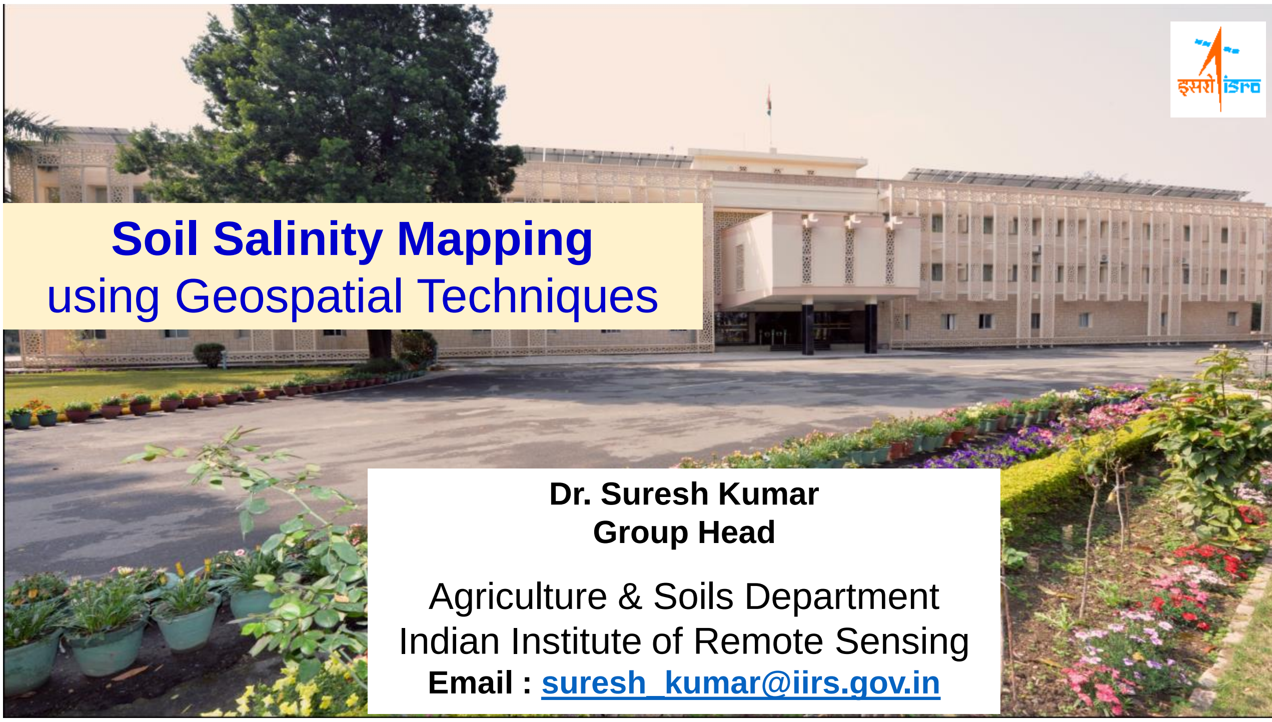

Soil Salinity Mapping using Geospatial Techniques

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Geospatial Technology

- **Remote Sensing Satellites**
- **GIS - Geospatial layer**
- **GPS : IRNSS (NAVIC)**

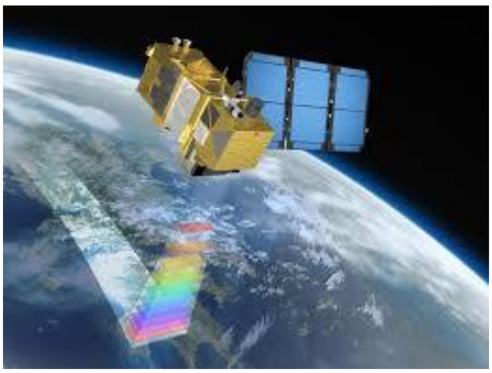
To provide reliable, updated spatial information of soil, crops, terrain geology etc.

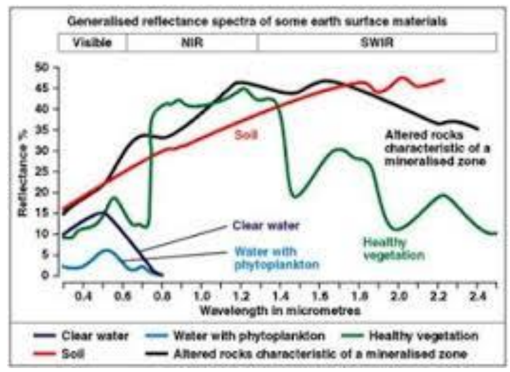
↕

To monitor and protect fragile ecosystems, enhance food security, reduce poverty, and improve governance

Remote Sensing is Science and Art.

It is science of obtaining spectral reflectance of object in several spectral bands and art to interpret these spectral reflectance / properties to derive information of the object.





Remote Sensing Programme has completed nearly 50 years.

First RS satellite : ERTS (Landsat MSS) – NASA (USA) – July 1972

India **–** **IRS** **LISS-1** & LISS II – ISRO- March 1982

Landsat 8 satellite: 07 spectral bands ,resolution is 30 m for bands 1 to 7. (Thermal infrared band 6 was collected at 120 m, but was resampled to 30 m. PAN (8th band) : 15 m (0.51-0.89 micro meter.

PAN: 0.5-0.85 micron with 10 bits

Spatial resolution < 1m

European Union's Sentinel-2A satellite
13 Multi spectral bands
Download (Since Dec. 2016) : EarthExplorer
ESA Sentinels Scientific Data

PSLV-C40/Cartosat-2 Series , launched on Jan 12, 2018

Sentinel-1 synthetic aperture radar (SAR) data processed by the European Space Agency

Spatial Resolution

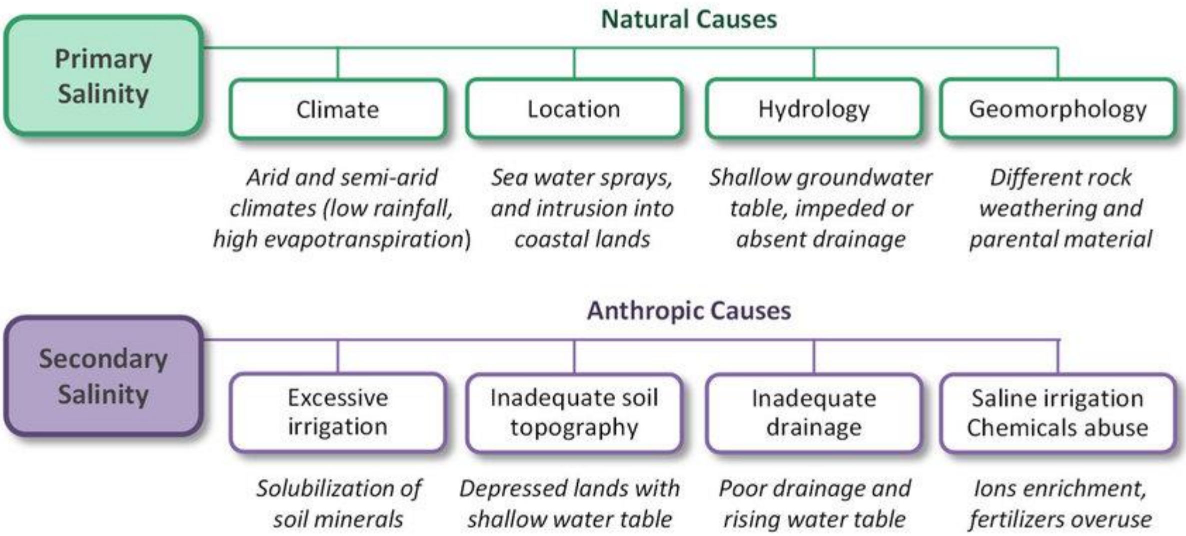
IIRS

RS Satellite	Spatial Resolution (Pixel Size – meter)	Temporal Resolution (Days)
Resourcesat 2 (2011) Resourcesat 2A (2017)	Optical Satellite	
LISS IV	5.8	24
LISS III	23.5	24
AWiFS	56	5
Cartosat 2A & 2B	PAN (1m)	-
IKONAS (USA-2000)	PAN (0.8m); MS (4 m)	3-5
World View- 3 (2014)	PAN (0.3m); MS (1.2m)	1-5
Planet Lab (USA 2014)	MS (5m); PAN (3m)	Daily
Sentinal 2 A & B	MS (10m)	5
Landsat 8 MSS	MS (30 m); PAN (15m); TIRS (100m)	16
	Microwave Satellite	
Sentinel 1 A & B	C Band (5-25m)	12
RISAT 1A & 1B	C Band (5-25)	12

Multispectral remote sensing data for mapping salt-affected soils

Image	Spatial resolution	Bands
Landsat Operational Land Imager (OLI)	30 m	Band 1 (Blue); Band 2 (Green) Band 3 (Red); Band 5 (NIR); Band 6 (SWIR1); Band 7 (SWIR2)
Sentinel 2A	10 m 20 m	Band 2(Blue); Band 3(Green); Band 4 (Red) Band 8(NIR) Band 11 (SWIR 1); Band 12 (SWIR 2)
MODIS (MOD09GA V6	500 m	Band 3(Blue); Band 4(Green); Band 1(Red) Band 2 (NIR); Band 6(SWIR 1); Band 7(SWIR 2

