].

For the purpose of implementing suitable management techniques and reclamation plans, current knowledge of soil salinity is essential. High geographical and temporal resolution data are very useful in this context. Traditional soil sampling methods and the corresponding laboratory studies are cumbersome, costly, and inappropriate for delivering high geographical and temporal specificity [10]. For instance, soil mapping is carried out every five years in Uzbekistan with a sample rate of one soil profile for every 100 hectares [11]. It is demanded to map enhanced soil salinity in farmed regions because to the significant geographical and time-scale changes in soil salinity. We set out to investigate this usage of remote sensing.

Since around 30 years ago, remote sensing has been used to measure soil salinity [12]. There have been two different remote sensing technology groups used. The soil reflectance when it is clear of vegetation is used by the first group, known as direct estimation, to determine salinity. The spectral reflection of canopy cover is used to infer salt stress in the second category of estimate techniques, known as indirect estimation, which employs vegetation reflectance as a measure of soil salinity. There are several strategies and methodologies for both approaches, but the majority employ salinity indices that are computed for bare soil or vegetation regions. In (semi-)arid regions all over the world, a number of these indexes are available and have been used with varying degrees of effectiveness [13–15]. Few studies have tested these indices after they were created for different soil types and in different areas. Those who have done so have discovered correlations and predictive power that are significantly lower than those first stated for the applications [16, 17]. The spectral sensitivity of to soil salinity has been investigated in greater detail, and classification methods based on sensitivity data have been suggested. These investigations have demonstrated decent performance for soil surface regions using both field and laboratory spectrometry of soils as well as analysis of aerial and satellite photos. Some sensitive spectral characteristics and spectral bands have now been established as a consequence. The near-infrared (NIR) and short-wave IR (SWIR) bands of Landsat and many other multispectral sensors [18] and the smaller absorption characteristics (NIR and SWIR) of the same spectral range [19–21] are the ones that have received the most attention among them. The employment of visible spectrums in addition to IR has been suggested by several writers [22, 23]. Dry saline soils exhibit greater overall reflectance than unaffected soils, according to Karavanova et al. [24]. To investigate soil salinity, almost every spectral band that is now accessible has been studied.

The use of vegetation as an oblique indication of soil salinity has been studied by a number of researchers [25–28]. Salinity hinders plant development and reduces yields, and remote sensing can identify these impacts. In general, a decreased NIR reflectance relative to the Red band is a sign of healthy plants and this might act as an indirect indicator of saline levels. However, using vegetation data to estimate soil salinity involves extra errors, just like any indirect indicator. For instance, a decreased NDVI (normalized difference vegetation index) can be brought on by a variety of variables, such as insufficient water supply and bad management. Additionally, for certain soils and vegetation species, it is challenging to locate vegetation indicators that could be linked precisely with soil salinity levels. Several techniques, the average vegetation index values per field and decision tree classification, have been employed [29, 30]. However, none has shown to be universally useful when performance in many contexts has been assessed.

Our investigation was conducted in a semi-arid cultivated region with considerable losses from salt in the soil. Reduced chlorophyll fluorescence and stomatal conductance are clear signs of crop stress response caused by soil salinity [31-34]. Significant fluctuations in canopy temperature can be due to stomatal closure. Unexpected changes in canopy temperature at the plant level with reference to soil salinity have been studied in several controlled laboratory and greenhouse investigations. The crops that were investigated were euonymus, *Philodendron erubescens* and *Syngonium podophyllum* [35], as well as grapevine [36], barley [37], wheat [38], sorghum [39], and cotton [40]. According to the findings of all these research, temperature variation can be utilized to detect plant stress due to salinity. The observed temperature variations in the canopy ranged from less than 1 ° to 1-3 °C [41] and even 8 °C [42].

The majority of earlier investigations on how soil salinity affects changes in canopy temperature were conducted on a plant-by-plant basis. Soil salinity assessment by canopy temperature or thermography has not yet been researched for this usage. Therefore, in the current work, we looked at the possibility of canopy temperature as a quick, non-destructive way to measure soil salinity in the irrigated lands of Syrdarya province in Uzbekistan from 2016 to 2019. Additionally, we evaluated the efficacy of thermal photography in comparison to the NDVI-based approach.

