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REMOTE SENSING FOR THE DETECTION OF SALINIZED SOIL USING A MULTISPECTRAL SENSOR IN THE ZERAVSHAN RIVER BASIN

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ABSTRACT

The Aral Sea Basin in Central Asia is a region plagued by a severe water crisis caused by the rapid expansion of irrigated land during the 19th century. This has in turn resulted in some emerging environmental problems including increased soil salinization. In order to understand the problem of salinity in farmlands, this study attempted to detect salinized soil in the Zeravshan river basin in Uzbekistan using satellite analysis. 15 salinity indices computed from MODIS spectral bands were applied. These indices were derived from existing techniques and consist of both the direct and indirect methods of salinized soil detection. Evaluation of Electrical Conductivity (EC) measurements collected from canals in this basin in August 2017 and MODIS reflectance data showed that all bands have a sensitivity to salinity changes. Results show that vegetation indices generally decreased with an increase in salinity, while reflectance indices increased with an increase in salinity. However, all of the indices reviewed had a low correlation with the EC measured. The R^2 value for some of the vegetative indices was: 0.0493 for Ratio Vegetative Index (RVI) and 0.0674 for Normalized Difference Vegetative Index (NDVI) while that of Salinity Indices was: 0.1109 for Salinity Index SI2, 0.1001 for Salinity Index S3 and 0.0976 for Salinity Index SI1. These results reflect on the negative impact of salinity on vegetation since the vegetation based indices decreased with an increase in salinity.

Keywords: Aral Sea Basin, Zeravshan river basin, MODIS, Soil salinization

1 INTRODUCTION

The Union of Soviet Socialist Republics (USSR) installed a massive scale irrigation project in the Aral Sea from the late 19th century until the collapse of USSR in 1991 (Micklin, 2000). This has resulted in some emerging environmental problems including excessive loss of water through low irrigation efficiency and increased soil salinization. The overall irrigation efficiency is a product of water application and conveyance efficiency and in this region, it is quite low with some studies estimating it to be between 30 and 50 percent (Nazirov, 2005; Ryan et al., 2004). Furrow irrigation is the main irrigation application technique used and this leads to excessive use of water beyond the plant water requirement. In addition, due to a lack of anti-filtration coating in the conveyance and distribution systems, water is lost through infiltration. Secondary salinization is a common persistent problem and occurs when the excessive application of irrigation water rises the groundwater level bringing the dissolved salts closer to the soil surface. Irrigation water naturally contains some dissolved salts and when plants use up this water, salts are left behind and eventually begin to accumulate. Central Asia is said to be one of the most severely affected regions by the salinization of irrigated land worldwide (Owens, 2001). Toderich et al., (2008) mentioned that, in the Syrdarya province, land affected by salinization, especially human-induced increased from 87 to 95 percent within 5 years. Of this, more than 80 percent of the land was considered heavy saline. A study by Bucknall et al. (2003) reported that water application rates in the basin are extremely high leading to a reduced quality of farmland through rising groundwater table and induced soil salinization. Ibrakhimov et al., (2007) also reported on the consequence resulting from the rising groundwater in Khorezm region Uzbekistan. On average, secondary soil salinization is annually adding 3.5 to 14 tons per hectare of salts.

Figure 1 (a) below shows a farm with accumulated salt on the soil surface as a result of high groundwater levels and (b) shows leaching water applied to a farm in Karakalpakstan located in lower Amu Darya. In order to prevent salinity in the irrigated soils from affecting crops, leaching water is applied. Leaching is the process of applying water in excess of the evapotranspiration needs of the crop in order to wash out salts in the root zone. This process further increases the water demand during spring. In highly saline regions such as Karakalpakstan, water for leaching accounts for one-third of the total water use (Bucknall et al., 2003). Central Asia is located in an arid region and drought days are expected to increase more than three times in most areas by the end of the 21st century (Hirabayashi et al., 2008). Since leaching and drainage are required to maintain salt balance in the soil profile and to sustain crop yield in arid areas, an accurate estimation of the extent of salinized soil is required for planning environmental preservation and economic growth.

(a) Salinized farm (b) Leaching water applied in a farm

Figure 1. Irrigated farmland in Uzbekistan

FAO, (2016) reported that the assessment of salinization at the national level was found to be difficult and very little information on the subject could be found. A study by Khujanazarov et al., (2012) reported that there was an increase of salinity levels in the Zeravshan river basin with time and from upstream regions towards the downstream as shown in **Figure 2** below. This gradation of salinity is attributed to salt load in the return flows from irrigated areas discharged via the collector drains, which are usually poorly maintained.