Types of Soil Salinity – Based on origin



Saline soils are widespread in the canal irrigated arid and semi-arid regions

Characteristics of different soil salinity classes based on saturation paste extracts

Salinity class	EC	ESP**	pH	SAR	Dominant ions and their concentrations	Gypsum*	Carbonates of earth metals*
Non-saline, non-alkaline (normal)	< 4	< 15	< 7 <	Low		+, -	+, -
Saline	> 4	< 15	< 8.5	Medium	Cl^-, SO_4^{2-}, HCO_3^-, - Low, CO_3^{2-} - absent, $Na^+ > Ca^{2+} + Mg^{2+}$	+	+
Alkaline	Medium	> 15	Usually > 8.5	high	Na^+, may be present in the form of $NaHCO_3^{2-}$ - $NaCO_3$	Rare +	
Saline – Alklaine	> 4	> 15	Usually < 8.5		Like in case of saline, but with higher concentration of sodium		

USDA Handbook No. 60, 1954

***Note:* * *+ present, - absent, ** the relative amount of the sodium ion expressed as a percentage (%) of the CEC or the sum of exchangeable bases*

Areal Extent

Total degraded land (2010-11) is 120.40 Mha

S. No.	Type of degradation	Area in Mha	% of Total Degraded lands
1.	Wind and Water Erosion	94.87	**79**
2.	Acidic soil	17.93	**15**
3.	Alkaline soil	3.70	**3**
4.	Saline soil	2.73	**1.8**
5.	Water logged	0.91	**1**
6.	Mining & Industrial waste	0.26	**0.2**
7.	**Total**	**120.40**	**100.0**

Salt-affected Soils

- Variations in **spectral reflectance** of salt crusts of salt-affected soils

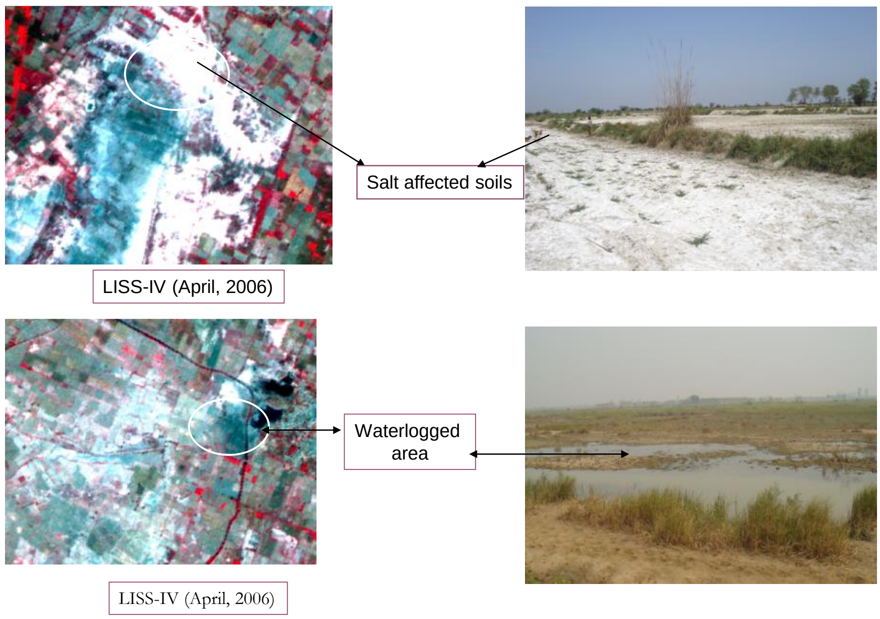
  affected by the physico-chemical properties of soil (e.g., soil moisture content, organic matter, texture, types of clay, color and surface roughness).
- The spectral reflectance of the salt features at the soil surface used as a direct indicator of soil salinity using remote sensing
- **Mapping soil salinity** based on only the soil surface **is limited**, despite decades of research (Allbed and Kumar, 2013; Metternicht and Zinck, 2013).
- Most notably, surface salts can only be readily detected in satellite data if the soils are sufficiently dry (salt content > 10-15%)

- Remote sensing is used for soil salinity mapping already for years (**Metternicht and Zinck, 2009**). Nevertheless, there are still no universally acceptable methods to derive soil salinity parameters from remote sensing data that can be used for different environments.
- Sub-surface salinity is not always associated with visible surface salts (surface reflectance is obstructed by overlying vegetation.
- Studies do not demonstrate the same high accuracy in different parts of the world, which means that **scaling up to a global scale is problematic.**

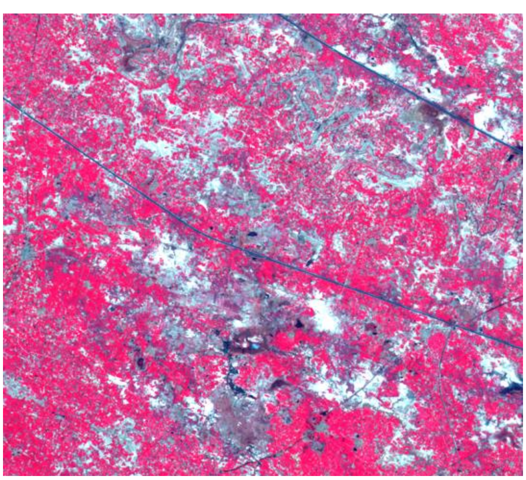
Approach for mapping salt-affected soils			
Input data requirements			
Data	Data type	Variables	Units
Soil data	Georeferenced soil profile data (between 0-100 cm of soil depth)	EC	dS/m
		pH (H2O)	-
		ESP	%
		Soluble ions*	Cmol/kg
		TSS*	g/l
Soil forming factors	Climate (Mean annual)	Rainfall	mm
		Min Temperature	°C
		Max Temperature	°C
	Land use/cover	Cover/use types	-
	Soil map	Soil types	-
	DEM	Elevation	m
	Remote sensing land surface reflectance	Visible (RGB) reflectance	-
		IR reflectance	-
		SWIR reflectance	-
	Geology	Lithology types	-
Other data	Hydrogeology*	Groundwater level	m
	Degradation*	Degradation types	-
	Distance to the coastline	Distance	m

FAO 2020. Mapping of salt-affected soils: Technical specifications and country guidelines

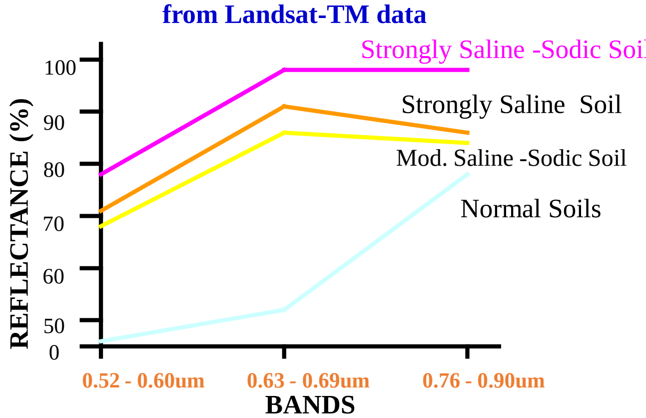
RS of Salt-affected soils and waterlogged areas