2. Materials and methods

2.1. Site description

The research area is the semi-arid, heavily salinized Syrdarya province of Uzbekistan (Figure 1). Syrdarya Province is situated in the middle of Uzbekistan on a sizable piedmont plain along the Syr Darya River’s western bank. The groundwater table is 1–2.5 m deep in the middle plain and climbs to 2–3 m on the terraces. The groundwater depth in depressions and hollows is 0–5–1 m. Additionally, the floodplains of the Syr Darya River show high groundwater levels (0.5–1 m; [43]). The majority of the province’s agricultural areas are damaged to varying degrees by salinity: 10% are highly saline, 61% moderately saline, and 22% weakly saline topsoil [43]. The region experiences 180–220 mm of annual precipitation on average, with typical annual temperatures of –5 °C in the winter and +28 °C in the summer. Crops are irrigated in furrows and wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum* L.) are the two principal crops in this province.

2.2. Mapping soil salinity

Using information from Uzgeodezkadastr [43] and the Scientific Research Institute of Soil Science and Agrochemistry of Uzbekistan [44] sources, we employed the 2019 soil salinity data at a provincial level and the 2019 soil salinity map for the reference dataset. The most recent maps that covered the whole research region, from 2016 to 2019 were chosen. According to methodological criteria for improving Solonetz soils and accounting for salt-affected soils, the maps were made. These recommendations call for the analysis of one soil profile that is two meters deep for every square kilometer of land. The Cl and SO_4 ion content served as the basis for classifying salinity. A distinction was made between non-saline, weak salinity, moderate salinity, and severe salinity of soils. The somewhat salinity class was most prevalent in the area, according to the maps.

2.3. Image analysis

The Aqua satellite carries a moderate-resolution imaging spectroradiometer (MODIS) that records satellite imagery that we employed for this study. Since Gómez-Bellot et al. [35] found the strongest association between salinity treatment and midday canopy temperature, we chose the Aqua satellite over the Terra satellite.

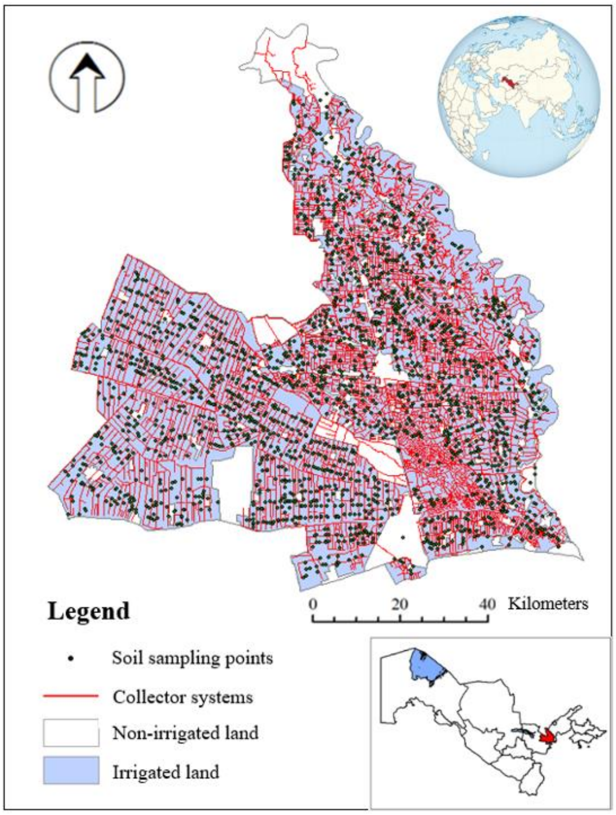

Figure 1. Map of the study area.

All datasets were first trimmed to the size of the research area and coordinated to the WGS 1984 UTM Zone 42 N reference system. After that, we extracted the irrigated land using an NDVI mask. We discriminated between pixels that were vegetated and those that were not employing the MOD13A2-based vegetation index and the NDVI threshold of 0.03. Only the canopy cover (NDVI > 0.3) were used for the rest of the analysis on the heat dataset and certain other remote sensing datasets. We determined the average values for the various parameters – surface temperature (T) and NDVI. The SPSS statistics program was used to conduct the statistical analysis [45]. Our primary strategy was analysis of variance (ANOVA), with F values being compared to assess the efficacy of the various indicators.

The monitoring point in time is crucial for irrigated areas. We repeated our investigation throughout the growth season to find the ideal period for salinity monitoring. All images that were accessible between April and September of 2016-2019 were analyzed, and F values for T and NDVI were computed.