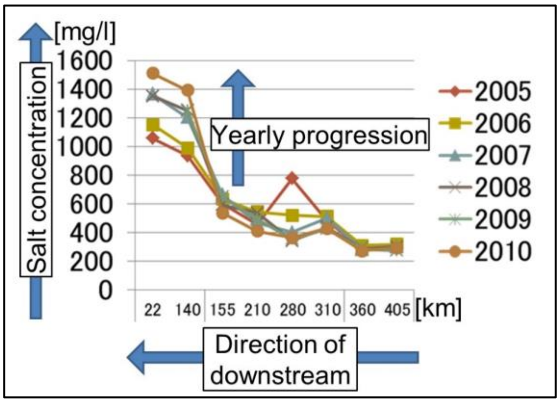

Figure 2. Salinity increase along the Zeravshan River (Khujanazarov et al., 2012)

The conventional method, of measuring soil salinity by collecting in-situ soil samples, and analyzing the solute content and electrical conductivity in the lab is both costly and time-consuming. Remote sensing techniques are therefore being progressively applied for the monitoring and mapping of these saline soils. It presents an invaluable opportunity for a detailed spatial and temporal observation of both the variability of irrigated land area and soil salinization and shows the potential to overcome the lack of information on water management in Central Asia at a regional scale (Conrad et al., 2007). Remote sensing analyses have been carried out using a variety of techniques worldwide including thermography, spectral reflectance based indices and vegetation based indices. These methods can be broadly categorized into two; direct methods and indirect methods (Metternicht et al., 2003). Direct methods involve the reflectance of the bare soil while indirect methods involve the assessment of vegetation type or condition. A study by Wang et al. (2002) using the Simple Ratio Vegetation index (SRVI) reported an indication that canopy reflectance in the near-infrared spectral region was reduced incrementally with increasing levels of salt stress. Wiegand et al. (1994) related NDVI to crop yield and noted that cotton lint yields decreased by 43 ± 10 kg per hectare for every 1 dS/m increase in salinity. Lobell et al. (2010) predicted the ground estimates of EC using only averaged Enhanced Vegetation Index (EVI) and reported a correlation of R^2 between 0.21 and 0.37. Several salinity assessment studies have used salinity and vegetation indices with varying levels of success in their analysis of salinized soils.

The primary aim of this research is to employ satellite analysis to analyze the spatial variability of salinity in the Zeravshan river basin. EC measurement of water from the conveyance and drainage canals was collected from the upstream to the downstream region of this study basin in August 2017. Salinity gradation data along the basin was then compared to the reflectance data of the MODIS bands to assess the sensitivity of the bands to EC. Salinity and vegetation indices are derived from the interaction of different spectral band reflectance and have been used widely in previous studies for the detection of salinized soils; with varying levels of success. In this study, firstly, the sensitivity of MODIS bands to varying levels of EC was assessed and then I5 indices derived from a combination of visible and near-infrared bands were employed in an attempt to detect salinized soil in the basin.

2 TARGET BASIN

Zeravshan river basin is the place of origin of the ancient agricultural and urban civilization of Central Asia. It is densely populated with more than 100,000 people in the main cities of Bukhara, Navoi, and Samarkand (ADB, 2010). This basin is heavily affected by the mismanagement of water resource not only due to the large diversions of water for irrigation to crop fields, but also water is lost as a result of infiltration into the soil and evaporation (Khujanazarov et al., 2012). At the turn of the 20th century, this basin was cut off from the Amu Darya river as a result of the increased diversions of water for irrigation. It previously constituted a sub-basin of the Amu Darya. Unsustainable water use in this basin is also causing a zone of disconnect in the river flow with the Zeravshan river retreating upstream due to reduced levels of water flow. **Figure 3** below shows the spatial extent of the Zeravshan river basin in the Aral Sea basin.

