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Applicability of spectral indices for sodic soils mapping in Sharda Sahayak Canal Command of Uttar Pradesh

R.H. Rizvi and Sanjay Arora*

ICAR-CSSRI Regional Research Station, Lucknow-226002, Uttar Pradesh, India
**Corresponding author email: aroraicar@gmail.com*

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ABSTRACT

Due to Sharda Sahayak Canal in Uttar Pradesh, considerable area has become salt-affected resulting into low agricultural productivity. Sodic soils are dominant in the Canal command. For planning and development of such problem soils, their accurate mapping and assessment is very much essential. With the availability of high spatial and spectral resolution remote sensing data, it has become possible to identify sodic soils. The only thing is to develop some scientific methodology for this purpose. An attempt has been made to develop methodology for mapping sodic soils on the basis of spectral indices. Various indices along with newly derived spectral index (SI-X) were investigated for mapping sodic soils in Sharda Sahayak Canal Command. Out of these indices, SI-X was found to have good correlation with sodium (Na), and hence may be used for mapping spatial extent of sodic soils.

Keywords: remote sensing, spatial and spectral resolution, spectral indices, Sentinel-2, LULC, waterlogged sodic soil

INTRODUCTION

Accumulation of salts in the soils is a major threat to crop production and global agriculture. Its accumulation is controlled and aggravated by a combination of several factors such as human activities, climatic conditions, land form variability and water table depths. Rapid and precise detection of salt-affected lands is highly critical for presenting soil sustainability and supporting food production. The identification and mapping of salt-affected lands can be efficiently approached by using satellite data mainly because they provide a wide spatial coverage and frequent datasets in different spatial resolution (Gao, 2008). Remote sensing methods are faster, more effective and can cover large areas. They are increasingly used in studies and mapping soil properties (Mulder *et al.,* 2011). Rizvi *et al.* (2024 and 2026) developed methodology for mapping waterlogged sodic soils in Sharda Canal Command of Uttar Pradesh using Sentinel-2 MSI data. They recommended remote sensing data of May for better identification and mapping of sodic soils.

Sreenivas *et al.,* (2021) reported an area of 91.2 M ha under land degradation during 2015-16 in the country. In Uttar Pradesh, 0.286 M ha area was under land degradation, of which 0.06 M ha area was affected by salinization/ alkalization. As per ICAR-Central Soil Salinity Research Institute (2022) report, there was an area of 3.8 million ha (15.8% of TGA) under salt-affected soils in Uttar Pradesh. Salinity indices developed earlier by researchers were investigated to demonstrate their usefulness in identification of sodic soils. A number of derivatives and alternatives to normalised difference vegetation index (NDVI) have been anticipated to discourse soils salinization monitoring and mapping (Montandon and Small, 2008). Zhang *et al*., (2015) used different bands of OLI-8 to develop a soil salinity detection algorithm based on Soil Salinity Information Extraction.

The present study deals with mapping spatial extent of sodic soils through spectral indices and also suggesting suitable/ adoptable agricultural interventions according to sodicity levels in the study districts. Applicability of a new spectral index was also investigated for mapping sodic soils in Sharda Sahayak Canal Command.

Table 1. Spectral/ salinity indices developed by researchers applied in this study

