UDK 528.837:629.783:631.423.5(560)
Original scientific paper / Izvorni znanstveni članak

Evaluating the Atmospheric Correction Impact on Landsat 8 and Sentinel-2 Data for Soil Salinity Determination

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ABSTRACT. Remote sensing technology effectively determines and evaluates salinity-affected areas' spatial and temporal distribution. Soil salinity maps for large areas can be obtained with low cost and low effort using remote sensing methods and techniques. Remote sensing data are delivered raw as Level-1 data, and they can be further atmospherically corrected to surface reflectance values, Level-2 data. This study evaluates the atmospheric correction impact on Landsat 8 and Sentinel-2 data for soil salinity determination. The study has been supported with in-situ measurements in Alpu, Eskisehir, Turkey, where samples were collected from various agricultural fields simultaneously with the overpass of the satellites. Two different analysis cases have been used to determine the effect of atmospheric correction. The first is to examine the relationship between the measurements taken from the areas with mixed product groups and the salinity indices for both data types. The other is to investigate the relationship between the measurement values taken only from the wheat and beet groups and the salinity index values. The results show that atmospheric correction has a high effect on the relationship between spectral indices and in situ salinity measurement values.

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Especially in all cases examined in Landsat, it was observed that atmospheric correction led to an improvement of over 140%, while nearly 50% was observed in Sentinel on a product basis.

Keywords: remote sensing, atmospheric correction, soil salinity, Landsat 8, Sentinel-2.

1. Introduction

Soil salinity is a significant environmental problem that negatively affects plant growth and development, causing critical effects, especially in arid, semi-arid, and humid regions (Hoffman and Shalhevet 2007, Li et al. 2015, Metternicht and Zinck 2003, Rhoades et al. 1992). Also, soil salinity is generally experienced in semi-arid and arid areas with low precipitation, high evaporation, high water table, and high water-soluble salt content (Ding and Yu 2014, Sidike et al. 2014, Wang et al. 2019). Soil salinity caused by unconscious land and water management causes desertification and land degradation to reduce soil productivity and negatively affect existing biodiversity (Dehaan and Taylor 2003, Farifteh et al. 2006, Ashworth 2007, Gorji et al. 2015, Zhang et al. 2015). Soil salinity negatively affects 20% of the world's total cultivated areas and 33% of irrigated agricultural areas (Gorji et al. 2015, Shrivastava and Kumar 2015). Salinity, which negatively affects many areas of the world, also has adverse effects on the fertile agricultural areas in Turkey. 1.5 million hectares of agricultural land in Turkey have been affected by salinity due to improper irrigation and fertilization methods. Around 60% of these areas affected by salinity are considered slightly salty, 19.6% salty, 0.4% alkaline (sodium), and 8% salty-sodium (FAO 2015, Koç and Kanber 2020). For this reason, it is essential to ensure the restoration and reclamation of the soils facing the salinity problem, to increase the quality of the Eco-Environment, and to ensure regional sustainable development (Grunwald et al. 2015, Jabbar and Chen 2008, Ludwig et al. 2018, Peng et al. 2019, Wang et al. 2019). For this purpose, the development, implementation of an adequate soil reclamation program and the determination of spatial and temporal changes in soil salinity in ensuring the continuity of agricultural areas make a dynamic quantitative monitoring process important (Avliyakulov et al. 2020, Ivushkin et al. 2019).

In general, on-site measurement and laboratory analysis are used to determine salinity parameters, which are essential for ensuring soil sustainability. However, collecting soil samples and performing laboratory analyses is a very costly and time-consuming process. Besides, it is challenging to determine salinity in large areas using these methods, dynamically monitor the temporal and spatial change of the salting process and determine the regions that tend to be salted (Barbouchi et al. 2014, El Harti et al. 2016, Ijaz et al. 2020, Seifi et al. 2020). Remote sensing technology can be used to effectively determine and evaluate the spatial and temporal distribution of salinity-affected areas (Allbed and Kumar 2013, Corwin and Scudiero 2019, Ramos et al. 2020, Zhang et al. 2010). Using remote sensing methods and techniques, soil salinity maps for large areas can be obtained with low cost and low effort. For this purpose, various band ratio indices have been developed to determine salinity by remote sensing (Douaoui et al. 2006, Khan et al. 2005, Khan and Abbas 2007).