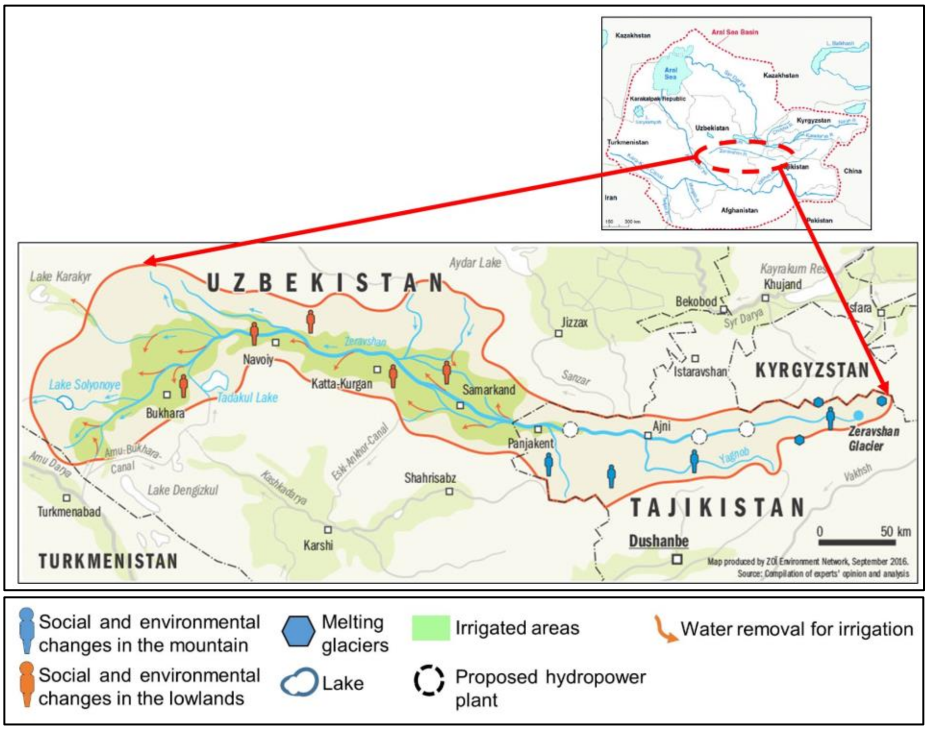

Figure 3. Zeravshan river basin

3 METHODOLOGY

3.1 Salinity measurements in the Zeravshan river basin

A two-week field study was carried out in the Zeravshan river basin Uzbekistan from July 30th to August 14^{th,} 2017. This was part of a collaborative study with the International Center for Biosaline Agriculture (ICBA) and the objective was to measure the spatial gradation of salinity with time along the basin. It forms part of a complementary study to previous observations carried out 7 years ago from 2005 to 2010 by Khujanazarov et al., (2012).

Salinity was measured using a portable EC meter along the Zeravshan river basin. The measurements were taken from water in canals transporting water to the farms and also in drainage canals collecting water from the farms. A study by Qiu et al., (2017) found a linear relationship between the EC in irrigation water and that of the different soil layers. In this study, data was used to assess the spatial variability of salinity in the basin using existing remote sensing indices due to the gradation of salinity with an increase from upstream towards downstream.

3.2 Remote sensing indices for salinity assessment in the basin

MOD09GA product which contains the MODIS satellite bands 1 to 7 was used to calculate for the vegetation and salinity indices at a spatial resolution of 500m. These indices are shown in Eq. [1-15] in **Table 1** below. MODIS is a sensor from NASA onboard the Aqua and Terra satellites which are polar orbiting. The product provides an estimate of the spectral reflectance of the Terra satellite MODIS bands. The band data has been corrected for atmospheric conditions such as gasses, aerosols, and Rayleigh scattering (Vermote et al., 2011).

Soil salinization in this basin occurs mainly due to secondary salinization, however, the local irrigation rules which may be exacerbating the problem are unknown. The agricultural irrigation practices have induced high accumulation of toxic salt in the Zeravshan river basin (Khujanazarov et al., 2012; Toderich et al., 2008). 15 salinity indices were applied in this study in an attempt to detect salinized soil. They are made up of both the

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direct and indirect methods of salinity detection and are based on the reflectance response of both the visible bands (1,3 and 4) and near Infra-Red band 2. Red band (MODIS band 1) has a wavelength of 620-670nm, the Near Infra-Red (MODIS band 2) has a wavelength of 841-876nm, the Blue band (MODIS band 3) has a wavelength of 459-479nm and the Green band (MODIS band 4) has a wavelength of 545–565nm. In the near infra-red, the spectral response of green leaves is much greater than in any portion of the visible spectrum while in the visible red band, the reflectance is sensitive to the mesophyll structure of the leaf (CCPO-ODU, 2015).

MOD09GA product contains MODIS data in a gridded Sinusoidal projection format. For points existing in the same tile but containing different EC values, the EC value representing the drainage was employed for salinity assessment. This is because the drainage contains water from the farm and is more representative of the conditions in it.