Acronym	Spectral/salinity index	Formula	Equation for sentinel 2	Source
SI 1	Salinity Index 1	$\sqrt{B \times R}$	$\sqrt{B2 \times B4}$	Khan *et al*. (2005)
SI 2	Salinity Index 2	$\sqrt{G \times R}$	$\sqrt{B3 \times B4}$	Khan *et al*. (2005)
SI 3	Salinity Index 3	$\sqrt{G^2 \times R^2 + NIR^2}$	$\sqrt{(B3)^2 + (B4)^2 + (B8)^2}$	Douaoui *et al*. (2006)
SI 4	Salinity Index 4	$\sqrt{G^2 \times R}^2$	$\sqrt{(B3)^2 + (B4)^2}$	Douaoui *et al*. (2006)
BI	Brightness Index	$\sqrt{R^2 + NIR^2}$	$\sqrt{(B4)^2 + (B8)^2}$	Khan *et al*. (2005)
S I	Salinity Index I	$\frac{B}{R}$	$\frac{B2}{B4}$	Abbas and Khan (2007) Abbas *et al*. (2013)
S II	Salinity Index II	$\frac{B - R}{B + R}$	$\frac{B2 - B4}{B2 + B4}$	Abbas and Khan (2007) Abbas *et al*. (2013)
SIII	Salinity Index III	$\frac{G \times R}{B}$	$\frac{B3 \times B4}{B2}$	Abbas and Khan (2007) Abbas *et al*. (2013)
S IV	Salinity Index IV	$\frac{B \times R}{G}$	$\frac{B2 \times B4}{B3}$	Abbas and Khan (2007)
S V	Salinity Index V	$\frac{R \times NIR}{G}$	$\frac{B4 \times B8}{B3}$	Abbas and Khan (2007)
S VI	Salinity Index VI	$\frac{G + R + NIR}{2}$	$\frac{B3 + B4 + B8}{2}$	Douaoui *et al*. (2006)
S VII	Salinity Index VII	$\frac{G + R}{2}$	$\frac{B3 + B4}{2}$	Douaoui *et al*. (2006)
S VIII	Salinity Index VIII	$\frac{SWIR1 - SWIR2}{SWIR1 + SWIR2}$	$\frac{B11 - B12}{B11 + B12}$	Bouaziz *et al*. (2011)
S IX	Salinity Index IX	$\frac{SWIR1}{SWIR2}$	$\frac{B11}{B12}$	Bouaziz *et al*. (2011)
NDVI	Normalized difference vegetation index	$\frac{NIIR - R}{NIIR + R}$	$\frac{B8 - B4}{B8 + B4}$	Rouse *et al*. (1973)
NDSI	Normalized difference salinity index	$\frac{R - NIIR}{R + NIIR}$	$\frac{B4 - B8}{B4 + B8}$	Khan *et al*. (2005)
SI-X	Salinity Index X	G x R NIR	$\frac{(B3 - B4)}{B8}$	New Index derived

MATERIALS AND METHODS

Total 27 soil samples were collected from Sharda Sahayak Canal Command of Barabanki district. These samples were collected at two depths: 0-15cm and 15-30cm with GPS locations.

Sentinel-2A/2B MSI data for two periods i.e. May 2022 and May 2023 was downloaded from Copernicus Data Space Ecosystem website (https://dataspace.copernicus.eu). These data comes with 13 spectral bands, which were subjected to pre-processing layer stacking, mosaicking and clipping by district's shape file. False colour composite (FCC) was generated from green (B3), red (B4) and NIR (B7) bands for identification of features like water, vegetation, builtups, etc. Sodic soil was identified with the help of GPS points collected for soil samples (Figure 1).

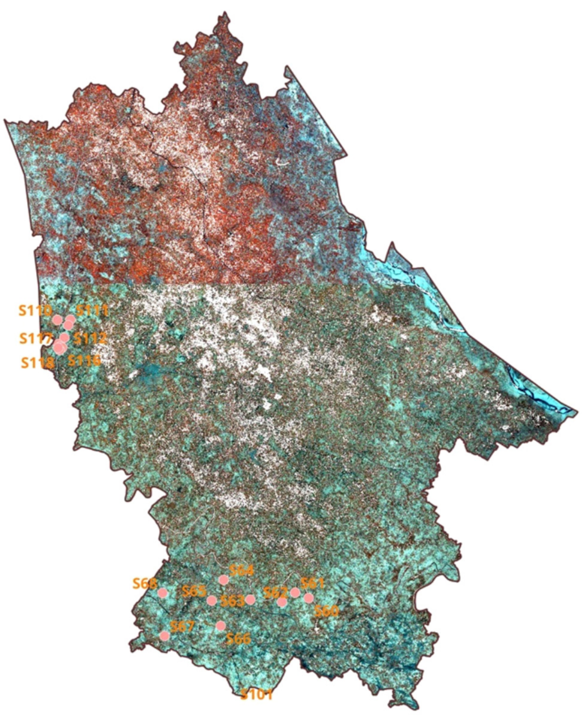

Fig. 1. False Color Composite showing soil samples in Barabanki district

A new spectral index SI-X = (B3xB4) / B8; where B3, B4 and B8 are green, red and NIR bands of Sentinel-2 has been derived and applied for this study.

