7. DELINEATION AND CHARACTERISATION OF SALT-AFFECTED AND WATERLOGGED SOILS IN IGNP (PHASE I), RAJASTHAN (CSSRI)

7.1 Introduction

The Thar Desert occupies about two-third part in the State of Rajasthan. Traditionally, agriculture in this region depends on the scanty rainfall. Irrigation was introduced in this area by commissioning Indira Gandhi Nahar Pariyojona (IGNP). The total irrigation potential is estimated as 13.87 lakh hectares. Canal irrigation has brought a significant change in the cropping pattern. The traditional rainfed subsistence crops have been replaced by cash crops. On an average annual area sown has increased by 200% after introduction of canal irrigation. As a result of canal irrigation, most part of the Ganganagar district experienced a significant increase in crop production. However, irrigation has also brought problems such as waterlogging and soil salinity, which not only degraded the good irrigated agricultural lands but also devastated the village hamlets. As a consequence, most part of the areas around the main canal where water delivery is comparatively high experienced high water tables and water stagnation particularly in the low-lying flats and depressions. Canal seepage, surface irrigation practices, sandy soil texture and the presence of hard impermeable layer at shallow depth are found to be among the several factors responsible for the development of water ponding, high water table and secondary salinization in the command area.

7.2 Study Area

The study area lies between 29°00' and 29°40' N and 74°00 and 74°40' E. The area is irrigated through the main canal (Indira Gandhi Canal) and its branches such as Rawatsar, Naurangdesar distributary and Suratgarh branch. About 59% of the land is non-irrigable and 80% of the irrigable land is sandy in nature (FAO/UNDP, 1971). Sandy plain, floodplain, dunes, depression, interdunal flat are the common landforms of the area. Aeolian sand and fluventile sediments are the major geological formations leading to the development of the vast sandy plain. The quaternary alluvium sediment forms major hydro-geological formations. Fig. 7 gives an overview of the selected study area. The areas selected for detailed studies on waterlogging and salinity are indicated with 'W' and 'S' respectively.

The groundwater conditions are highly variable. It occurs at shallow depth in the low-lying interdunal flats close to the main canal where waterlogging condition appeared. Based on the continuous monitoring of the groundwater data, the water level is reported to increase at an alarming rate. Pearl millet, sorghum cluster bean, sesamum, in the kharif and wheat, gram, in the rabi season, are mainly grown. Besides, paddy, sugarcane, cotton, mustard, is also cultivated in the irrigated areas. Climatic parameters categorise the soils in Ustic and Hyperthermic soil moisture and temperature regimes respectively. The light texture, presence of subsurface fine textured/mixed kankar (CaCO₃ nodules)/gypsum impermeable layer and absence of natural surface drainage are some of the principal constraints limiting sustained irrigated agriculture.
Figure 7. A FCC showing study areas for waterlogging (W) and salt-affected (S) studies
7.3 Methodology

The IRS LISS II imageries of February, November 1996 and June 1998 were used for the identification of the waterlogged areas and salt-affected soils. For detailed analysis, IRS digital data of February 1996 were processed. The imageries were geo-referenced using tie-points method, thereafter geo-coded through re-sampling. A colour composite was prepared using band 4, band 3 and band 2 of the LISS II data. (see also the flow chart in Fig. 8).

7.3.1 Preparation of the Base Maps

The basemaps indicating permanent settlements such as roads, railways, river, streams, village boundaries, city, towns, tehsils, irrigation network were prepared in GIS. For this, Survey of India toposheets were used as reference material. The permanent fixtures were transferred in digital format through digitisation. Initially, the Soil toposheets were geo-referenced using UTM co-ordinate system. For this, the co-ordinates of the toposheets were converted into the UTM values in meters using transform co-ordinate function in ILWIS. Finally, eight toposheets on 1:50,000 scales covering the study area were digitised. A part of the study area indicating permanent features and irrigation network is used as base-layer to support mapping of waterlogging and soils salinity in the command area.

7.3.2 Interpretation of IRS Data

False colour composites of selected sections of the study area pertaining to waterlogged and salt-affected areas were visually interpreted overlaying the base map and other ancillary information. Based on the differential manifestations of tone, texture, pattern on the satellite imageries, the image elements were identified and further verified during field checks. The interpreted units were digitised (on-screen) to create a polygon map. The area statistics were generated through histogram analysis.

7.3.3 Characterisation of Soil Samples

Field check was done during the post monsoon season for spot identification and images correlation. Based on the image interpretation, sampling sites for soils profiles were selected and representative soil profiles were studied for morphological characteristics (Soil Survey Staff, 1995). The water samples were collected from the accumulated seepage lakes (Tal), auger bore and profile pits. The water table depths were recorded at selected locations.