Table 1. Salinity indices used in this study

Indices	Equation	Applied studies	
Ratio Vegetation Index	$RVI = NIR/R$	(Wang et al., 2002)	[1]
Normalized Difference Vegetation Index	$NDVI = (NIR - R)/(NIR + R)$	(Wiegand et al., 1994)	[2]
Enhanced Vegetation Index	$EVI = 2.5(NIR - R)/(NIR + 6R - 7.5BLUE + 1)$	(Lobell et al., 2010)	[3]
Normalized Difference Salinity Index	$NDSI = (R - NIR)/(R + NIR)$	(Khan et al., 2005)	[4]
Brightness Index	$BI = \sqrt{(R^2 + NIR^2)}$	(Bouaziz et al., 2011)	[5]
Salinity Index	$SI = \sqrt{Blue \times R}$	(Khan et al., 2005)	[6]
Salinity Index	$SI1 = \sqrt{G \times R}$	(Bouaziz et al., 2011)	[7]
Salinity Index	$SI2 = \sqrt{G^2 + R^2 + NIR^2}$	(Bouaziz et al., 2011)	[8]
Salinity Index	$SI3 = \sqrt{G^2 + R^2}$	(Bouaziz et al., 2011)	[9]
Salinity Index	$S1 = Blue/R$	(Elhag, 2016)	[10]
Salinity Index	$S2 = (Blue - R)/(Blue + R)$	(Elhag, 2016)	[11]
Salinity Index	$S3 = (G \times R)/Blue$	(Elhag, 2016)	[12]
Salinity Index	$S4 = \sqrt{Blue \times R}$	(Elhag, 2016)	[13]
Salinity Index	$S5 = (Blue \times R)/G$	(Elhag, 2016)	[14]
Salinity Index	$S6 = (R \times NIR)/G$	(Elhag, 2016)	[15]