RESULTS AND DISCUSSION

Analysed soil samples were classified on the basis of soil pH and EC (Table 2). About 89 percent samples were moderate to highly sodic out of which 63 percent were found highly sodic. Also 81 percent samples were found to be non-saline according to soil EC.

Soil pH ranged from 7.23 to 11.05 at 0-15 cm depth whereas it was 6.83 to 10.98 at 15-30 cm depth (Table 3). Soil EC ranged from 0.106 to 5.621 dS/m whereas ECe ranged from 0.114 to 13.74 dS/m at 0-15 cm depth. Maximum exchangeable sodium percent (ESP) was found to be 91.19 and 86.54 percent at 0-15 cm and 15-30 cm soil depths.

Spectral signatures of land uses and land covers

Spectral signatures of different land uses and land covers viz. water, builtups, vegetation, fallowland, sodic soils and sandy areas have been generated from Sentinel-2 bands (B2………B8). It can be observed that signature of sodic soils (pink line) is quite distinct from signatures of other land uses and land covers (Figure 2). Spectral signature of vegetation show the upward reflectance from B3 to B7. Signatures of builtups and bareland have some overlapping. Thus sodic soils can be differentiated from other land uses and land covers with the help of Sentinel-2 bands.

Land uses land covers mapping of Barabanki district

Land uses land covers (LULC) analysis of Barabanki district was done using Sentinel-2 MSI data for two periods i.e. May 2022 and May 2023 (Table 4). Estimated area under sodic soils has marginally increased from 5.20 percent in May 2022

Table 2. Soils samples collected from Barabanki district according to sodicity classes

pH classes	No. of samples	EC classes	No. of samples
Non-sodic (< 8.5)	3	Non-saline (EC<=4)	22
Slightly sodic (8.5–9.0)	0	Saline (EC >4)	5
Moderately (9.0–9.5)	5		
Sodic (9.5–10.0)	2		
Highly sodic (> 10)	17		

Table 3. Soils samples at two depths analysed for different soil parameters

Depth		pH	EC (dS/m)	Na (meq/l)	K (meq/l)	pHe	ECe (dS/m)	CEC	ESP
0-15 cm	Min.	7.23	0.106	3.074	0.856	6.06	0.114	0.072	4.13
	Max.	11.05	5.621	409.807	4.086	10.61	13.74	27.747	91.19
15-30 cm	Min.	6.83	0.043	3.483	0.883	6.81	0.830	0.000	3.65
	Max.	10.98	4.498	242.393	2.604	10.52	14.140	30.608	86.54

Table 4. Area statistics of LULC in Sharda Sahayak Canal Command of Barabanki district

Class#	LULC class	May 2022		May 2023	
		Area (ha)	Area (%)	Area (ha)	Area (%)
1	Sodic soils	18652.36	5.20	20125.16	5.61
2	Water/ water bodies	17460.11	4.87	20011.29	5.58
3	Builtups/ sandy areas	63002.91	17.57	65929.53	18.39
4	Bareland/ fallow land	84166.07	23.47	52406.7	14.61
5	Vegetation/ plantations	175300.87	48.89	200109.64	55.81
		358582.32		358582.32	