3. Results and discussion

We examined images taken over the growth season (April–September) to find the ideal timing for soil salinity assessment between 2016-2019. Temporal characteristics of NDVI are shown in Figure 2. May and August are the vegetative maximum for wheat and cotton, respectively. Since NDVI declines from non-salty to very saline classes, the distinction among salinity classes is clear. The findings from the cotton season are more distinct and show bigger variances across salinity groups. Separations across salinity classes may be seen clearly and consistently in the canopy temperature record (Figure 3). High salinity regions get the greatest temperatures, whereas non-salinity regions experience the lowest temperatures. The graph displays averaged statistics for the whole research region. The thermal data's standard deviation for various time periods ranges from up to 1.5 °C.

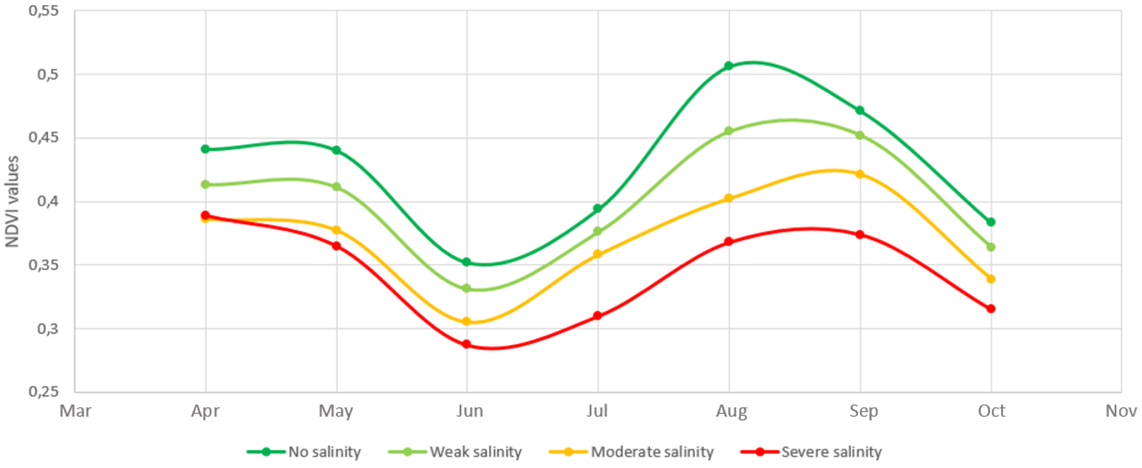

Figure 2. NDVI time series for Syrdarya province in Uzbekistan.

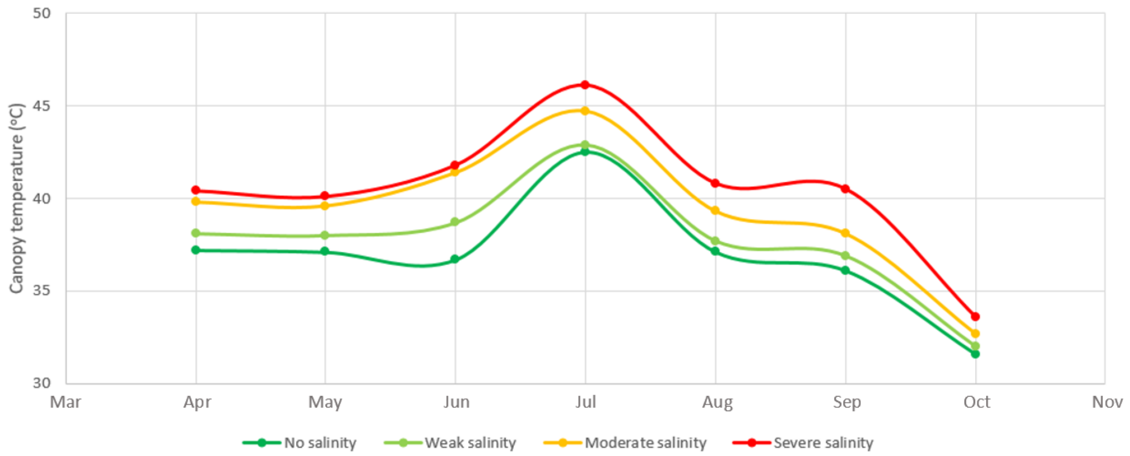

Figure 3. Canopy temperature time series for Syrdarya province in Uzbekistan.

The best correlation between thermal imaging and the soil salinity map, as shown by the outcomes of our ANOVA test, occurs from the end of August to the middle of September over the experimental years (Table 1).