4 Results and discussion

4.1 Spectral bands sensitivity to salinity

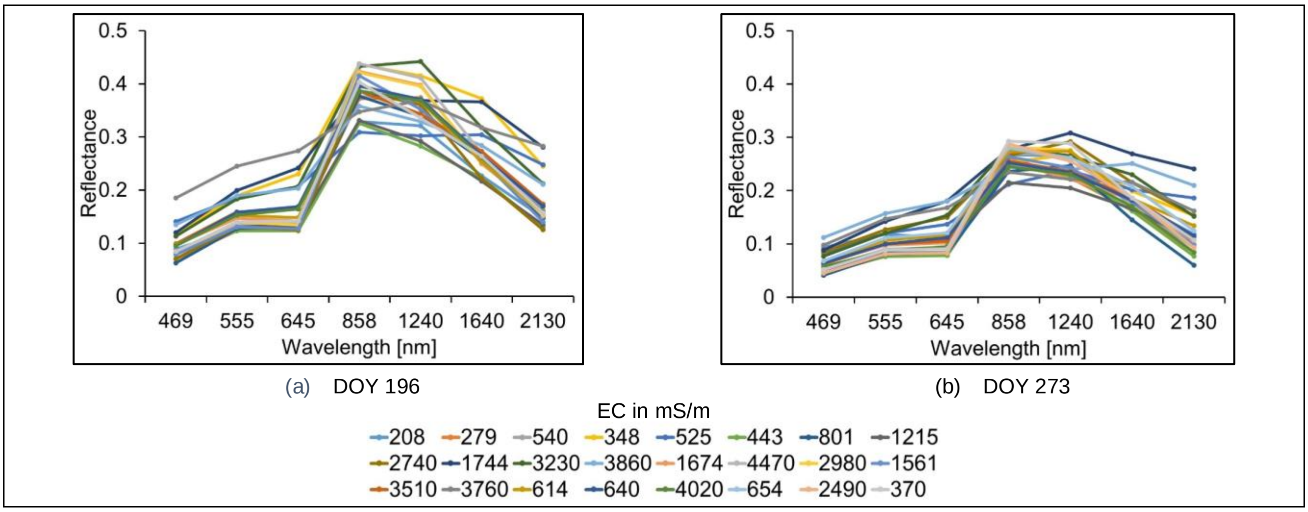


Figure 4. Variation of spectral reflectance as a result of the difference in EC

The reflectance response of the MODIS spectral bands under different EC levels shows sensitivity to salinity both in Day of Year (DOY) 196 at the beginning of summer and DOY 273 at the end of summer. These two days were selected for analysis due to the presence of cloud free data from the study site. Summer is an irrigation intensive period with the main crop under irrigation being cotton. Salinity levels continuously increase throughout the irrigation season (Qiu et al., 2017). In this analysis, pronounced sensitivity to salinity varied in the different visible and short wave infra-red bands with no particularly clear trend as seen in **Figure 4** above. The correlation coefficient R-squared of EC and reflectance on both DOY 196 and DOY 273 are shown in **Figure 5** below. This figure shows 4 bands, with the two bands which had the highest correlation in the two days used in this assessment. R^2 was highest; in the green band at 0.1209 and in the short wave infra-red band 5 at 0.1201 in DOY 196. While the highest R^2 in DOY 273 was; 0.1146 for the short wave infra-red band 6 and 0.1024 for the red band. However, the trend was still not clear in this assessment.

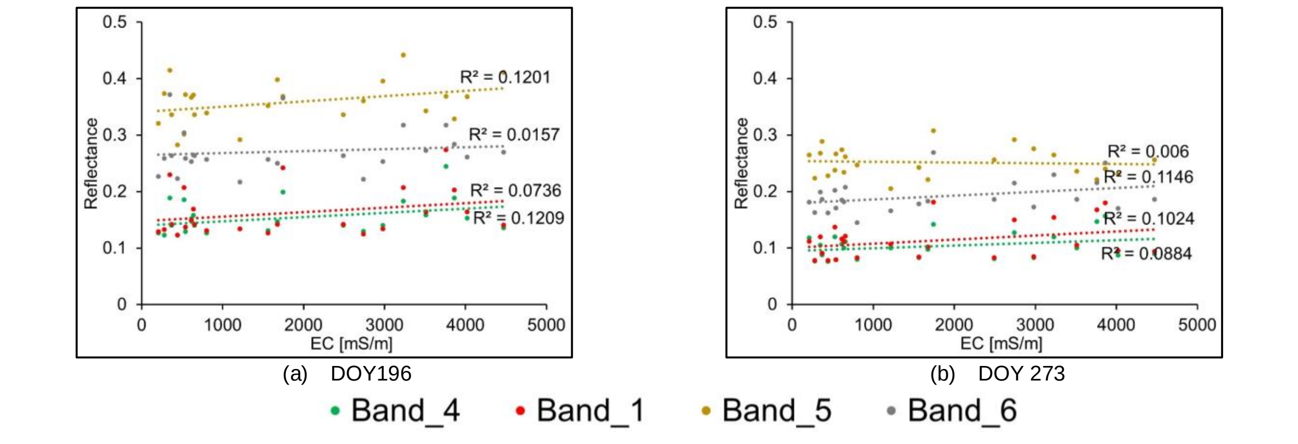


Figure 5 Correlation of EC with reflectance for MODIS bands

4.2 Salinity analysis using the 15 indices

In this study, a significant correlation between the vegetation and salinity indices employed and the EC levels measured in the basin was not established. However, the value for vegetation based indices generally decreased with an increase in salinity, while those of the reflectance indices increased with increasing salinity levels. **Figure 6** below shows RVI distribution in the Zeravshan river basin. RVI correlation with EC was found to have a decreasing trend. This can be seen in (b) below for DOY 273. The correlation coefficient R^2 for the indices is shown in **Figure 7** (a) to (o) below. A study by Wiegand et al., (1994) found evidence of moisture stress in high osmotic concentration which reduced the crop yield. This could explain why vegetation indices reduced with an increase in salinity. Spatial analysis of the gradation of salinity in the whole basin was not very clear both for the vegetation and salinity indices. This could be because of the crop type variability in the basin. Reflectance varies not only due to the crop health but is also affected by the crop type. In addition, due to the coarse resolution of MODIS, there are some mixed-cell effects where one mesh contains different crop types and the retrieved reflectance data is influenced by this. In turn, the results of the computed index are affected.