A satellite image is a two-dimensional array of intensity values known as Digital Number (DN). DN usually refers to pixel values that have not yet been converted into meaningful units such as top-of-atmosphere (TOA) radiance or reflectance. With atmospheric correction, scattering and absorption effects caused by the atmosphere are eliminated. Atmospheric correction is significant in analyzing multi-temporal imagery (Vermote and Kotchenova 2008). Digital Number values are converted to surface reflectance or Bottom-of-Atmosphere (BOA) reflectance values after this process.

In many studies to determine soil salinity by remote sensing methods, atmospheric correction is used to preprocess satellite images to eliminate atmospheric effects. Fan et al. (2015) applied an atmospheric correction to EO-1 (Earth Observing-1) remote sensing data. El Harti et al. (2016) used Dark Object Subtraction algorithm (DOS) (Chavez Jr 1988) to remove atmospheric effects. Davis et al. (2019) used Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) and Sen2cor module to atmospheric correction of Landsat 8 OLI and Sentinel-2 MSI images. Similarly, Sahbeni (2021) used FLAASH module to obtain top-of-atmosphere reflectance. Taghadosi et al. (2019) used Sen2cor module to produce surface reflectance of Sentinel-2 MSI image. In these studies, atmospheric correction is applied as a preprocessing while examining the relationship between salinity and remote sensing images. Unlike studies in the literature, the effect of atmospheric correction on salinity determination was investigated specifically in this study. Thus, this study explores the impact of the atmospheric correction on soil salinity determination using remote sensing data. For this purpose, two satellite images from the widest used satellite sensors, Landsat 8 and Sentinel-2 have been used. Also, in-situ measurements were done on the same data on the passing of the satellite over the study area.

2. Materials and Methods

The study was carried out in the Alpu district of Eskisehir, which has productive agricultural areas. Alpu district has an area of 1.059.130 decares and an altitude of 700 meters. When the distribution of this area was examined, it was determined that 400.490 decares were agricultural land, 389.640 decares were forest land, 220.700 decares were grass-pasture land, and 48.300 decares were non-agricultural land. When the lands used in agricultural production were examined, it was determined that 150.320 decares were wet farming land and 250.170 decares were dry farming land (Bursa Eskişehir Bilecik Kalkınma Ajansı 2012).

The in-situ measurements were carried out on 06.10.2020 and 07.10.020 in different cultivated areas located in Eskisehir, Alpu local region, such as beet, wheat, tomato, corn, etc. The sampling and land surveying performed in the study were performed using a random sampling method in cultivated and harvested areas. During the surveying process, the coordinates of each survey point were recorded using handheld GPS. The study area and location of terrestrial surveying points are given in Fig. 1.