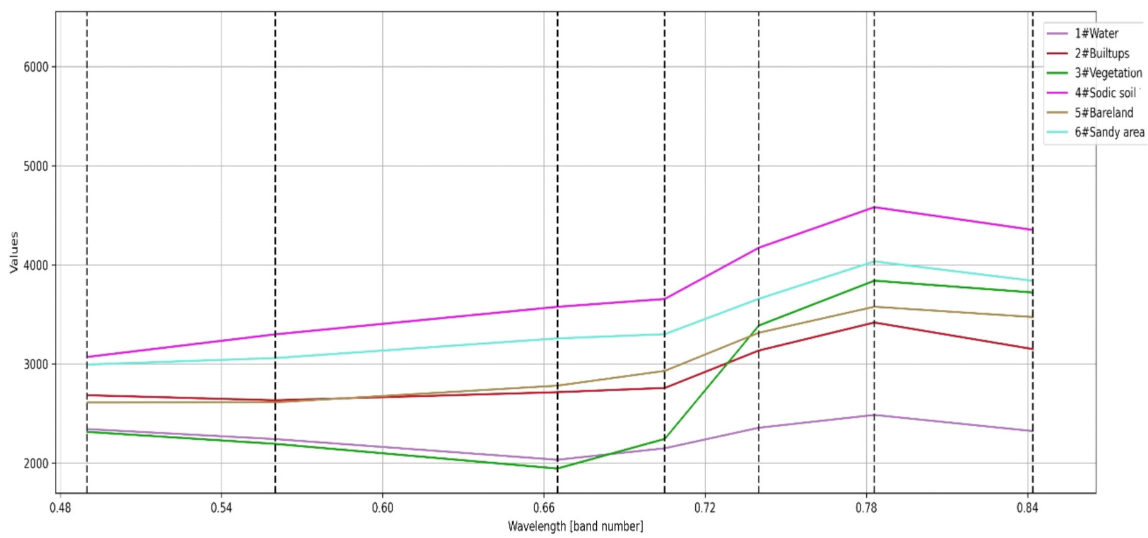

Fig. 2. Spectral signatures of different land uses land covers generated by Sentinel-2 data

to 5.61 percent in May 2023 and by 1472.80 in terms of ha. An increase of about 6 percent was observed in vegetation/ plantation area in the district. LULC maps of Barabanki district for May 2022 and May 2023 are depicted in Figures 3(a) & 3(b).

Correlation analysis between soil parameters and spectral indices

Amethi district

Correlations between soil parameters (pH, EC, OC, Na, etc.) and spectral indices (SI1, SI3, SI5, SI7 & SI8) were computed using statistical software (Table 5). Soil pHe has very good correlations with SI1 and SI8 (0.628 & 0.664).

Non-linear model of the form Y = a + b. Ln(X) has been fitted between pHe and spectral index 8.

The model pHe = -6.484 + 2.044 Ln (SI8), R^2=0.639; was found good fit and may be used for estimating soil pHe on the basis of SI8.

Soil pHe has been estimated using the developed model and sodic soils were classified according to pHe, which are depicted in Figure 4(a) & 4(b). Fig. 4(a) shows three types of sodic soils: sodic (pHe <10.0), highly sodic (pHe =10.0-10.5) and severely sodic (pHe >10.5).

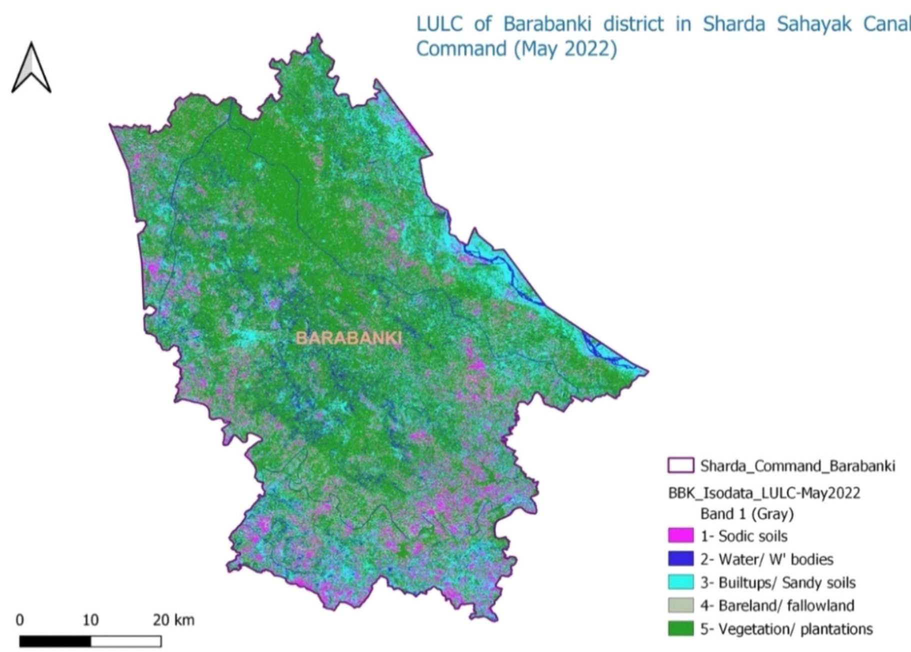

Fig. 3(a). LULC of Barabanki district in Sharda Sahayak Canal Command (May 2022)