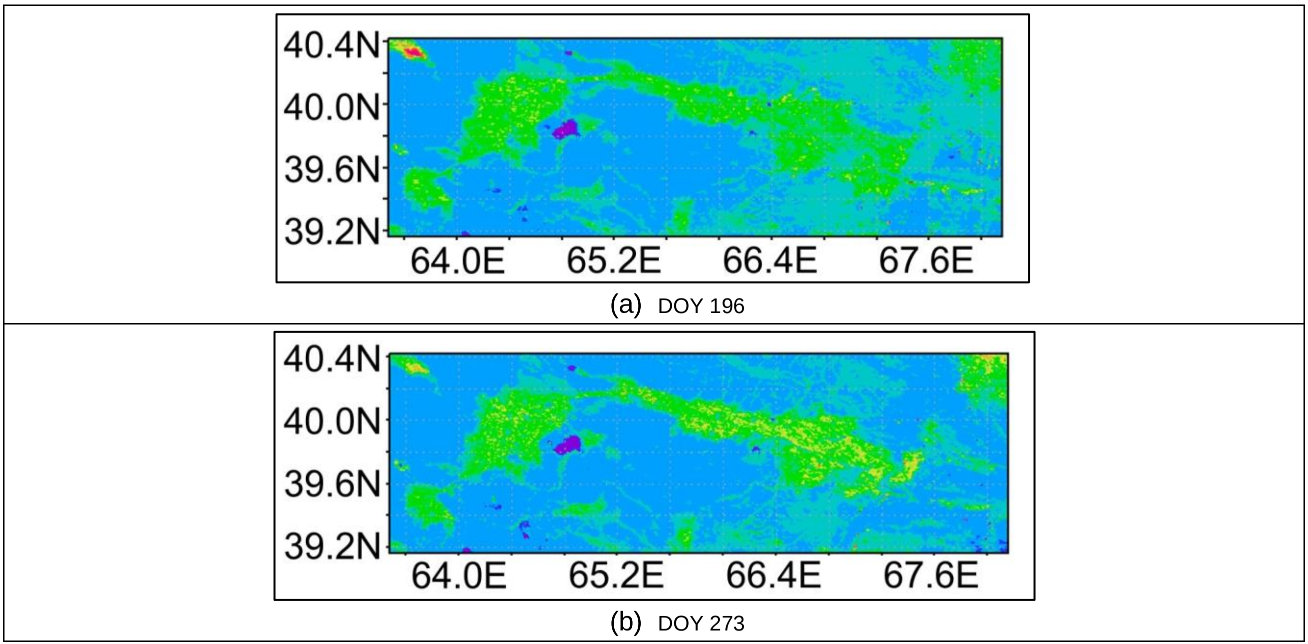
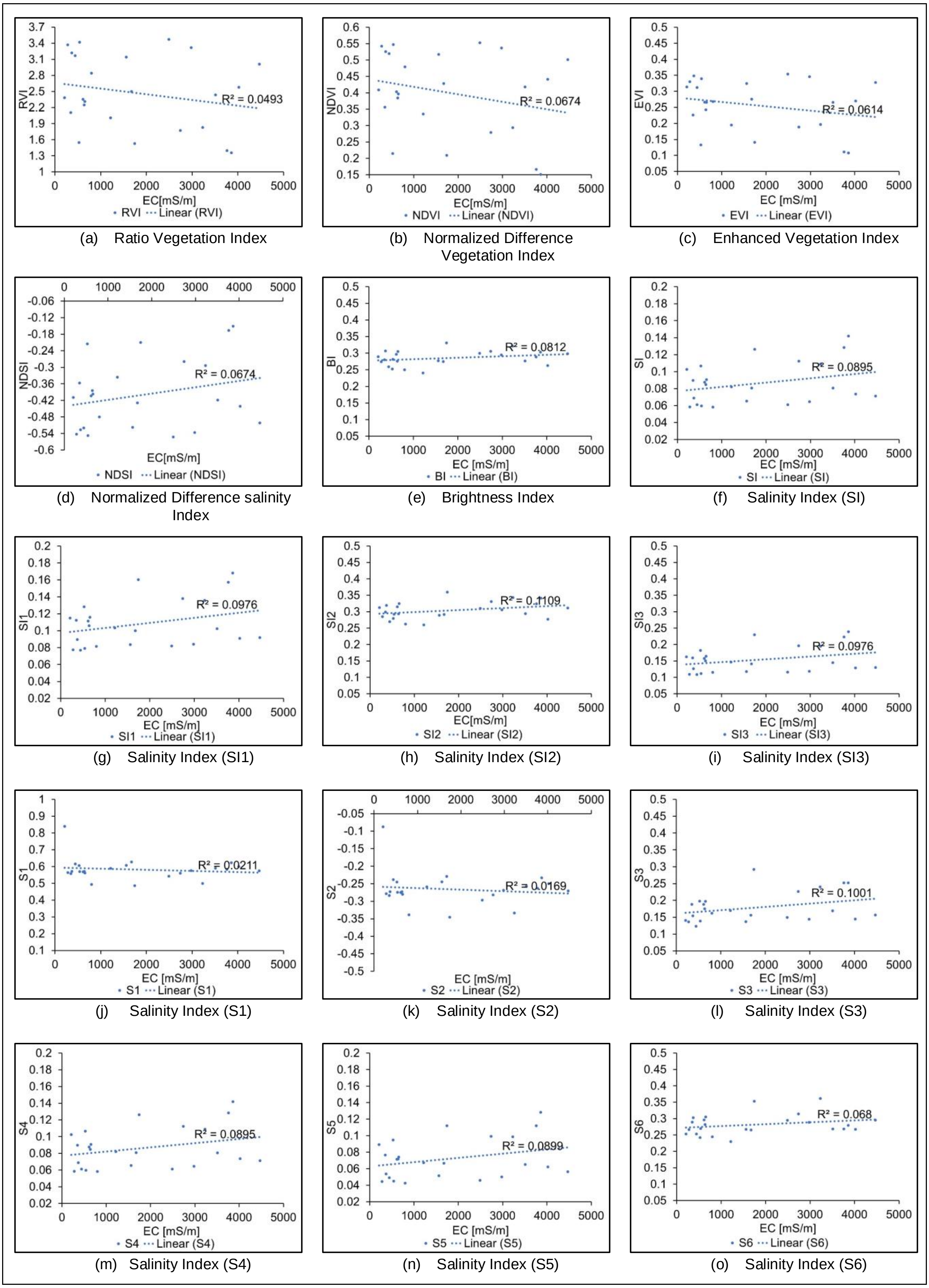