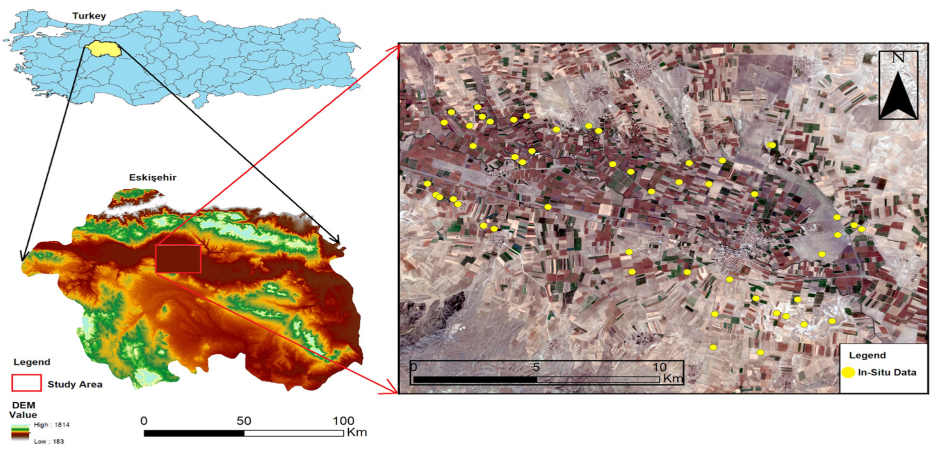

Fig. 1. *Study area and location of the in-situ measurements.*

Electrical conductivity values at terrestrial surveying points were surveyed using the PNT 3000 COMBI + device. In-situ measurements were carried out in three stages: (1) from the soil surface (EC-1); (2) 10 cm below the soil surface (EC-2), and (3) taking a soil sample from a depth of 0–10 cm (EC-3). The main reason for making three different electrical conductivity surveying is to determine the differences in the electrical conductivity values caused by irrigation. In-situ measurement process has been given in Fig. 2.

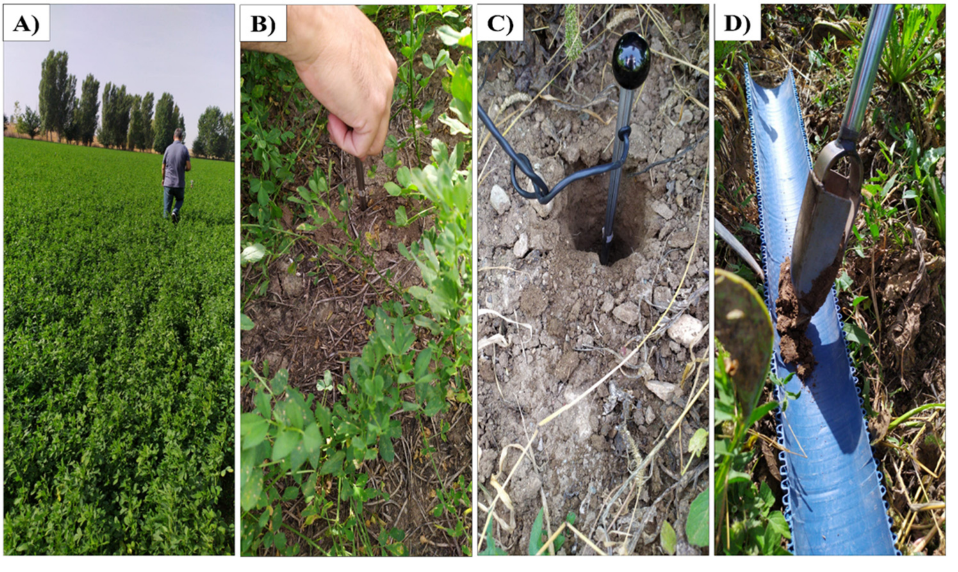

Fig. 2. *In-situ measurement: A) Random sampling measurement point determination on field B), C) EC measurement on the soil with PNT 3000 COMBI + device, D) Taking soil samples from the EC measurement point.*

This study investigates the atmospheric impact over salinity prediction on two different satellites, Landsat 8 OLI, and Sentinel-2. For this purpose, satellite images acquired from Landsat 8 over the study area on 07/10/2020 and Sentinel-2 acquired on 06/10/2020 were used. To achieve the study's goal, four satellite images were investigated in this study, two Landsat 8 and two Sentinel-2 images, before and after atmospheric correction.

While Landsat 8 OLI images have a spatial resolution of 30 m, Sentinel-2 offers four 10 m, six 20 m, and three 60 m bands. Landsat 8 and Sentinel-2 are currently the most recently used sources of open-access satellite data for various research topics. Technical specifications and comparison between the sensors are given in Table 1.