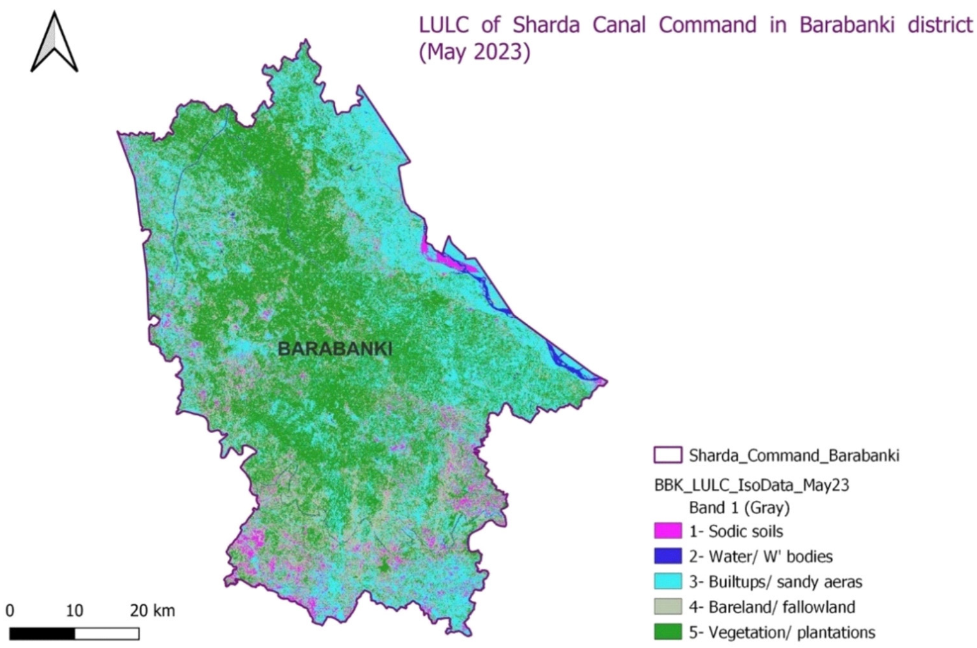

Fig. 3(b). LULC of Barabanki district in Sharda Sahayak Canal Command (May 2023)

Table 5. Pearson correlations between soil parameters and spectral indices

Soil parameter	Spectral indices				
	SI1	SI3	SI5	SI7	SI8
pH	0.422	0.091	0.058	0.275	0.521
EC	-0.211	-0.345	-0.399	-0.226	-0.114
OC	0.066	-0.149	-0.134	-0.016	0.182
Na	0.372	0.18	0.168	0.196	0.37
K	-0.388	-0.432	-0.507	-0.337	-0.283
pHe	0.628	0.321	0.309	0.431	**0.664**
ECe	0.537	0.318	0.284	0.387	0.565