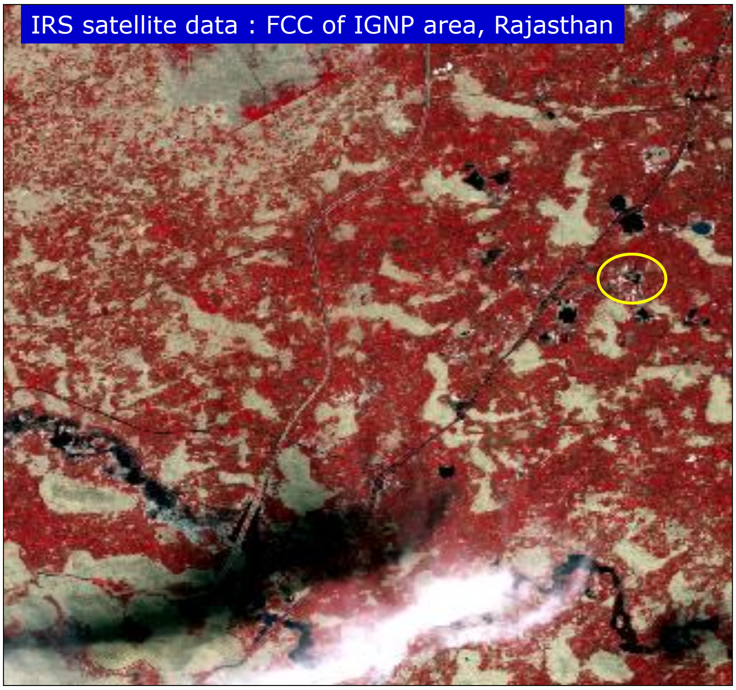


Salt affected and water logged land



Spectral Reflectance of Salt Affected Soils from Landsat-TM data





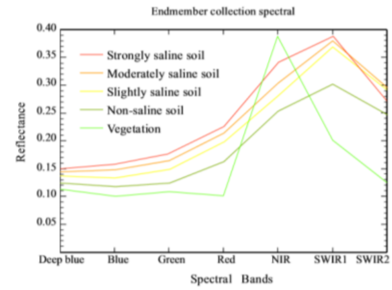
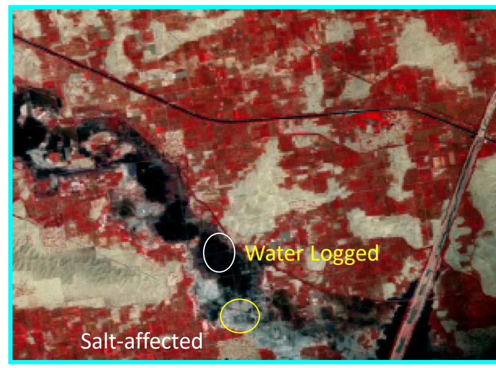
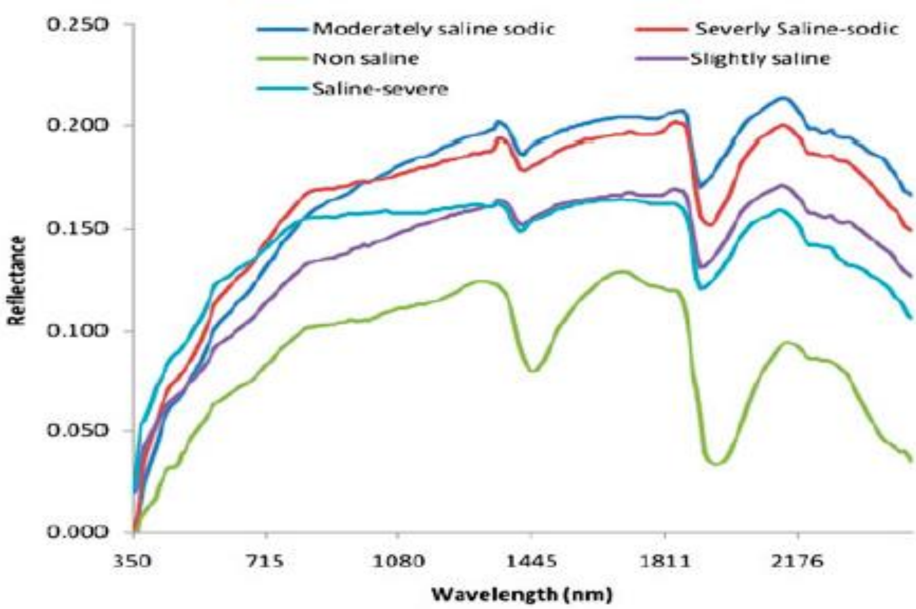


Fig. 5. Reflectance spectra curves of different soil salinization in the study area.



Spectral Characteristics



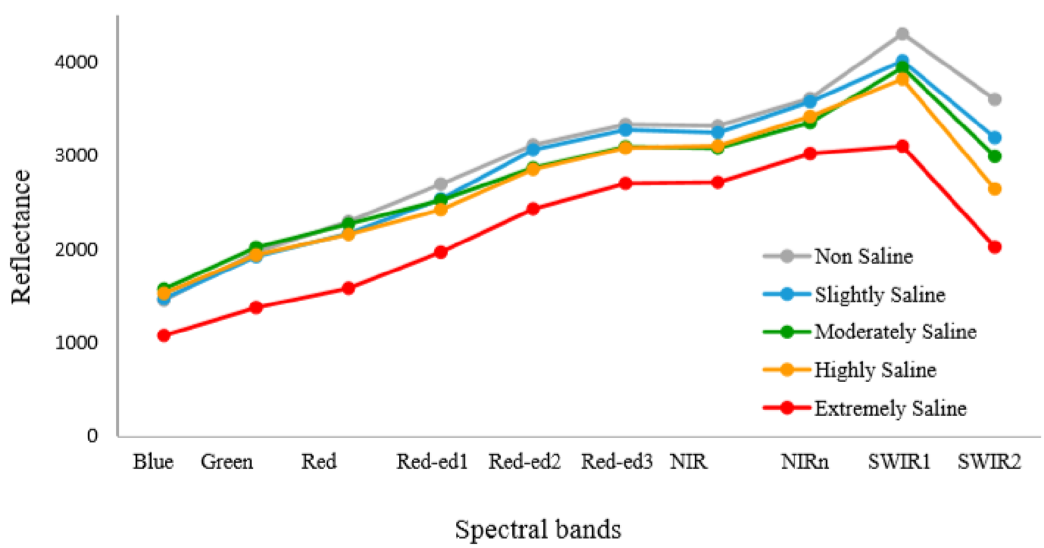
On the other hand, **vegetation condition provides**

a potential alternative proxy of soil salinity.

Normally, plants subjected to salinity stress

- lower photosynthetic activity, causing increased visible reflectance and reduced near-infrared reflectance (NIR) from the vegetation.

- Several vegetation indices (Vis) [e.g., NDVI (normalized difference vegetation index), REP (red edge position), PRI (photosynthetic reflectance index)] were found to be correlated with the salinity.
- The type of vegetation can also be an indicator for salinity according to the tolerance to salt stress of various plant species.
- Halophytic plants tolerate high soil salinity and can grow on salt- affected land, and therefore are promising indicators to distinguish saline areas from non-affected areas
- Sensitive spectral bands were identified with a field hyper- spectrometer, which could enhance monitoring salinization across various vegetation types.



Sentinel 2A spectral reflectance spectrum of soil samples with different salinity levels – Paddy Crop

Sustainability 2020, 12, 8317

RS data analysis and interpretation methods

- **Visual (Manual)**

  False colour composites: Colour, tone, texture, pattern, shape, size etc

- **Digital Image Processing (Machine)**

- **Image Enhancement :** Contrast stretching, Filtering, spectral Indices,
- **Image transformations**: Band ratios and Principal component analysis, IHS transformation, image merging etc
-
- **Image Classification:**
- **Supervised:** User driven. Parametric: mean, variance, covariance, min & max

  Various algorithms: Max Likelihood, Parallelopiped, Minimum distance to Mean

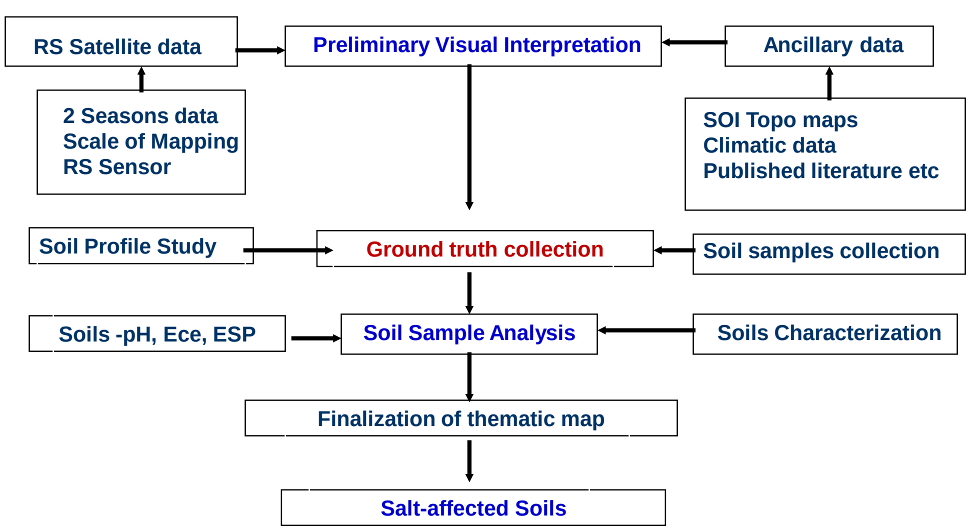
- **Unsupervised**: Aggregation based on spectral similarity (clustering).

  Analyst determines the thematic class identity of these spectral groups by comparing the classified image data to ground reference data

- Spectral indices: Spectral indices images are derived from empirical transformations of spectral responses in different spectral bands (NDVI, SBI, WI, SI etc)

- **Microwave RS:** Salinity identification by relating salinity levels to the *imaginary part* of the complex dielectric constant

Methodology For Land Degradation Studies Visual Interpretation



Digital Image Processing

Image enhancement

- Contrast stretching
- Spatial filtering
- Spectral indices
- Principal components analysis

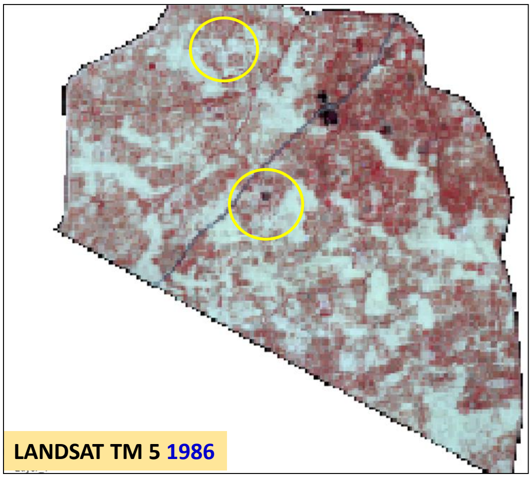
Digital Image classification

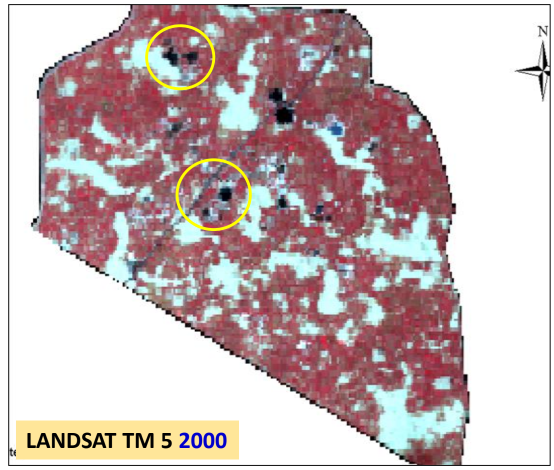
- **Supervised classification are : Maximum Likelihood Classifier (MLC), Minimum Distance to Mean Classifier (MDMC) and Parallelopiped Classifier (PC).**
- **In unsupervised classification approach, the image data are first classified by aggregating them into the natural spectral groupings or clusters present in the scene using clustering algorithms.**