Table 1. *Comparison between Landsat 8 OLI and Sentinel-2 bands.*

Landsat 8 OLI			**Sentinel-2**		
Bands	**Spatial resolution (m)**	**Central wavelength (μm)**	**Bands**	**Spatial resolution (m)**	**Central wavelength (nm)**
B1 – Coastal	30	443	**B1 – Coastal**	60	444
B2 – Blue	30	482	**B2 – Blue**	10	497
B3 – Green	30	561	**B3 – Green**	10	560
B4 – Red	30	655	**B4 – Red**	10	665
			B5 – Vegetation Red Edge	20	704
			B6 – Vegetation Red Edge	20	740
			B7 – Vegetation Red Edge	20	782
			B8 – NIR	10	835
B5 – NIR	30	865	**B8A – Narrow NIR**	20	865
			B9 – Water Vapour	60	945
B9 – Cirrus	30	1337	**B10 – SWIR-Cirrus**		1375
B6 – SWIR 1	30	1609	**B11 – SWIR**	20	1614
B7 – SWIR 2	30	2200	**B12 – SWIR**	20	2202
B8 – Pan	15	590			

To investigate the impact of the atmospheric correction in the two sensors, commonly used spectral indices developed and used for detecting and mapping soil salinity has been calculated. Statistical prediction models have been designed in order to assess their correlation with the in-situ data. Spectral indices used in this study are given in Table 2.

Table 2. *Salinity indices used in the study.*

Salinity Index (SI)	Formula	Reference
SI_1	$SI_1 = \sqrt{B \times R}$	Khan et al. 2005
SI_2	$SI_2 = \sqrt{G \times R}$	Khan et al. 2005
SI_3	$SI_3 = \sqrt{G^2 + R^2 + NIR^2}$	Douaoui et al. 2006
SI_4	$SI_4 = \frac{G \times R}{B}$	Bannari et al. 2008

3. Results and Discussion

3.1. Landsat results

In this study, the effect of atmospheric correction applied to satellite images to relationship between the calculated salinity indices and the salinity values from the in-situ measurement was investigated. Firstly, in this direction, index values and measured salinity ratios obtained from images without atmospheric correction were examined by multiple regression. The values obtained from this analysis are given in Table 3.

Table 3. *Relationship between salinity indices and in-situ salinity values for Level-1 data.*

EC	R-Square	Ad. R-Square
EC-1	0.46	0.42
EC-2	0.19	0.17
EC-3	0.14	0.12

The results showed that the highest correlation was obtained with EC-1 values. In this direction, the model established using the spectral indices and the EC-1 values is given with Formula (1):

$$\hat{Y} = 3.89 + 0.0051 \cdot SI2 - 0.0043 \cdot SI1 - 0.0011 \cdot SI4 \qquad (1)$$

In the second stage of the study, the analyzes were repeated for the index values obtained from the atmospherically corrected images and the measured salinity rates. The values obtained from this analysis are given in Table 4.

Table 4. *Relationship between salinity indices and in-situ salinity values for Level-2 data.*

EC	R-Square	Ad. R-Square
EC-1	0.52	0.50
EC-2	0.32	0.30
EC-3	0.40	0.39

The results showed that the highest correlation was obtained with EC-1 values. The model established using spectral indices and EC-1 value is given in Formula (2):

$$\hat{Y} = 4.53 + 0.001 \cdot SI3 - 0.0049 \cdot SI1 \quad (2)$$

Another case we examine to see the effect of atmospheric correction on the relationship between spectral salinity indices and EC values is product-based analysis. Accordingly, measurements were taken from wheat and beet fields. The relationship between the measured values and salinity indices was examined before and after atmospheric correction. In this direction, the relationship between the measurements taken from the wheat field and the salinity indices is given in Table 5.

Table 5. *Relationship between salinity indices and in-situ salinity values for data obtained from Wheat Fields.*

	EC	R-Square	Ad. R-Square
Before Atm. Correction	EC-1	0.49	0.46
	EC-2	0.25	0.21
	EC-3	0.48	0.41
After Atm. Correction	EC-1	0.51	0.48
	EC-2	0.62	0.60
	EC-3	–	–

When the results obtained were examined, it was observed that there were differences in all EC values. R^2 and Adjusted R^2 values of EC-2 values showed a significant increase.