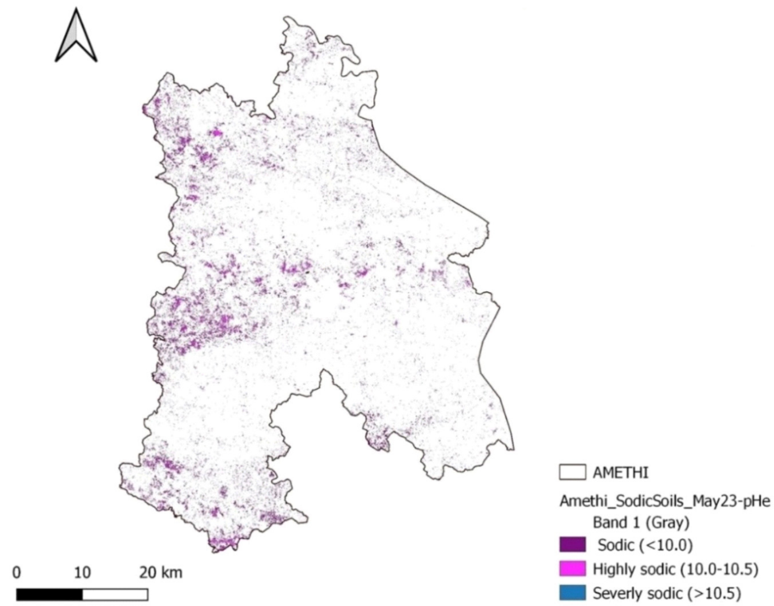

Fig. 4(a). Sodic soils is shown with brightness index (SI5) in Amethi district

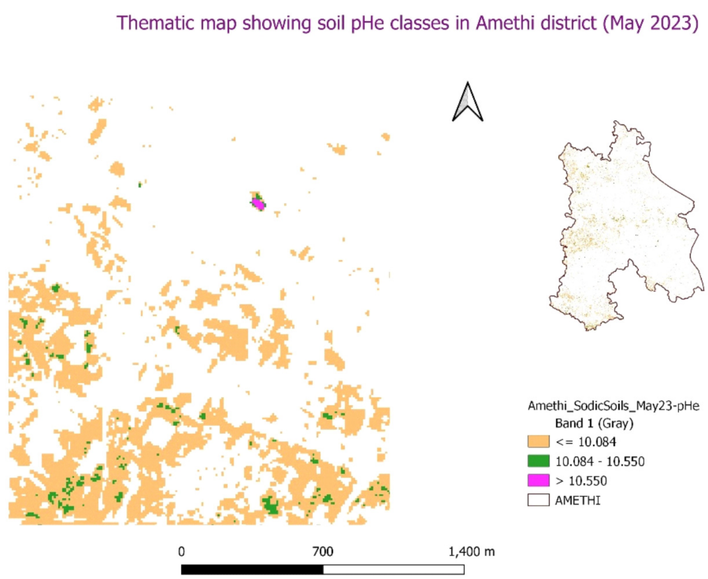

Fig. 4(b). Sodic soils classes according to soil pHe in part of Amethi district

Suitable/ adoptable agricultural interventions as per sodicity levels have been suggested (Figure 5). For example salt-tolerant varieties, micro-bio formulations and agroforestry may be suggested as technological interventions for highly sodic soils (pink colour).

Barabanki district

Association of soil parameters with spectral indices was determined through correlation analysis. A new index SI-X was used for Barabanki data and compared with previously developed indices (Table 6). It can be observed that both SI-III and brightness index (BrInd) have good correlations with soil EC, but correlation value between EC and SI-X is higher (0.620). SI-X has also good correlation with Na (0.562), which is an important parameter/ indicator for soil sodicity.

Non-linear model between Na and SI-X

Non-linear model of the quadratic form Na = a + b (SI-X) + c $(SI\text{-}X)^2$ has been fitted between soil

Table 6. Pearson correlation matrix between soil parameters and spectral indices

	SI-I	SI-II	SI-III	SI-IV	SI-V	BrInd
pH	0.070	-0.085	0.402	0.281	0.173	0.456
EC	-0.173	-0.334	**0.575**	0.420	0.399	**0.554**
OC	0.040	0.123	-0.369	-0.251	-0.192	-0.413
Na	-0.010	-0.287	**0.523**	0.375	0.310	0.503
K	-0.075	0.177	0.028	0.135	-0.007	0.149
pHe	0.039	-0.162	0.420	0.294	0.209	0.496
ECe	-0.155	-0.314	0.487	0.326	0.328	0.436
CEC	0.035	-0.047	0.156	0.146	0.150	0.152
ESP	0.154	0.121	0.215	0.150	-0.088	0.265
	SI-VI	**SI-VII**	**SI-VIII**	**SI-IX**	**SI-X**	
pH	0.381	0.311	0.315	0.355	0.468	
EC	0.479	0.501	0.454	0.410	**0.620**	
OC	-0.416	-0.372	-0.230	-0.391	-0.458	
Na	0.395	0.401	0.328	0.298	**0.562**	
K	0.226	0.198	0.260	0.349	0.093	
pHe	0.406	0.363	0.365	0.366	0.481	
ECe	0.399	0.450	0.419	0.334	**0.539**	
CEC	0.132	0.104	0.169	0.097	0.175	
ESP	0.250	0.222	0.207	0.281	0.250	