Spectral Indices	Formula
• Salinity index (SI)	SI= $(B4\times B2)^{0.5}$
• Salinity index (SI1)	SI1= $(B4\times B3)^{0.5}$
• Salinity index (SI2)	SI2= $[(B5)^2+(B4)^2\times(B3)^2]^{0.5}$
• Salinity index (SI3)	SI3= $[(B4)^2+(B3)^2]^{0.5}$
• Salinity index I	B2/B4
• Salinity index II	(B2−B4)/(B2+B4)
• Salinity index III	B3×B4/B2
• Normalized Difference Salinity Index (NDSI)	NDSI = (red − NIR)/(red + NIR)
• Normalized Difference Vegetation Index (NDVI)	NDVI = (NIR − red)/(red + NIR)
• Enhanced vegetation index (EVI)	g×(B5−B4)/(B5+C1×B4−C2×B2+L)
• Soil Adjusted Vegetation Index (SAVI)	SAVI = (1 + L) × NIR − red/L + NIR + red
• Vegetation Soil Salinity Index (VSSI)	VSSI = 2 × green − 5× (red + NIR)
• Tasseled cap transformation for Landsat TM • Brightness Index (BI)	BI=B1*0.3561+ B2*0.3972 + B3* 0.3904 + B4*0.6966 + B5*0.2286 + B7*0.1596
• Greenness Index (GI)	GI= - B1*0.3344 – B2*0.3544 – B3*0.4556 + B4*0.6966 - B5*0.0242 – B7*0.2630
• Wetness Index (WI)	WI= B1*0.2626 + B2 *0.2141 +B3* 0.0926 + B4 * 0.0656 – B5* 0.7629 – B7*0.5388

MONITORING OF LAND DEGRADATION USING TEMPORAL SATELLITE DATA

IN IGNP COMMAND AREA ,HANUMANGARH, RAJASTHAN

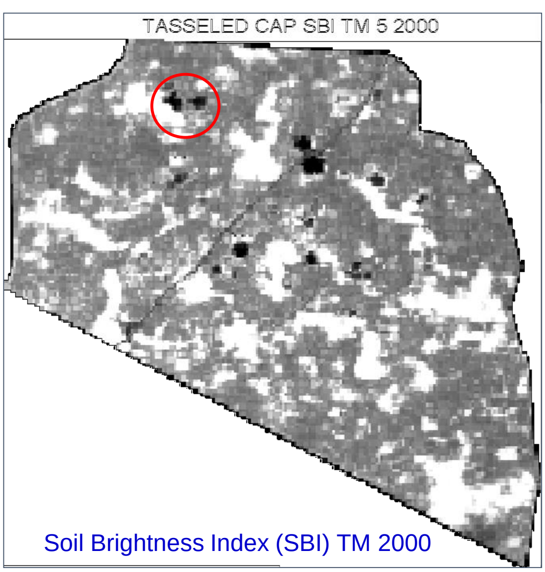


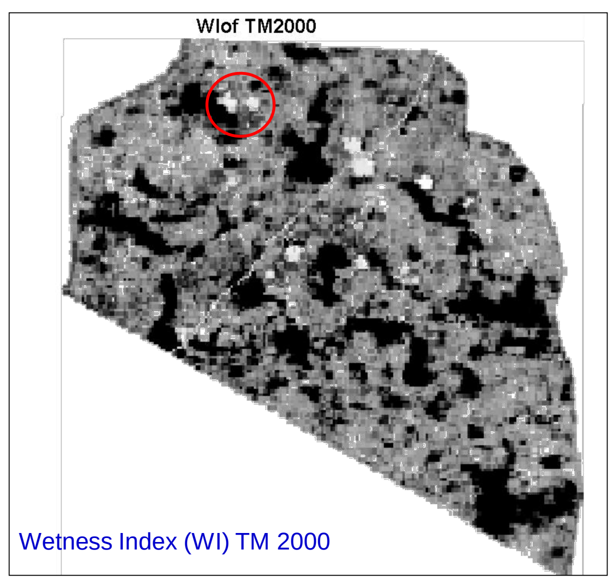


Geographical location :

74^{0} 22’12’’E-29^{0} 27’36’’N
74^{0}34’12’’E-29^{0}21’36’’N.

Hanumangarh District of Rajasthan

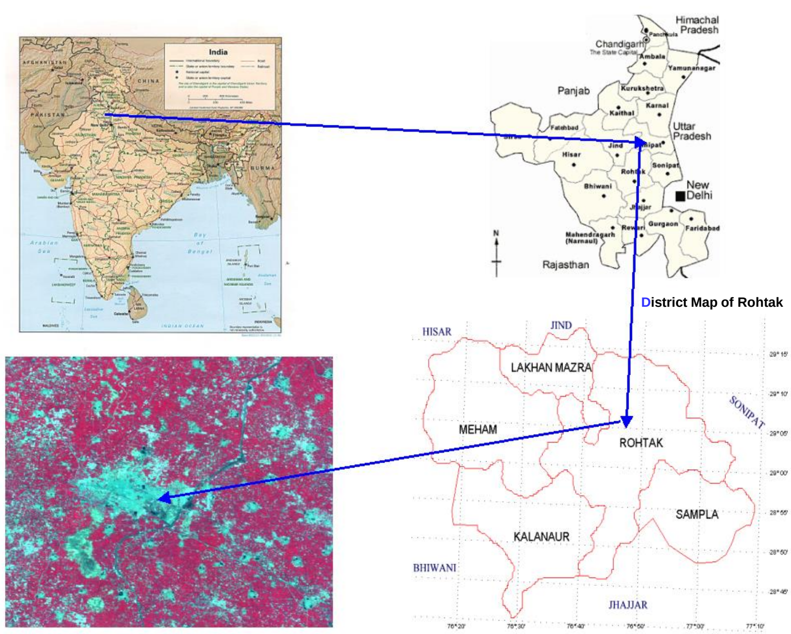


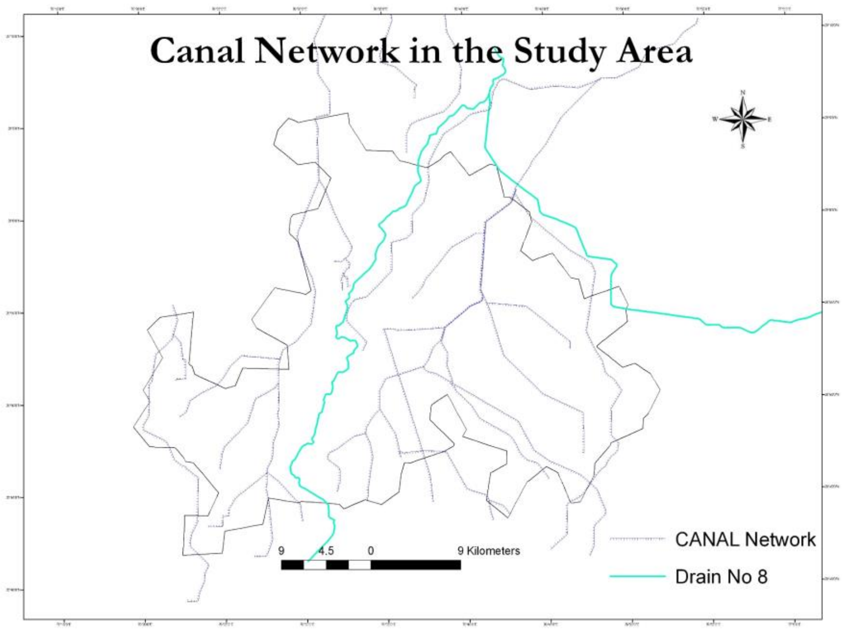


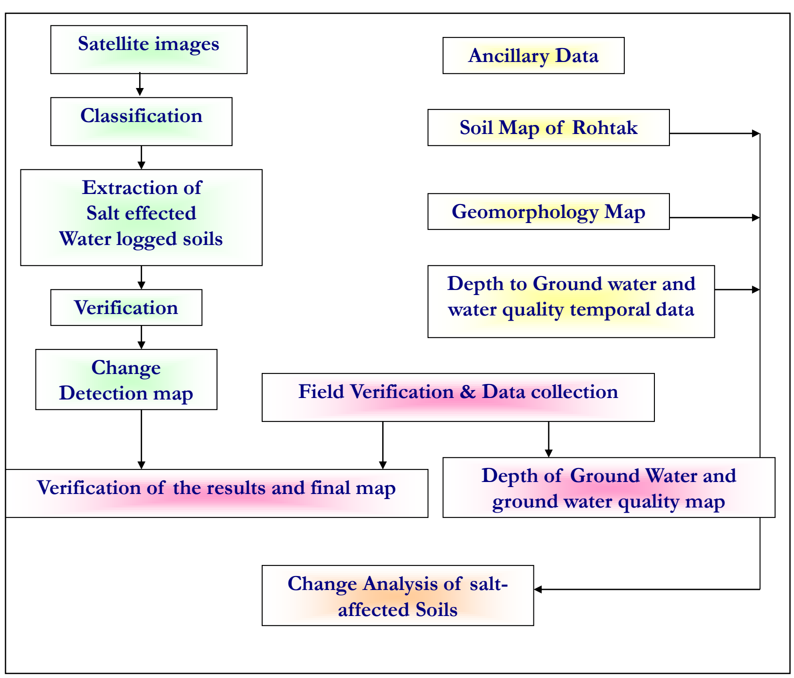
Change Analysis using Temporal Landsat data