A similar analysis was made for the values collected from the beet field. When the results obtained were examined, it was observed that atmospheric correction had a great effect on the values. There was no significant relationship between the spectral index and in-situ salinity value before atmospheric correction. High significance was observed in EC1 and EC3 values after atmospheric correction.

3.2. Sentinel-2 results

The soil salinity indices were also calculated for the Sentinel-2 Level-1 and Level-2 data, and the results were evaluated using the in-situ measurements done in the scope of the study. It is important to mention that the in-situ measurements were done over different yield types. Statistical analyses were done using all of the in-situ measurements with EC-1, EC-2, and EC-3. First, we present the Sentinel-2 Level-1 results.

The results from the analyses using the Sentinel-2 Level-1 data showed the highest correlation between EC-3 and the used indices, followed by EC-1 and EC-2. The results are shown in Table 6.

Table 6. *Correlation between Sentinel-2 Level-1 indices and in-situ measurements.*

EC	R-Square	Adj R-Square
EC-1	0.39	0.36
EC-2	0.28	0.26
EC-3	0.47	0.45

Afterward, statistical models were calculated for each salinity parameter. The statistical model of EC-1 and the calculated indices are shown in Equation (3). While no meaningful statistical model was found using EC-2 data, the statistical model using EC-3 and salinity indices showed the highest correlation. The EC-3 model uses SI3 and SI4 indices. The model is given in Equation (3). EC-3 showed significant results using three of the four used indices with $R^2 = 0.47$ and Adj $R^2 = 0.45$.

$$\hat{Y} = 1.67 + 0.00007 \cdot SI3 - 0.002 \cdot SI4 \tag{3}$$

The results from the analyses using the Sentinel-2 Level-2 data showed the highest correlation between EC-3 and the used indices, followed by EC-1 and EC-2. The results are shown in Table 7.

Table 7. *Correlation between Sentinel-2 Level-2 indices and in-situ measurements.*

EC	R-Square	Adj R-Square
EC-1	0.38	0.35
EC-2	0.26	0.24
EC-3	0.49	0.47

The statistical model using SI3 and SI4 showed a significant correlation of $R^2 = 0.49$ and Adj $R^2 = 0.46$. The model is given with Equation (4):

$$\hat{Y} = 1.95 + 0.0005 \cdot SI3 - 0.001 \cdot SI4 \tag{4}$$

Another case we examine to see the effect of atmospheric correction on the relationship between spectral salinity indices and EC values is product-based analysis. Accordingly, measurements were taken from wheat and beet fields. The relationship between the measured values and salinity indices was examined before and after atmospheric correction. In this direction, the relationship between the measurements taken from the wheat field and the salinity indices is given in Table 8.

Table 8. *Relationship between salinity indices and in-situ salinity values for data obtained from Wheat Fields.*

	EC	R-Square	Ad. R-Square
Level-1	EC-1	0.47	0.40
	EC-2	0.34	0.30
	EC-3	0.56	0.50
Level-2	EC-1	0.53	0.47
	EC-2	0.51	0.55
	EC-3	0.59	0.53

When the results obtained were examined, it was observed that there were differences in all EC values. R^2 and Adjusted R^2 values of EC-2 values showed a significant increase.

A similar analysis was made for the values collected from the beet field. When the results obtained were examined, it was observed that atmospheric correction has no significant relationship between the spectral index and in-situ salinity value for the beet fields.

As soil salinity is becoming a big concern for sustainable agriculture management, monitoring soil salinity is essential for decision-making. As one of the alternatives to estimate soil salinity in a more practical way than the conventional methods, remote sensing has been successfully used in many studies (Çullu 2003, Ivushkin et al. 2018, Masoud et al. 2019). However, the use of the type of satellite data, atmospherically corrected or not, for soil salinity estimation has not been investigated in detail. Thus, this study aimed at investigating the effect of atmospheric correction over Landsat 8 and Sentinel-2. For this reason, we used two satellite images from each sensor, Level-1 and Level-2 two and compared the results.