Standard methods were followed for determining the mechanical composition, calcium carbonate (<2 mm size), organic matter, cation exchange capacity and exchangeable sodium percentage (Jackson, 1967). Saturation extract of the soils were prepared and analysed for pH, EC, soluble cations and anions and water samples were analysed for pH, EC, Na⁺, K⁺, Ca²⁺ + Mg²⁺, CO₃⁻, HCO₃⁻, Cl⁻, and SAR for quality appraisal using standard methodology (Richards, 1954). Based on the morphological and chemical data, the soils were characterized and classified as per Soil Taxonomy.
Figure 8. A flow chart of the adopted methodology
7.4 Results

7.4.1 Soil Characteristics

The soil morphology showed coarse texture, poor structure, weak consistency and presence of abundant CaCO$_3$ nodules within the control section of soil profiles. Little iron and manganese concretions/mottling around micro-pores were observed in the subsurface horizons. A weak to violent effervescence was observed due to the presence of kankar layer within the saturated zone of the soil profile. The soil contains an appreciable quantity of soluble salts (EC$_e$ ranging from 1.9 to 50.0 dSm$^{-1}$) comprising of chlorides (13 to 902 meq/l). In many cases, the quantity of magnesium showed higher preponderance indicating the presence of magnesium bearing minerals in the parent material. Sodium was often found to exceed calcium and magnesium in the severely affected zones. The soils were classified as Ustorthent, Ustifluvent, Ustipsamment, Torripsamments and Torrifluvent at the sub-group level.

7.4.2 Waterlogged Areas

Prominent waterlogging was identified from the image elements of dark blue to blue/black tone. This class is indicated in Fig. 9 as ‘Ponded water’. This phenomenon occurred due to seepage and accumulation of irrigation water and is mostly confined to the localized low-lying areas. Statistical analysis showed that at the test site, about 12% of the area was affected due to surface ponding (Fig. 9). Besides, ground truth verification of some areas under irrigation, showing light to dark grey tone intermixed with reddish mottles in the images, were found to possess shallow water table depth ranging from 0 to 1.5 m.

7.4.3 Soil Salinity Features

Visual interpretation of the IRS LISS II data of February and November 1996 identified salinity features in patches of 10-40 ha by a mixed spectral response of white and grey to yellowish white tones classified as ‘surface salt efflorescence’. During ground verification, salt accumulation (2-3 cm depth) was found to be associated with the ‘ponded water’ class with salt grasses. During post-monsoon ground truth, a thin layer of salt accumulation was found in the irrigated areas co-existing with vegetative cover. Soil physico-chemical data indicated accumulation of salts in the subsurface layers of some soils. This phenomenon indicates operating process of secondary salinization in the normal soil areas. Image interpretation could only delineate the thick salt efflorescence on the bare soils. The area statistics showed that it occupies about 11% of the selected area (Fig. 10).

7.5 Conclusions

- Not much difference was observed on the November and February images. Both the images could give similar visual interpretation results. The June image gives a mixed picture, only the permanently submerged areas could be identified.
Figure 9. Waterlogged areas in the part ofIGNP command

Figure 10. Salt-affected areas in the part ofIGNP command
Interpretation of IRS data easily revealed the 'ponded water' class.

On the image, no differentiation could be made between critical and potential waterlogging so they are merged. Tone difference could be observed between the normal cropped and the above-mentioned classes.

A good relation was found between the characteristics of image elements and the ground observations of ponded water, normal cropped and highly salinized areas.

Visual interpretation revealed presence of surface soil salinity as salt efflorescence on the bare soil. Ground truth studies also found salt accumulation in the subsoil zones indicating secondary salinization. This was not expressed on the images.

7.6 Recommendations

Temporal data over a period of ten years could be used for monitoring the changes of the extent of waterlogging and secondary salinization. Either February or November images could be used. Groundwater levels, crop yields and surface salinity levels should be monitored at a regular interval in various representative parts of the command area. Additional field observations should be taken at the time of the satellite overpass.

After pre-field visual interpretation, a stratified sampling of basic soil parameters and crop status should be collected to provide additional information on the spatial variation of the waterlogging condition and salinity status.

Digital image processing such as supervised classification supported by GPS assisted ground truth should be undertaken to fully utilize the potential of the satellite images.
8. MONITORING AND EVALUATION OF IRRIGATION SYSTEM PERFORMANCE IN SALINE IRRIGATED COMMAND, BHALAUT DISTRIBUTORY, HARYANA (CSSRI)

8.1 Introduction

In irrigated agriculture where waterlogging and soil salinity prevail, information on state/ severity of these problems under cropped condition and their adverse impact on crop production would be helpful to understand the dynamics of intra-seasonal waterlogging/ salinity and to forecast crop production. In the past, most studies pertaining to delineation of waterlogged/ salt-affected areas were mainly confined to bare soil condition. Therefore, this study was initiated with the objective to identify the waterlogging/ salinity conditions in irrigated cropped land. Surface radiative properties, vegetation indices and moisture indicators have been used to identify the severity of waterlogging/ salinity in the Bhalaut distributary of the Western Yamuna Canal system in Haryana.