- **Post classification comparison method**
  - Supervised classification of various types of land cover levels including salt-affected soils between two image dates
- **Spectral enhancement methods**
  - PCA – combination PCs to generate FCCs
  - Multi-date PCA
- **Tasseled Cap transformations**
  - Soil brightness Image (SBI),
  - Wetness Image (WI)
  - Greenness image (GI)
- **Hybrid FCCs** : combination of PCA and Tasseled cap transformation images

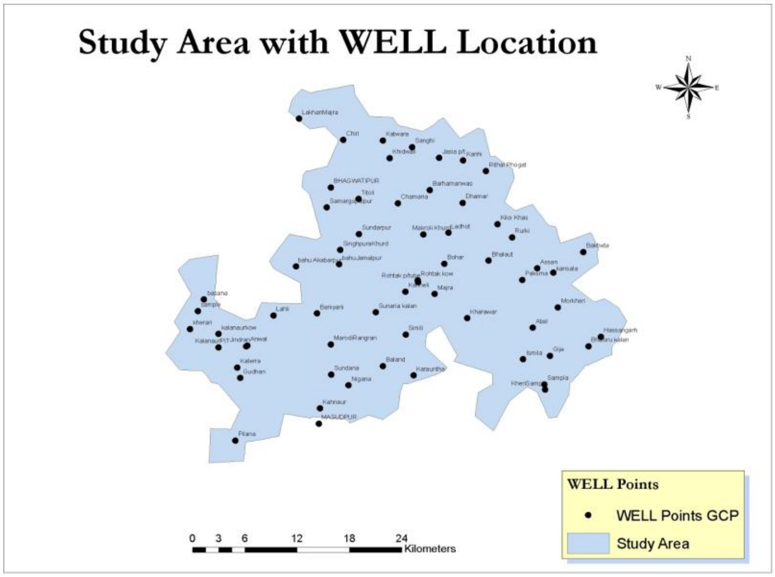
A case study : Rohtak (Haryana)



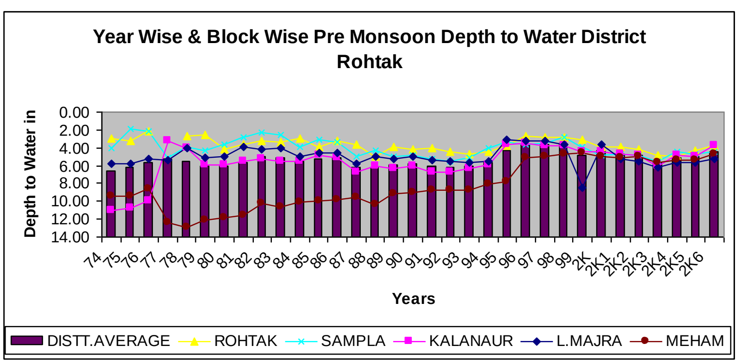


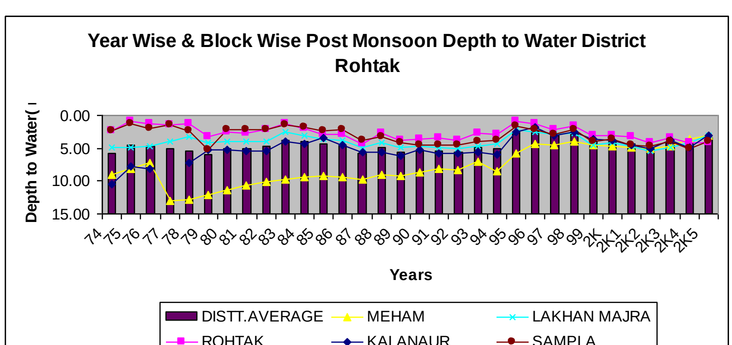


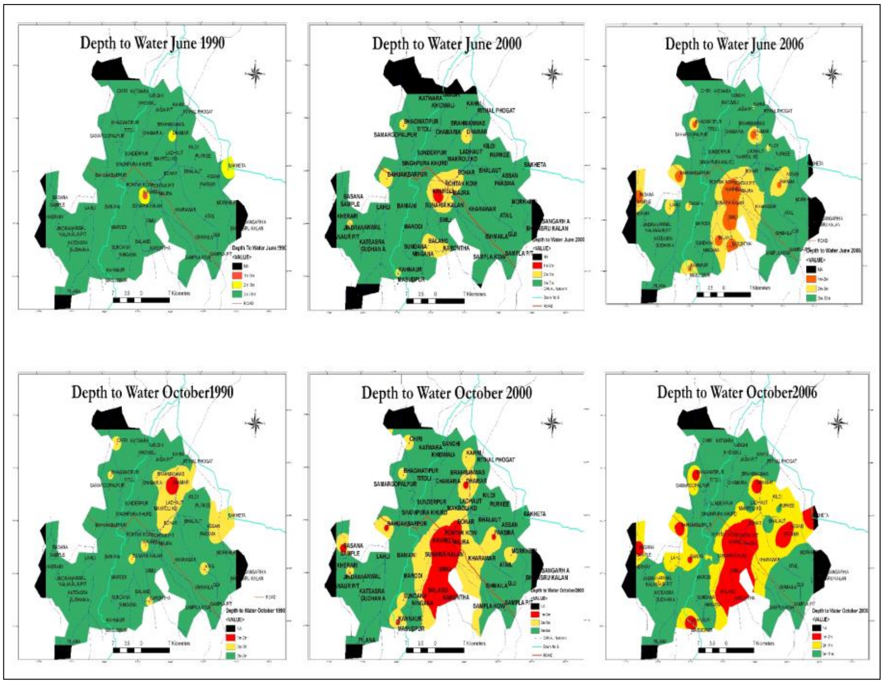
Flowchart showing Methodology:

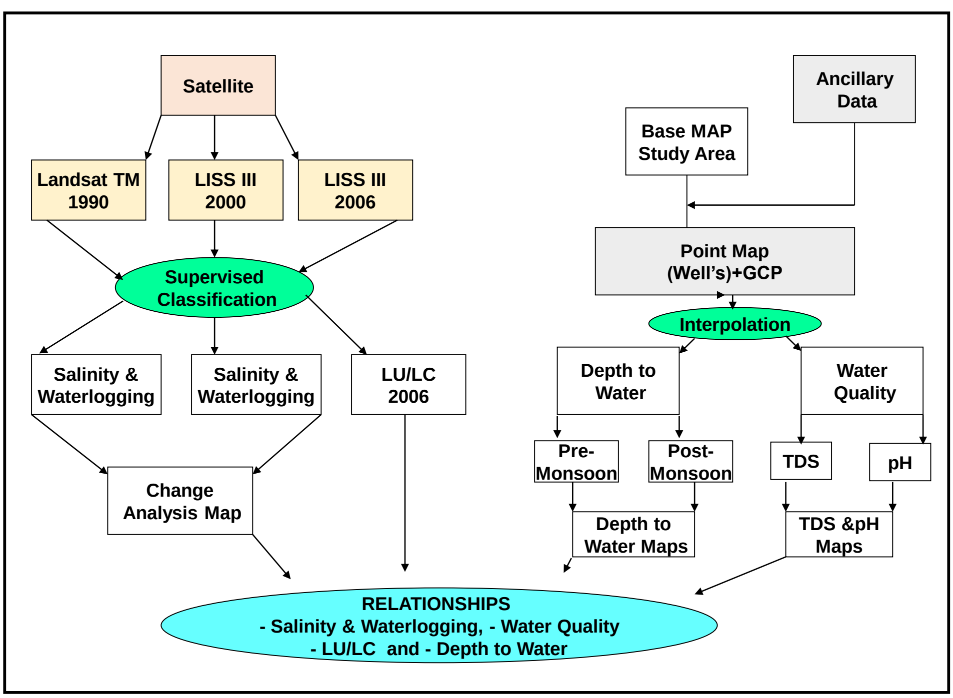


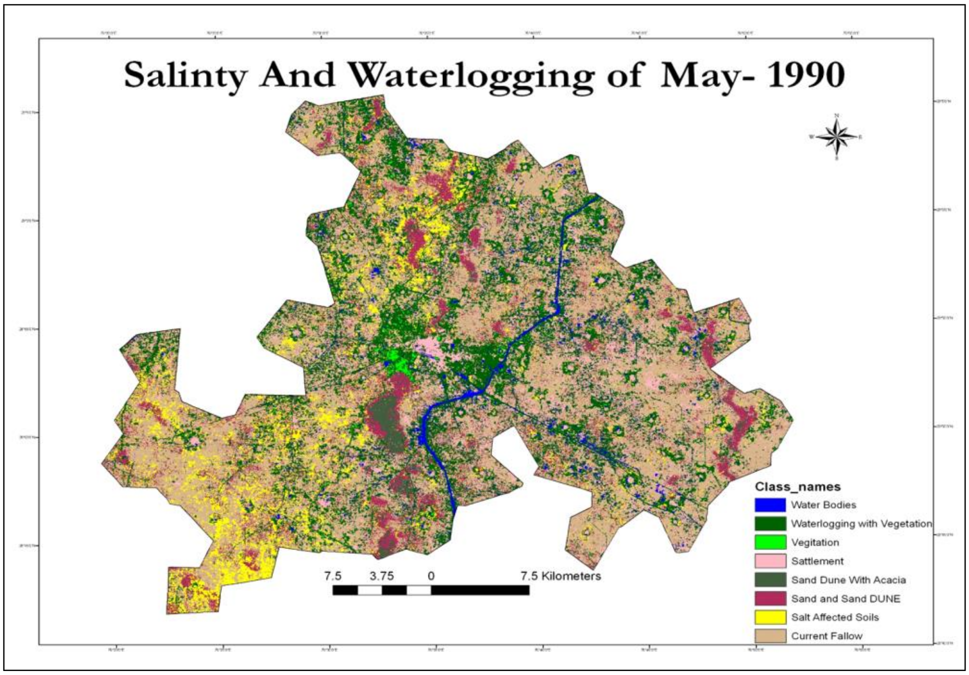
Point coverage showing the exact location of each observation well.
(*Source: Ground Water cell, Agriculture Department Rohtak Haryana.*)

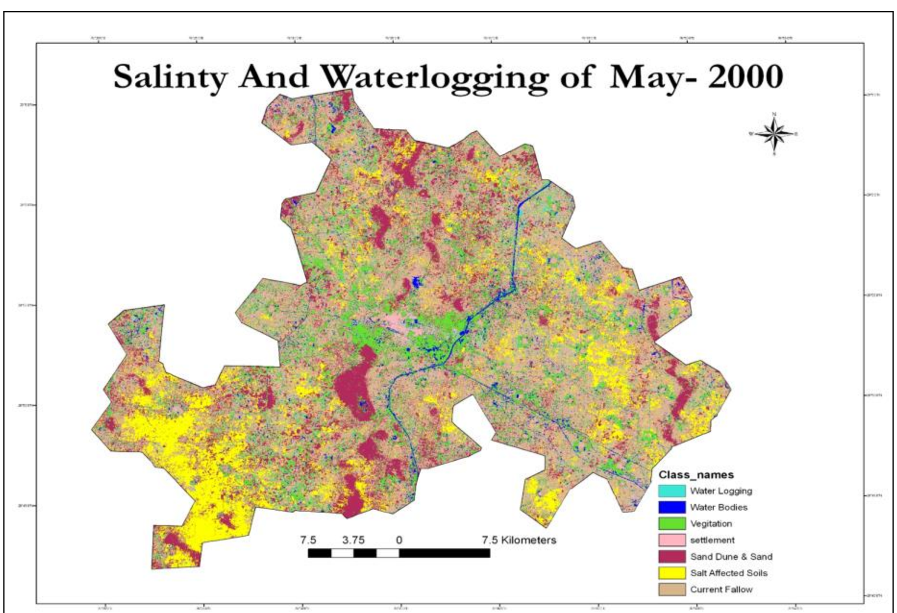


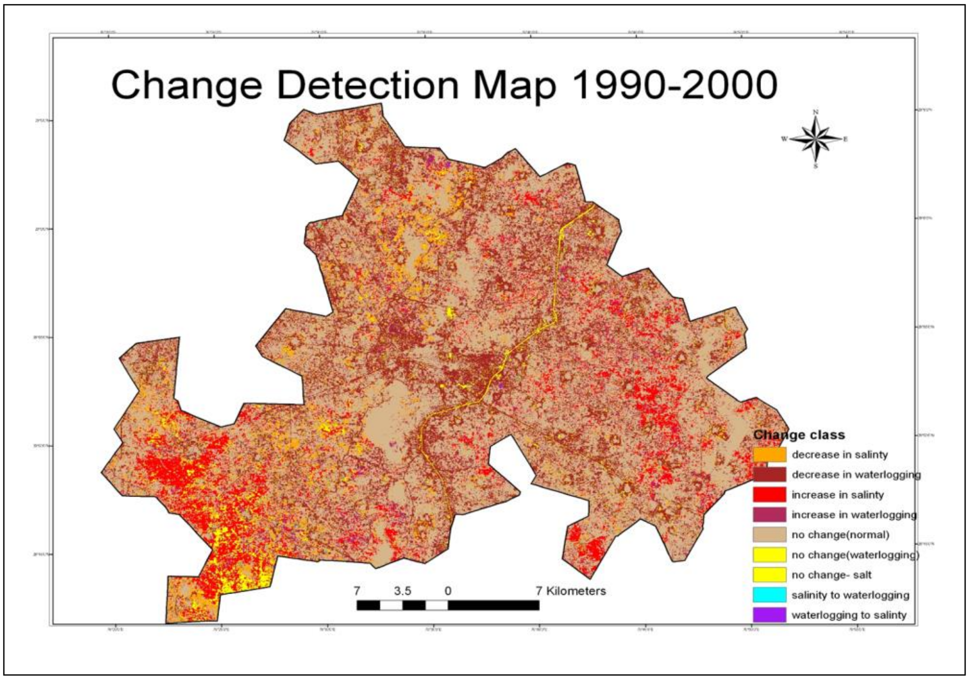



Depth to Water June 1990
Depth to Water June 2000
Depth to Water June 2006
Depth to Water October1990
Depth to Water October 2000
Depth to Water October2006


Satellite
Landsat TM 1990
LISS III 2000
LISS III 2006
Supervised Classification
Salinity & Waterlogging
Salinity & Waterlogging
LU/LC 2006
Change Analysis Map
Ancillary Data
Base MAP Study Area
Point Map (Well's)+GCP
Interpolation
Depth to Water
Water Quality
Pre-Monsoon
Post-Monsoon
TDS
pH
Depth to Water Maps
TDS &pH Maps
RELATIONSHIPS
- Salinity & Waterlogging, - Water Quality
- LU/LC and - Depth to Water

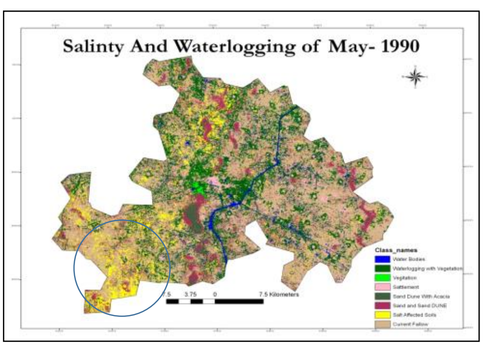

Salinty And Waterlogging of May- 1990
Class_names
Water Bodies
Waterlogging with Vegetation
Vegitation
Sattlement
Sand Dune With Acacia
Sand and Sand DUNE
Salt Affected Soils
Current Fallow
7.5 3.75 0 7.5 Kilometers

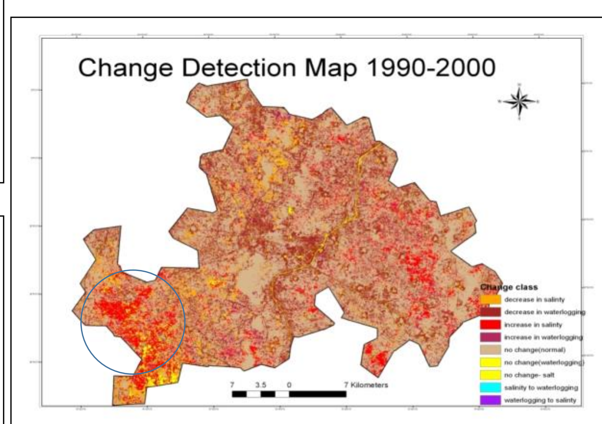

Salinty And Waterlogging of May- 2000
Class_names
Water Logging
Water Bodies
Vegitation
settlement
Sand Dune & Sand
Salt Affected Soils
Current Fallow
7.5 3.75 0 7.5 Kilometers

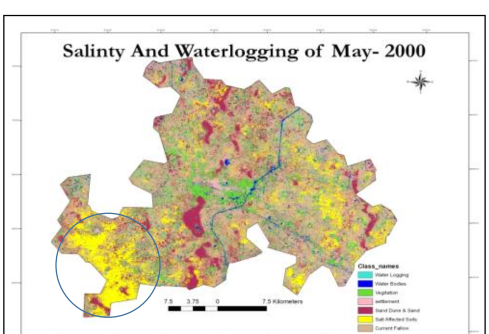


Monitoring Salt affected soils in canal Irrigated area

: Rohtak District (Haryana)







- Hyperspectral remote sensing (HRS) is emerging as a promising tool for these application owing to its capability to measure the reflectance of earth surface features

- Advantage - Hyper spectral data can improving the accuracy in quantitative estimation of soil chemical compounds

• Due to continuous spectral bands HRS contains the exact information over the full length of the spectrum, where as in MRS information lies only in the discrete patches of spectrum thus lacks information content.