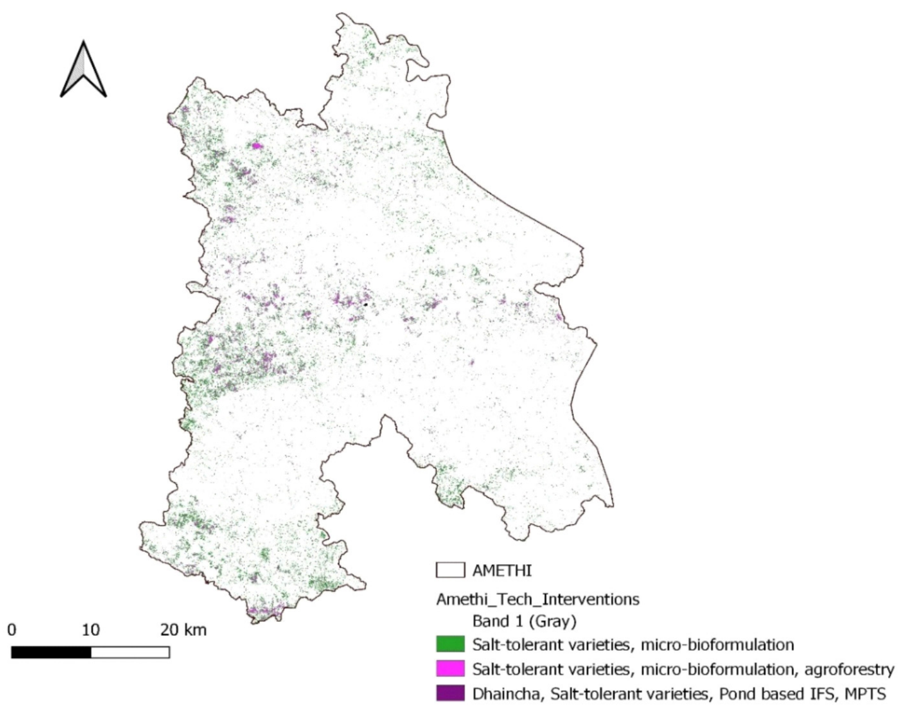

Fig. 5. Suitable agril. interventions as per sodicity levels in Amethi district

parameter (Na) and spectral index (SI-X); where, a = 102.635, b = -2520.261, c = 59147.983 (R^2 = 0.433). Graphical presentation of the fitted non-linear model shows the goodness of fit (Figure 6).

CONCLUSIONS

The spectral indices derived from Sentinel-2 MSI bands (B2, ……., B7) have potential to identify the waterlogged sodic soils. Newly developed spectral

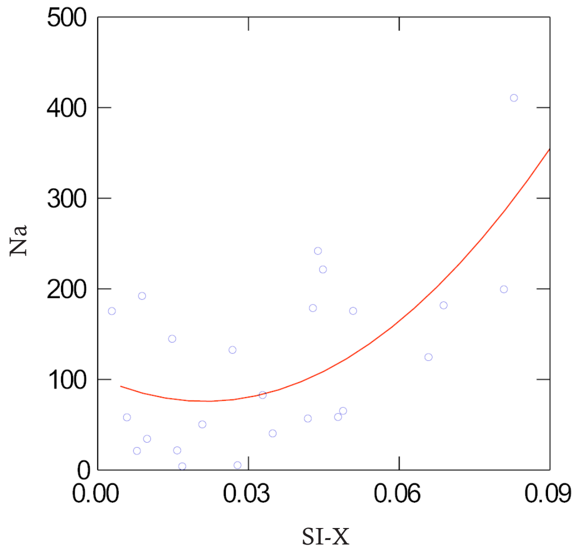

Fig. 6. Non-linear model fitted between Na and SI-X

index (SI-X) has shown positive high correlation with sodium (Na) and may be a good predictor of soil sodicity. Thematic maps of different sodicity levels generated with an appropriate spectral index will be useful for suitable planning and management of sodic areas. The suggested suitable agricultural interventions based on sodicity classes may be adopted by the farmers for development of their sodic fields.

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