Table 1. ANOVA tests (F values) between canopy temperature and NDVI for Syrdarya Province, Uzbekistan ($p < 0.01$).

Time	April	May	June	July	August	September
			2016			
Canopy temperature	20.6	22.3	34.2	30.7	35.1	33.9
NDVI	12.3	18.0	21.5	35.8	34.6	28.3
			2017			
Canopy temperature	21.2	23.1	32.5	32.4	36.7	32.3
NDVI	10.9	17.6	23.3	34.9	33.1	29.0
			2018			
Canopy temperature	19.4	22.8	35.6	31.9	34.4	34.1
NDVI	13.8	19.2	20.8	34.7	35.5	30.1
			2019			
Canopy temperature	25.2	27.1	32.9	33.0	37.3	38.2
NDVI	11.4	16.7	23.1	33.1	27.5	21.9

F values are often high from the end of July to the middle of September, which is when cotton development is at its peak. This suggests that during this time, soil salinity has the greatest impact on cotton. Winter wheat was insignificantly salt-affected during the wheat season since the F values were significantly lower but still considerable.

Similar regional trends were seen when the soil salinity record as well as the canopy temperature mapping were compared visually (Figures 4 and 5). The most salinity-prone regions of the province's center were where the canopy temperatures were greater. The NDVI and canopy temperature maps' visual interpretations showed a chaotic, cluttered pattern, that was not as obvious on the thermal map. Given the ANOVA findings, this is unexpected. Because these vegetative indices were previously employed for salt monitoring and other research indicated strong relationships, we would anticipate a greater resemblance with salinity.

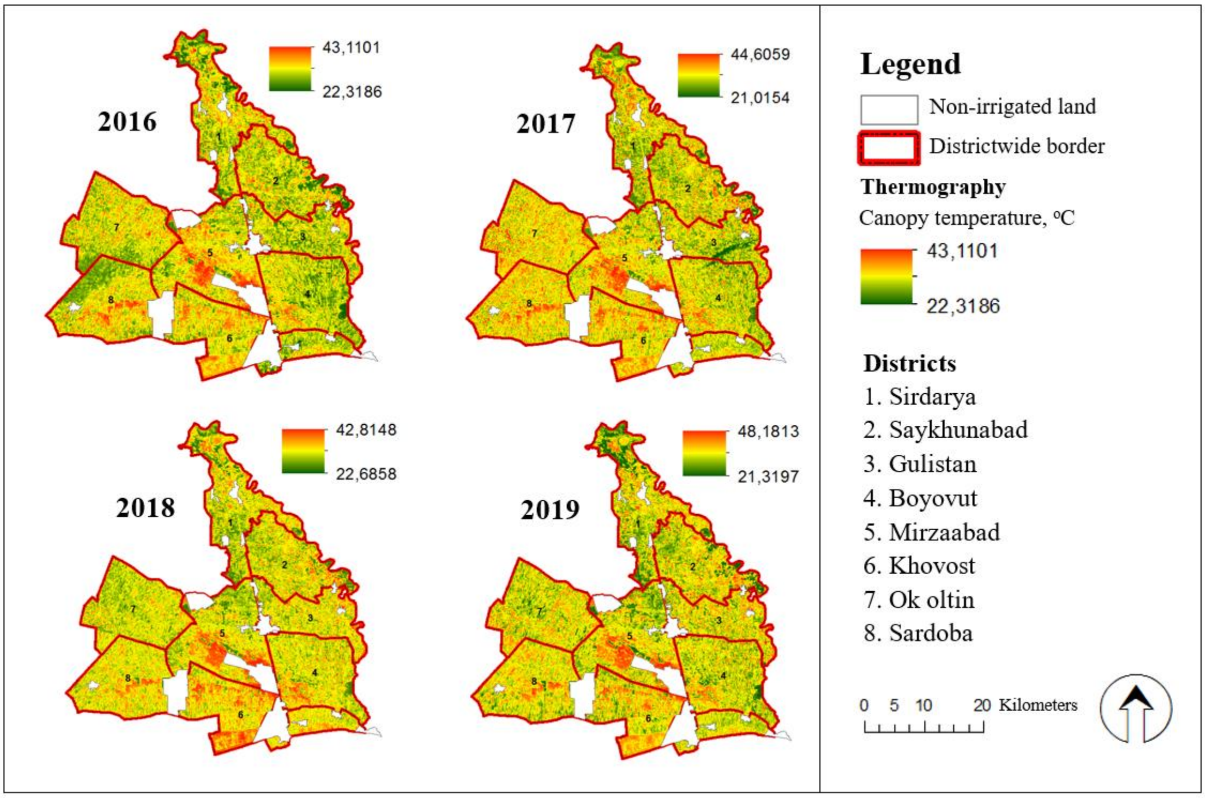

Figure 4. Canopy temperature time series maps for soil salinity assessment of Syrdarya province in Uzbekistan throughout 2016-2019.