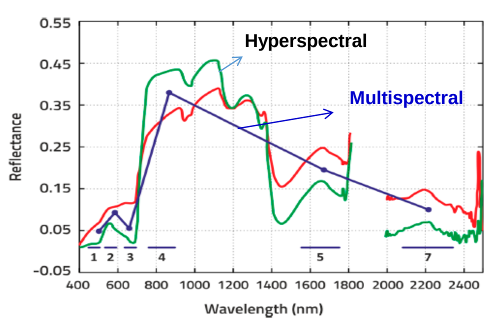
• Specific chemical compounds has specific absorption feature at specific wavelength, hence narrow band width helps to pick those specific absorption feature unlike the broad bands in MRS

Thus Hyper spectral data can improving the accuracy in quantitative estimation of soil chemical compounds

Hyperspectral Vs Multispectral Remote Sensing

- **Powerful and versatile tool** for characterization, mapping and monitoring of salt-affected soils as it records continuous sampling and the high spectral resolution (<5 nm).

- Multispectral broadband sensors (>50 nm) may lose important spectral information, while narrow bands can discriminate critical spectral differentials in detail.



Hyperspectral provide spectral signature that is unique of one object

Hyperspectral sensing technology should be preferred when it comes to sense chemical and physical properties of an object.

Remote Sensing of Salt-affected Soils

- Bare soil surface with salt incrustation
- Vegetation as proxy for monitoring salinity

- Saline soils contain liquid water molecules in their crystal lattice, the absorption range of liquid water is useful to estimate soil salinity.
- With increasing salinity, the depth and width of the absorption increase especially to the long wavelength side, and spectral feature shows “shoulder” around 1970-1980 nm.
- BenDor et al. (2009) showed that the position of peak depth around 1400 and 1900 nm shifted to long wavelength with increasing soil salinity.

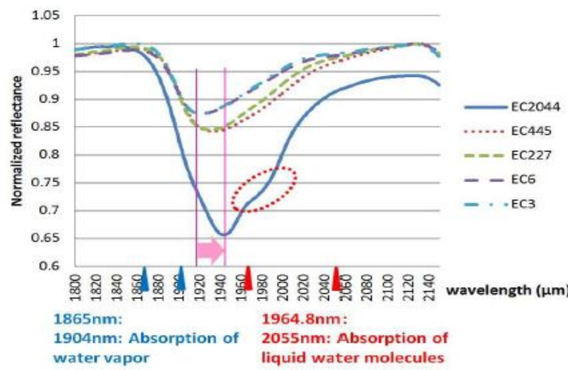


Figure 2. Change of spectral features with increasing soil salinity.

Hyperspectral vegetation indices as a proxy

- Vegetation stress responses to chlorophyll reduction and cell structure damage
- Increased visible reflectance (VIS) and the reduced near-infrared reflectance (NIR)

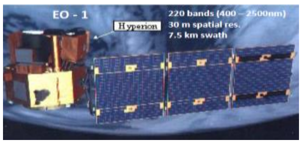
Study shows:

- Wavelengths at 395–410, 483–507, 632–697, 731–762, 812–868, 884–909, and 918–930nm were determined to be the **most sensitive bands (VNIR)**.
- By combining the most sensitive bands in a SAVI form, four soil adjusted salinity indices (SASIs) for all plant species (Halophytes and Non- Halophytes).
- Findings indicate the **potential to monitor salinity** with the hyperspectra of salt-sensitive and halophyte plants.

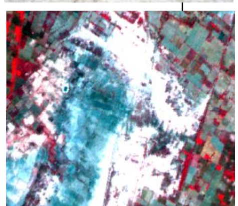
- IOP Conf. Series: Materials Science and Engineering **274** (2017)
- *Zhang et al. (2011). Ecological Indicators 11 : 1552–1562*

Spectral Characterization and Mapping of Salt-Affected Soils Using Hyperspectral Satellite

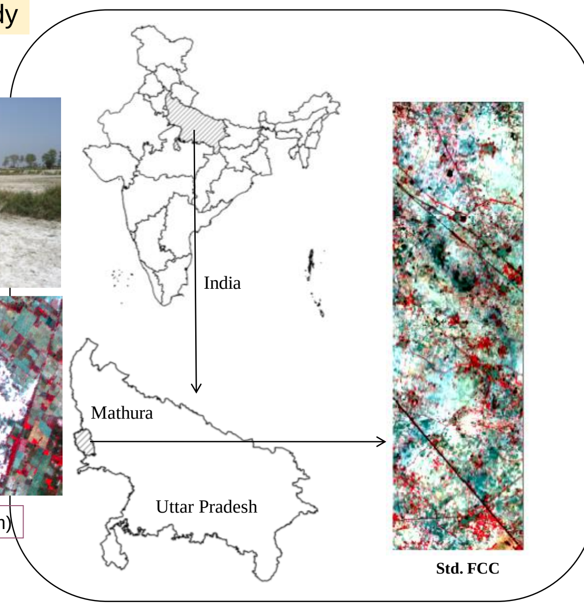
A case study



HYPERION (EO-1)	
No of bands	242
Spectral resolution	10 nm
Spatial resolution	30 m
Swath	7.5 km
Altitude	705 km



IRS LISS-IV (5.8 m)



Objectives

1. To study soil laboratory spectra to characterize soil salinity using portable Field Spectrometer and to compare with the Hyperspectral satellite derived spectra

2. Characterization and mapping of salt-affected lands using Hyperspectral satellite data with the following sub-objectives:

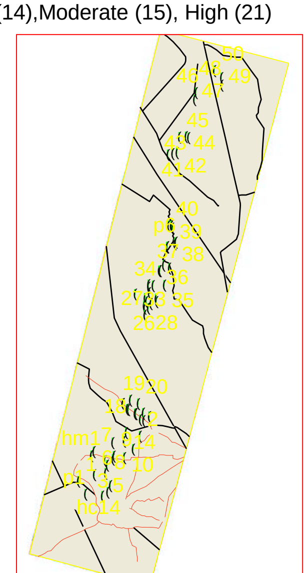
   (a) Sorting of suitable spectral bands for characterizing salt - affected soils

   (b) Study relationships between hyperspectral indices and soil salinity and mapping salinity severity

   (c) Spectral unmixing analysis for mapping various kinds of salt-affected lands.

   (d). SVM technique in mapping severity of soil salinity

- **Soil sampling plan** : **Three transects** :
  No. of samples: **64** : Normal (14), Slight (14),Moderate (15), High (21)



Sensitive Bands based on the Correlation of Mean Reflectance Value and EC 1:2 (ds/m) and pH

Bands	Wavelength (nm)	R^2 EC (ds /m)	R^2 pH
Band 9	436.99	0.6977	0.5576
Band 10	447.17	0.6839	0.5279
Band 11	457.34	0.672	0.5203
Band 13	477.69	0.6779	0.5349
Band 14	487.87	0.6813	0.5204
Band 16	508.22	0.6744	0.539
Band 19	538.74	0.639	0.5321
Band 20	548.92	0.6359	0.5321
Band 22	569.27	0.6151	0.5208
Band 26	609.97	0.5973	0.5043
Band 28	630.32	0.5976	0.5058
Band 29	640.50	0.5917	0.5083
Band 30	650.67	0.5887	0.5053
Band 40	752.43	0.5761	0.5125
Band 46	813.48	0.5717	0.5226

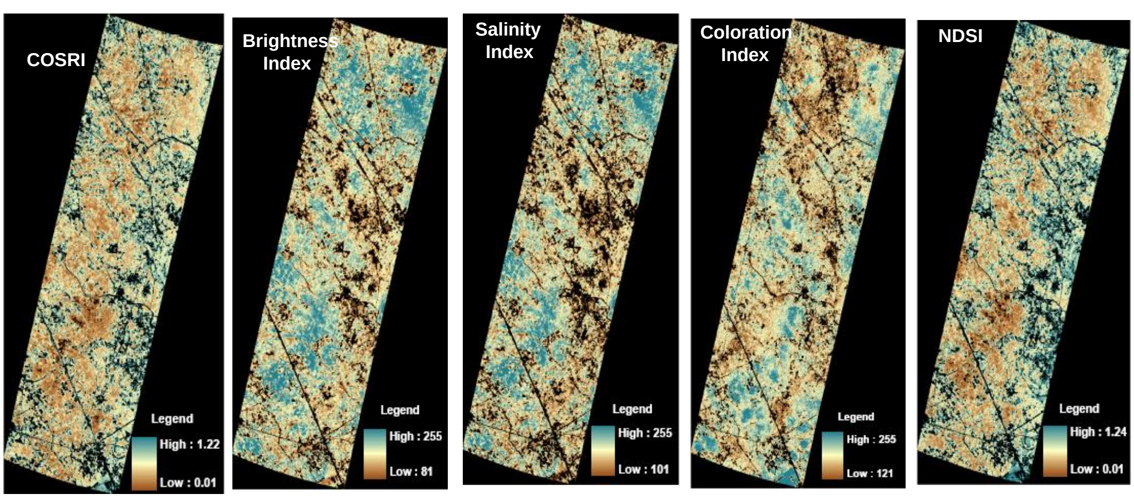
Formulae of spectral indices based on sensitive spectral bands