The results showed that the atmospheric correction did cause a significant difference between the in-situ measurements and the calculated salinity indices from the satellite images. When the results obtained with Landsat images are examined, it is observed that atmospheric correction increases the relationship in both cases. This increase was higher on a product basis. Similarly, if Sentinel-2 results are considered, it is observed that the most significant effect of atmospheric correction is seen in the analysis made with the measurements taken from the wheat field. These results are similar to the study of Sharma et al. (2008), who investigated the atmospheric correction impact over mase and sunflower using IRS-P6 LISS IV data. Their results were showed that while there was no impact in band 1 and band 2, band 3 and the NDVI values showed significantly different values (Sharma et al. 2008).

Information about the studies on salinity determination by remote sensing is given in Table 9. It is seen that atmospheric correction is generally applied as a pre-processing in salinity determination studies. The study with the highest R^2 value for Sentinel-2 MSI is Farahmand and Sadeghi (2020) with 0.98. In this study, the atmospheric correction process has been applied before the soil salinity determination. Similarly, Didi et al. (2017) have achieved 0.94 R^2 for soil salinity determination using atmospherically corrected Landsat 8 OLI data. There are two studies in which atmospheric correction was not performed. El hafyani et al. (2018) have used Landsat 8 OLI images as a result of multiple regression analyses, they have achieved 0.75 R^2. Similarly, Habibi et al. (2021) used Landsat 8 OLI images and they have achieved 0.80 R^2 as a result of an Artificial Neural Network regression model.

Table 9. *Studies on salinity determination with remote sensing.*

Reference	**Satellite Sensor**	**Atmospheric Correction**	**Number of Samples**	**Method**	R^2
Gorji et al. 2017	Landsat 5 TM	Yes	28	Exponential regression analysis	0.93
Nguyen et al. 2021	Landsat 8 OLI	Yes	143	XGR-GOA	0.86
Abuelgasima and Ammadb 2019	Landsat 8 OLI	Yes	30	Exponential regression analysis	0.71
Didi et al. 2017	Landsat 8 OLI	Yes	35	Linear regression analysis	0.94
El hafyani et al. 2018	Landsat 8 OLI	No	25	Multiple Regression Analysis	0.75
Habibi et al. 2021	Landsat 8 OLI	No	63	Artificial Neural Network	0.80
Ijaz et al. 2020	Landsat 8 OLI	Yes	55	Linear regression analysis	0.55
Fourati et al. 2015	Landsat 8 OLI	Yes	75	Linear regression analysis	0.52
Wang et al. 2021	Landsat 8 OLI	Yes	60	Artificial Neural Network	0.62
Ramos et al. 2020	Sentinel-2 MSI	Yes	80	Multiple Regression Analysis	0.91
Wang et al. 2021b	Sentinel-2 MSI	Yes	160	SVM	0.88
Gopalakrishnan and Kumar 2020	Sentinel-2 MSI	Yes	198	Partial Least Squares Regression (PLSR)	0.69
Gorji et al. 2020	Landsat 8 OLI Sentinel-2 MSI	Yes	70	Multiple Regression Analysis	0.77 0.75
Wang et al. 2020	Landsat 8 OLI Sentinel-2 MSI	Yes	64	Multiple Regression Analysis	0.89 0.91
Farahmand and Sadeghi 2020	Sentinel-2 MSI	Yes	38	Nonlinear Regression Model	0.98
Taghadosi et al. 2019	Sentinel-2 MSI	Yes	58	Support Vector Regression	0.87

In the studies of El hafyani et al. (2018) and Habibi et al. (2021), applying atmospheric correction as a pre-processing could increase R^2 values. On the other hand, lower correlations could have been obtained in other studies if atmospheric correction had not been used. The fact that atmospheric correction was made in all studies that exceeded the R^2 of 90% threshold supports the findings of this study.