Our study's major objective was to examine the possibility of thermal imaging as a quick, non-destructive tool to determine salt-affected in locations where crops are being grown. Our findings demonstrate a strong correlation between soil salinity and georeferenced canopy temperature at the local scale. Significant disparities between salinity groups were shown by statistical analysis. Despite a standard variation of 1-2 °C in the dataset, salinity class differences were clearly noticeable in the thermal imaging time series data (Figure 3). Interestingly, as indicated by the higher F values, the ANOVA output corresponding canopy temperature was significantly greater compared to that of vegetation indicators. Numerous earlier research [8, 21, 37] that employed vegetation indices frequently discovered significant relationships between soil salinity. We observed that canopy temperature performed adequately and revealed statistically significant variations between salinity classes, which may be due to a number of variables. First, our research site was a homogenous agricultural province where, at any one moment, the great majority of the land was submerged under a single crop. We were able to utilize the MODIS data with a 1 km spatial resolution because of its homogeneity. Other variables that may have influenced the temperature, such as irrigation schedule and management variations, may have gone unnoticed due to the coarse spatial resolution and sizable research region. These characteristics may have enabled the aggregate of our research area across a wider region and permitted the detection of patterns that would not have been obvious with more detailed data. The MODIS data's poor resolution, however, can also have drawbacks. The increased pixel size may muddle information from the soil and plants, influencing temperature readings. Future study may find it beneficial in this regard to utilise Landsat data. Since the 1970s, the Landsat archive has continuously collected data for the majority of the planet. Moreover, it has previously been demonstrated at the regional [32] and local [40] levels that Landsat data has the potential by using for soil salinity monitoring.