Figure 6 RVI distribution in the Zeravshan river basin



(a) Ratio Vegetation Index

(b) Normalized Difference Vegetation Index

(c) Enhanced Vegetation Index

(d) Normalized Difference salinity Index

(e) Brightness Index

(f) Salinity Index (SI)

(g) Salinity Index (SI1)

(h) Salinity Index (SI2)

(i) Salinity Index (SI3)

(j) Salinity Index (S1)

(k) Salinity Index (S2)

(l) Salinity Index (S3)

(m) Salinity Index (S4)

(n) Salinity Index (S5)

(o) Salinity Index (S6)

Figure 7. Salinity indices used for salinity assessment in the basin

5 CONCLUSIONS

EC collected along the Zeravshan river basin was found to increase from the upstream towards the downstream. However, assessing the sensitivity of the 7 MODIS bands to salinity gradation along the basin revealed no significant correlation between EC and the band reflectance. This is because reflectance is not only a factor of crop health but is also affected by the varying crop type in the basin. In general, the vegetation indices decreased with an increase in salinity while the reflectance indices increased with an increase in salinity. Although 15 indices were employed in this study in an attempt to find the best-suited index for salinity detection, the correlation coefficient R-squared was quite low. The highest R-squared value for the indices tested was salinity index SI2 with R^2 of 0.1109. Effects of soil salinization are mainly localized and a basin-scale analysis may be affected by the mixed-cell effect where the retrieved reflectance data is contaminated by the influence of different crop types and varying crop health.