4. Conclusion

Soil salinity, which occurs naturally or due to human-induced reasons, is a severe environmental problem, especially in arid and semi-arid areas. Therefore, it is vital to monitor and map soil salinity at an early stage to produce an effective soil reclamation program that helps reduce or prevent the future increase in soil salinity. Remote sensing is an essential tool that can be used to monitor soil salinity with up-to-date and accurate data. However, these valuable data obtained by remote sensing methods must be processed correctly and made ready for use.

In this study, we used both Level-1 and Level-2 images of Landsat 8 and Sentinel-2 to calculate spectral salinity indices to investigate the impact of atmospheric correction over satellite images for soil salinity prediction in various agricultural fields in Central Anatolian Turkey, Eskisehir, Alpu. We conducted the study in two different scenarios. In the first scenario, salinity values obtained from mixed product groups were used. In the second scenario, only the data from the wheat and only beet fields were used.

The results showed a significant difference between the Level-1 and Level-2 data over the salinity indices. For Landsat OLI images, while the R-Square value of EC-1 was 0.49 before atmospheric correction, this value increased to 0.51 after atmospheric correction. Similarly, EC-2 increased significantly from 0.25 to 0.62. It was observed that atmospheric correction led to an improvement of over 140% on Landsat 8 OLI images. When Sentinel-2 results are examined, it is seen that higher R-Square is obtained for all EC values after atmospheric correction. In particular, the EC-2 increased from 0.34 to 0.51. Overall, a nearly 50% increase was observed in Sentinel on a product basis. This work contributes to existing knowledge of soil salinity determination using remote sensing by examining atmospheric correction impact. Further research should be carried out to establish the atmospheric correction impact on soil salinity determination in different crop types.

ACKNOWLEDGMENT. This study was supported by Eskisehir Technical University Scientific Research Projects Commission under grant no: 19ADP084. All authors contributed equally to the study.

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Procjena utjecaja atmosferske korekcije na podatke Landsat 8 i Sentinel-2 za određivanje saliniteta tla

SAŽETAK. Uz pomoć tehnologije daljinskih istraživanja učinkovito se određuje i procjenjuje prostorna i vremenska rasprostranjenost područja zahvaćenih salinitetom. Karte saliniteta tla za velika područja mogu se izraditi uz niske troškove i malo truda koristeći metode i tehnike daljinskih istraživanja. Podaci dobiveni daljinskim istraživanjima isporučuju se neobrađeni kao podaci Level-1 te se zatim mogu atmosferski korigirati na vrijednosti površinske refleksije, podaci Level-2. Ova studija procjenjuje utjecaje atmosferske korekcije na podatke Landsat 8 i Sentinel-2 za određivanje saliniteta tla. Studija je potkrijepljena mjerenjima in situ u Alpu, Eskisehir, Turska, gdje su uzorci bili prikupljeni na različitim poljoprivrednim poljima istovremeno s preletima satelita. Upotrijebljene su dvije različite analize kako bi se odredio učinak atmosferske korekcije. Prva je analiza primijenjena kako bi se ispitao odnos između mjerenja provedenih na područjima s miješanim skupinama proizvoda i indeksima saliniteta za obje vrste podataka. Druga je analiza primijenjena kako bi se istražio odnos između vrijednosti mjerenja dobivenih samo iz skupina pšenice i repe te vrijednosti indeksa saliniteta. Rezultati pokazuju da atmosferska korekcija ima visok učinak na odnos između spektralnih indeksa i vrijednosti mjerenja saliniteta in situ. Posebno se u svim slučajevima ispitivanja putem Landsata moglo primijetiti da je atmosferska korekcija dovela do poboljšanja za više od 140%, dok je gotovo 50% primiećeno za Sentinel na temelju proizvoda.

Ključne riječi: daljinska istraživanja, atmosferska korekcija, salinitet tla, Landsat 8, Sentinel-2.

Received / Primljeno: 2021-08-20

Accepted / Prihvaćeno: 2021-09-25