S. No	Spectral Indices	Formulae
1	NDVI	(Band 40(752.43 nm) – Band 30(650.67 nm) / Band 40(752.43 nm) + Band 30(650.67 nm))
2	COSRI	(Band 9(436.99 nm) + Band 20(548.93nm) / Band 28(630.32 nm) + Band 46(813.48 nm))*NDVI
3	NDSI	(Band 29(640.50 nm) – Band 46(813.48 nm) / Band 29(640.50 nm) + Band 46(813.48 nm))
4	BI	√ ((Band 9^2 (436.99 nm) + Band 20^2 (548.93nm) + Band 28^2 (630.32 nm))/3)
5	CI	(Band 29 (640.50) – Band 22 (569.27) / Band 29 (640.50) + Band 22 (569.27))
6	SI	√ Band 9(436.99 nm) * Band 28(630.32 nm)

Correlation coefficient (r^2) between spectral indices and soil salinity parameters

Spectral Indices	EC	pH	ECe	ESP	SAR
Salinity index	0.814	0.519	0.777	0.804	0.801
Brightness Index	0.773	0.517	0.732	0.796	0.772
COSRI	0.591	0.436	0.524	0.596	0.552
NDSI	0.522	0.228	0.534	0.271	0.389
Coloration Index	0.433	0.312	0.312	0.444	0.451

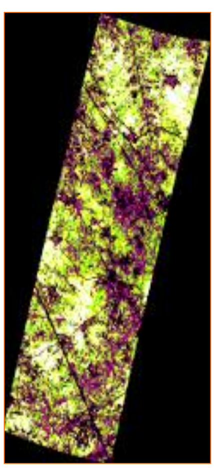
Spectral Indices



RMSE : Observed and Predicted EC, SAR and ESP

Spectral Indices	No.of randomly selected sites	EC	SAR	ESP
Salinity index	10	**7.48**	**18.14**	**7.85**
Brightness index	**10**	**7.7**	**33.36**	**9.60**
COSRI	**10**	**11.7**	**48.21**	**13.79**
NDSI	**10**	**10.4**	**62.02**	**27.67**
Coloration index	**10**	**21.2**	**68.67**	**18.15**

Hyperspectral remote sensing data derived spectral indices in characterizing salt-affected soils: a case study of Indo-Gangetic plains of India. ***J. Environmental Earth Sciences***, DOI:10.1007/s12665-014-3613-y.

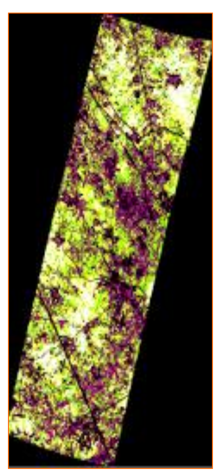


y = 1.1518(SI _ Map)–47.516

SAR Map using Salinity Index

Legend

- Normal Soil (**6.16 - 12.36**)
- Slightly Salt Affected Soil (**16.05 - 19.36**)
- Mod. Salt Affected Soil (**38.06 - 113.99**)
- Highly Salt Affected Soil (**117.58 - 270.30**)



y = 0.1189 (SI _ Map)+4.3019

ESP Map using Salinity Index

- Normal Soil (**5.48 - 13.16**)
- Slight Salt Affected Soil (**14.36 - 15.73**)
- Mod. Salt Affected Soil (**16.27 - 23.95**)
- Highly Salt Affected Soil (**24.33 - 36.21**)

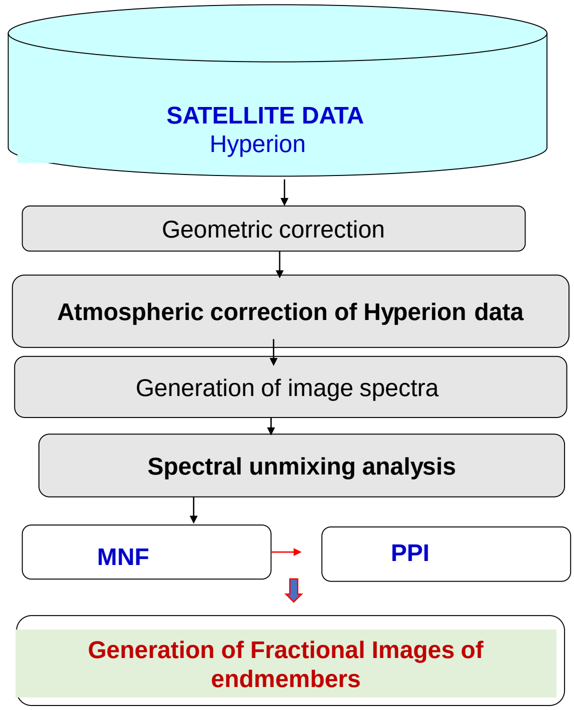
y = 0.0438(SI_Map)+ 4.347

EC Map using Salinity Index

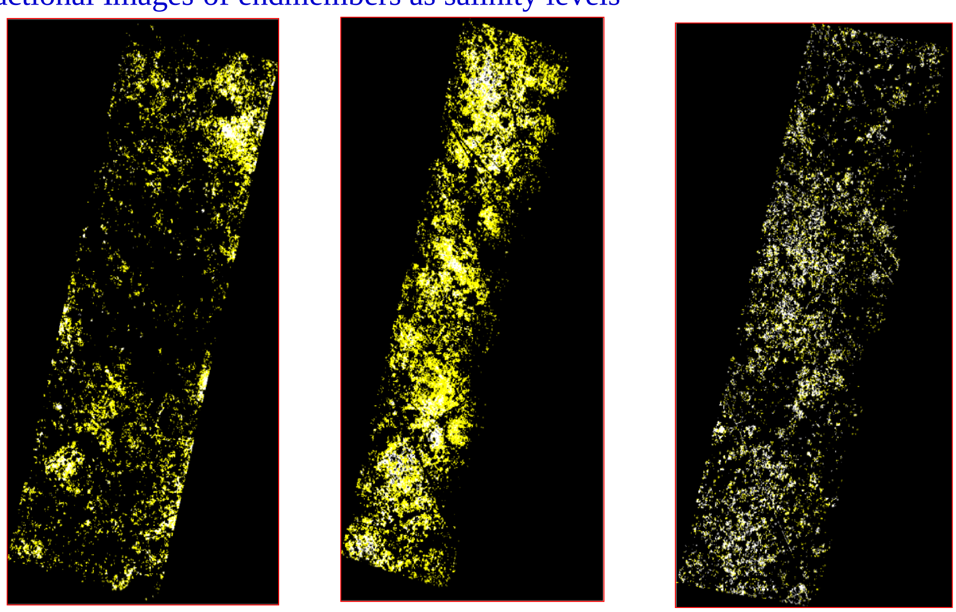
- Normal Soil (**0.16 – 3.07**)
- Slightly Salt Affected Soil (**4.28 – 7.70**)
- Moderately Salt Affected Soil (**8.10 – 10**)
- Highly Salt Affected Soil (**10.21 – 30.41**)

Environ Earth Sci (2015) 73:3299-3308

Spectral unmixing analysis



Fractional Images of endmembers as salinity levels



Highly Salt Affected Soil | Moderately Salt Affected Soil | Slightly Salt Affected Soil

J. Indian Soc. Remote Sens., 40 (1): 129-136.

Future Global Hyperspectral Satellite

Satellite	Country	Resolution (m)	Spectral bands
HySIS on IMS-2	India (Nov. 2018)	550	64
HySIS on IMS-1	India (May, 2008)	550	64
AHySIS-2	India (2020-24)	30	55 (0.4 to 0.95μm)
EnMAP	Germany (2017)	30	232
EnMAP	Germany (2020)	30	232 (420-2450 nm)
ALOS-3	Japan (2019)	30	VNIR – **57** bands,SWIR- **128 bands**

India : Future Geostationary Imaging SATellite (GISAT) – 2019-20

Spectral bands	# channels	Resolution (m)	Spectral range
MX-VNIR	4	50	0.45-0.86
HyS-VNIR	>60	500	0.375- 1.0
Hys-SWIR	>150	500	0.9-2.5
MX-LWIR	6	1500	7.0-13.5

5 minute (0.5 -1.5 Km) and 30 minutes (50 m)

Thermal infrared imagery was used to distinguish between different levels of soil salinity on agricultural lands. The principle behind this approach is that **canopy temperature of the plants** grown in affected areas will be higher than of plants growing in non-affected areas.

The approach was tested on regional and local scales and showed its robustness in different climatic conditions and on areas covered with different crops. Therefore, it **seems promising** for use on a global scale.

But needs to establish because of the different climatic zones and extreme temperature differences between regions, and use without normalization will just lead to characterization of climate, rather than soil salinity.

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- Ivushkin, K., Bartholomeus, H., Bregt, A.K., Pulatov, A., 2017. Satellite thermography for soil salinity assessment of cropped areas in Uzbekistan. Land Degrad. Dev. 28, 870–877. https://doi.org/10.1002/ldr.2670.

Thank You.

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- Allbed, A., Kumar, L., Sinha, P., 2014b. Mapping and modelling spatial variation in soil salinity in the Al Hassa oasis based on remote sensing indicators and regression techniques. Remote Sens. 6, 1137–1157. https://doi.org/10.3390/rs6021137.