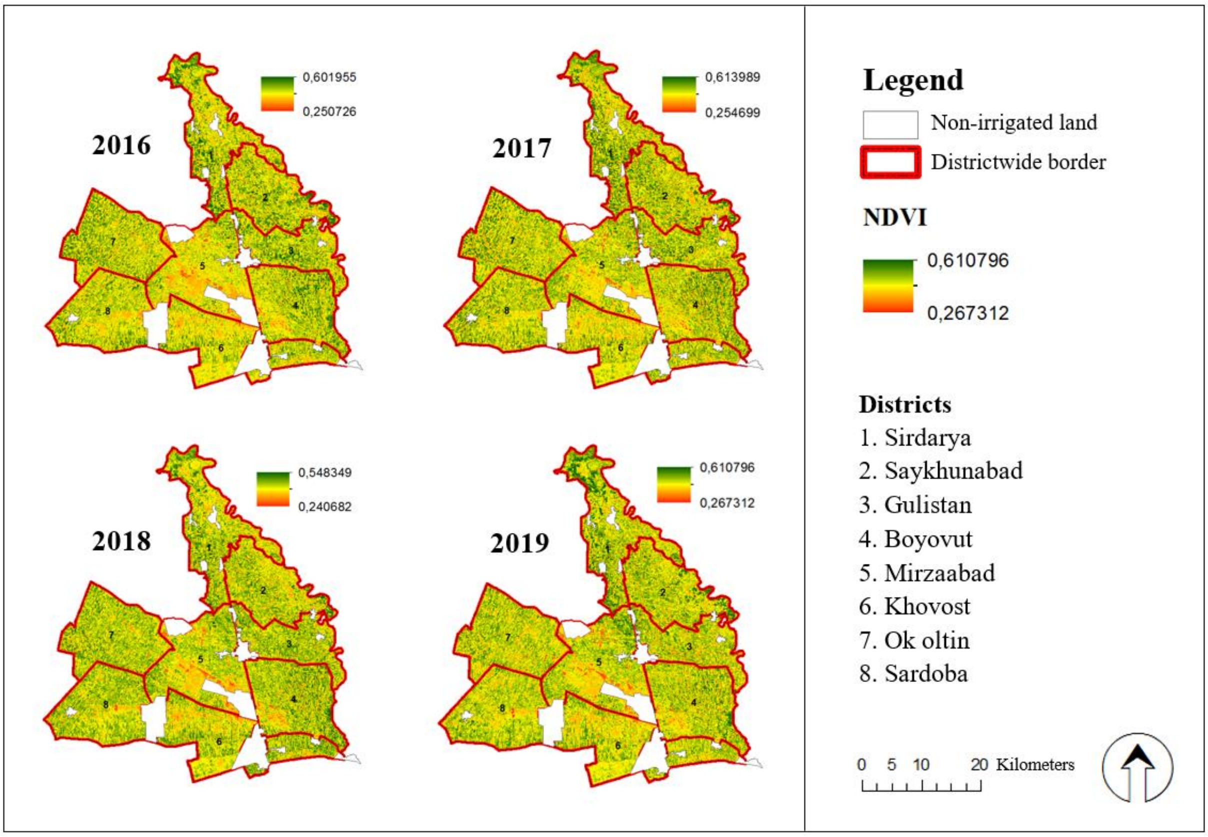

Figure 5. NDVI time series maps for soil salinity assessment of Syrdarya province in Uzbekistan throughout 2016-2019.

From the end of August to the middle of September, we discovered the greatest link between heat data and soil salinity. This is supported by Metternicht & Zinck [12], who discovered that the ideal period for monitoring was towards the conclusion of a dry season. However, instead of canopy thermography, their investigation made use of optical remote sensing to assess bare soil. However, their reasoning also makes sense in our situation. Salts are leached in in the study area from December to February. Therefore, due to recent leaching, the salt level in the active soil layer (root zone) is comparatively low in May, as winter wheat is fully grown and at its maximal biomass. As a result, there is an insufficient relationship among soil salinity and canopy temperature. Due to the capillary increase of saline groundwater, the impact of salts is more pronounced closer to the conclusion of a dry season. We found a greater association across soil salinity and canopy temperature throughout cotton season, irrespective of the fact, cotton is perceived to be more salt resistant than wheat [18]. We would anticipate fewer salt-tolerant (halophyte) crops (such corn, rice, and vegetables) for revealing an even higher correlation across soil salinity and canopy temperature according to the high capability for salt tolerance of cotton [12].

The study's straightforward methodology encourages more practical applications and the spread of the methodology to other fields. Of course, the simplicity also brings up problems, such as the difficulty in distinguishing signals from soil and plants and the have to take into consideration the irrigation schedule since irrigation would affect temperature. Future research might possibly be directed in one of these ways. We recommend using auxiliary data, such as information on groundwater level and soil types, in the analysis as an additional direction for future study. A technique for measuring soil salinity in agricultural lands that is adaptable enough to be used in a variety of (semi-)arid parts of the world may be created with the inclusion of auxiliary data. The data is free and widely accessible, and the techniques we employed here were simple. We thus view our research as a first step towards the development of a more broadly applicable method for determining soil salinity.

4. Conclusions

The current study investigated the viability of canopy temperature like a landscape-level predictor of soil salinity and evaluated its performance in comparison to the NDVI. We came to the conclusion that soil salinity and satellite thermography data are substantially connected. Our remotely sensed data produced F values that were higher than the other variables under investigation because they clearly discriminated across salinity classes. Additionally, a visual inspection of the maps revealed that the map created using vegetation indices was less representative of the real salinity patterns than the canopy temperature map. Thus, it appears that satellite thermography has a lot of promise for monitoring salinity in agricultural regions. The time of the monitoring, however, is crucial. The highest F values, which indicate the strongest prediction potential, were created by thermal pictures captured in September. However, the F values were generally consistent and shown strong associations throughout the entire experimental years, specifically from the end of July to mid-September, showing a great extent of potential for application in surveillance. The highest F values in Syrdarya Province, the study region, coincided with the height of crop growth towards the conclusion of the dry season. Additionally, in July and August, when the green biomass of cotton was almost at its peak, the highest F values for vegetation indicators were recorded. Therefore, the optimal time to use the techniques we utilized might be thought of as the period of maximal vegetation development following the dry season.

For our research region in Uzbekistan, we also discovered encouraging findings for employing satellite thermography to identify soil salinity levels in the irrigated lands. Evaluating the broad applicability of the suggested technique in terms of various crops and geographical locations may prove to be a fruitful direction for future study.

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