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REFERENCES

ADB. (2010). *Central Asia ATLAS of Natural Resources. Central Asian Countries Initiative for Land Management Asian Development Bank Manila, Philippines*. Manila, Philippines: ADB Manila, Philippines.
Bouaziz, M., Matschullat, J., & Gloaguen, R. (2011). Improved remote sensing detection of soil salinity from a semi-arid climate in Northeast Brazil. *Comptes Rendus - Geoscience*, *343*(11–12), 795–803. https://doi.org/10.1016/j.crte.2011.09.003
Bucknall, J., Klytchnikova, I., Lampietti, J., Lundell, M., Scatasta, M., & Thurman, M. (2003). Irrigation in Central Asia. Social, economic and environmental considerations. *Europe and Central Asia Region*, (February), 104. Retrieved from www.worldbank.org/eca/environment
CCPO-ODU. (2015). Center for Coastal Physical Oceanography. Studying Earths Environment from Space. Chapter 4: Plant and Vegetation Community Properties. Retrieved July 12, 2018, from http://www.ccpo.odu.edu/SEES/veget/class/Chap_4/4_ref.htm
Conrad, C., Dech, S. W., Hafeez, M., Lamers, J., Martius, C., & Strunz, G. (2007). Mapping and assessing water use in a Central Asian irrigation system by utilizing MODIS remote sensing products. *Irrigation and Drainage Systems*, *21*(3–4), 197–218. https://doi.org/10.1007/s10795-007-9029-z
Elhag, M. (2016). Evaluation of Different Soil Salinity Mapping Using Remote Sensing Techniques in Arid Ecosystems, Saudi Arabia. *Journal of Sensors*, *2016*. https://doi.org/10.1155/2016/7596175
FAO. (2016). AQUASTAT website. Food and Agriculture Organization. Central Asia. Retrieved July 19, 2018, from http://www.fao.org/nr/water/aquastat/countries_regions/profile_segments/asiaC-EnvHea_eng.stm
Hirabayashi, Y., Kanae, S., Emori, S., Oki, T., & Kimoto, M. (2008). Global projections of changing risks of floods and droughts in a changing climate. *Hydrological Sciences Journal*, *53*(4), 754–772. https://doi.org/10.1623/hysj.53.4.754
Ibrakhimov, M., Khamzina, A., Forkutsa, I., Paluasheva, G., Lamers, J. P. A., Tischbein, B., … Martius, C. (2007). Groundwater table and salinity: Spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan, Aral Sea Basin). *Irrigation and Drainage Systems*, *21*(3–4), 219–236. https://doi.org/10.1007/s10795-007-9033-3
Khan, N. M., Rastoskuev, V. V., Sato, Y., & Shiozawa, S. (2005). Assessment of hydrosaline land degradation by using a simple approach of remote sensing indicators. *Agricultural Water Management*, *77*(1–3), 96–109. https://doi.org/10.1016/j.agwat.2004.09.038
Khujanazarov, T., Ichikawa, Y., Abdullaev, I., & Toderich, K. (2012). Water Quality Monitoring and Geospatial Database Coupled with Hydrological Data of Zeravshan River Basin, *202*, 199–202.
Lobell, D. B., Lesch, S. M., Corwin, D. L., Ulmer, M. G., Anderson, K. A., Potts, D. J., … Baltes, M. J. (2010). Regional-scale Assessment of Soil Salinity in the Red River Valley Using Multi-year MODIS EVI and NDVI. *Journal of Environment Quality*, *39*(1), 35. https://doi.org/10.2134/jeq2009.0140
Metternicht, G. I., & Zinck, J. A. (2003). Remote sensing of soil salinity: Potentials and constraints. *Remote Sensing of Environment*, *85*(1), 1–20. https://doi.org/10.1016/S0034-4257(02)00188-8
Micklin, P. (2000). *Managing Water in Central Asia*. Royal Institute of International Affairs.
Nazirov, A. A. (2005). *Central Asia: Water for Food* (No. 31).
Owens, S. (2001). Tackling the most difficult diseases. Genetics and genomics open new strategies to fight vector-borne diseases. *EMBO Reports*, *2*(10), 875–877. https://doi.org/10.1093/embo-reports/kve218
Qiu, R., Liu, C., Wang, Z., Yang, Z., & Jing, Y. (2017). Effects of irrigation water salinity on evapotranspiration modified by leaching fractions in hot pepper plants. *Scientific Reports*, *7*(1), 1–11. https://doi.org/10.1038/s41598-017-07743-2
Ryan, J., Vlek, P., & Paroda, R. (2004). *Agriculture in Central Asia: Research for development*. ICARDA.
Toderich, K., Ismail, S., Massino, I., Wilhelm, M., Yusupov, S., & Kuliev, T. (2008). *Extent of salt-affected land*

in Central Asia: Biosaline agriculture and utilization of the salt-affected resources. *Advances in assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation, Dubai, UAE. World Soil Resources Reports No. 104.*

Vermote, E. ., Kotchenova, S. ., & Ray, J. (2011). MODIS Surface Reflectance User ' s Guide. *Orbit An International Journal On Orbital Disorders And Facial Reconstructive Surgery*, 1–40.

Wang, D., Poss, J. A., Donovan, T. J., Shannon, M. C., & Lesch, S. M. (2002). Biophysical properties and biomass production of elephant grass under saline conditions. *Journal of Arid Environments*, *52*(4), 447–456. https://doi.org/10.1006/jare.2002.1016

Wiegand, C. L., Rhoades, J. D., Escobar, D. E., & Everitt, J. H. (1994). Photographic and videographic observations for determining and mapping the response of cotton to soil salinity. *Remote Sensing of Environment*, *49*(3), 212–223. https://doi.org/10.1016/0034-4257(94)90017-5