8.2 Study area

The study was conducted in the Bhalaut distributary command covering an area of about 19,000 ha. The project area is located between 28°45' to 29°15' N latitude and 76°30' to 76°55' E longitude. Climatically, the study area falls in semi-arid region with an average annual rainfall of 545 mm and average annual evapotranspiration of 1650 mm. The average minimum and maximum temperature fluctuates between 5-45 °C, respectively. The soil is mainly alluvium, light textured categorised as sandy loam to loamy sand. In the study area, the soil salinity varies between 0-12 dSm⁻¹ in 0-60 cm layer at the time of harvest of wheat crop. In the soils, salts are mainly calcium, magnesium and sodium chloride. The water table ranges from 1 to 5 m below the soil surface. The warabandi system is followed for water distribution from the canal.

8.3 Methodology

8.3.1 Image Selection

In the study area, the performance of irrigation system is mainly of concern during the middle to late rabi season, when evaporative demand is high and soil salinity increases to a great extent. Wheat is the major crop during the rabi season (more than 80% area) and phenologically, it attains maximum vegetative growth by middle of February and hence the effect of cultural practices minimises afterwards. The severe problem of waterlogging is observed in the beginning of the crop growth, which tapers down and is least at the time of crop harvest. However, in many low-lying areas, it remains severe throughout the season. The requirement of irrigation water during ripening period (3rd week of March onwards) also decreases. Considering all these aspects, the ideal time for selection of satellite remote sensing image specially for assessing irrigation system performance was considered from middle of February to middle of March. The availability of
cloud free Landsat-TM data for this period was explored. As no cloud free data were available for the said period, therefore, a quadrant scene (approx. 75,000 ha) of Landsat 5-TM on a clear sky day (30th January 1996 for Path/Row-147/40) was procured. A flow chart of the adopted methodology for identification of crops affected by waterlogging and soil salinity is shown in Fig. 11.

8.3.2 Data Pre-processing and Spectral Characteristics

The sub-scene was geometrically corrected on a state plane coordinate system (scale-1: 50,000). The in-band planetary reflectance was determined for visual interpretation of spectral pattern of different land uses. The spectral reflectances for various land uses (using ground information) in different band spectrum were retrieved. It showed that water has in general lower reflectance in all the bands than all other features. The cropped land has higher reflectance than water in all the bands. Due to the influence of high moisture, waterlogged crop has low reflectance than the normal crop in all the bands whereas the salt-affected crop has higher reflectance in bands other than red and near infrared (NIR). The reflectance from bare soil and salt surface are higher than the cropped land except in NIR band. The reflectance from saline surface is higher than bare soil and other features but lower than bare soil in middle infrared region. This is mainly due to the hygroscopic characteristics of many salts or due to the high moisture content of fresh salts. On the basis of spectral characteristics of different land uses, a land use classification in the irrigated command has been made.

8.3.3 Surface Radiative Indicators

For the analysis of waterlogged and salt-affected surface crops, various surface radiative property indicators i.e. surface albedo ($\alpha$), different band ratios for salinity index 1 ($SI_1 = 5/7$), salinity index 2 ($SI_2 = (4-5) / (4+5)$) and salinity index 3 ($SI_3 = (5-7) / (5+7)$) are used.

8.3.4 Vegetation Indicators

Chlorophyll has a strong spectral absorption in the visible region at 0.475 and 0.65 µm and thus provides information on vegetation condition. Among several vegetation indices, normalised difference vegetation index (NDVI) has been used for generating the crop condition map.

8.3.5 Moisture Indicators

The moisture indicator is determined as evaporative fraction ($\Lambda$) using relationship $\Lambda = \lambda E / (\lambda E + H)$. A model, Surface Energy Balance Algorithm for Land, SEBAL (Bastiaanssen, 1995) has been applied on Landsat-TM sub-scene to solve the surface energy balance equation:

$$Rn = G + H + \lambda E$$

where $Rn$ is the net radiation flux density (W m$^{-2}$), $G$ the soil heat flux density (W m$^{-2}$), $H$ the sensible heat flux density (W m$^{-2}$) and $\lambda E$ the latent heat flux density (W m$^{-2}$). The model combines analytical and empirical relationships to obtain distributed $Rn$, $G$ and $H$ fluxes. $\lambda E$ flux is obtained as the residue of the surface energy balance.
Digital RS data

Weather data

Geometric correction and pre-processing

Ground truth identification

Spectral characteristics of ground features

Atmospheric correction and surface albedo (α)

Vegetation index (NDVI)

Moisture indicator (Λ)

Is NDVI > NDVI_{datum}?

If NDVI < NDVI_{datum}:

Noncropped land

Yes

No

Is α < α_{crit}?

Salt-affected/water-stressed crops

Yes

No

Waterlogged crops

Iso-data clustering

Crop classification

Accuracy estimation, Statistical information

GIS application

Normal crop

Figure 11. A flow chart for identification of crops affected by waterlogging and soil salinity
8.3.6 Identification of Waterlogged and Saline Bare Surfaces

The lack of vegetation or scattered vegetation on waterlogged land and highly salt-affected soil surface makes it possible to detect waterlogged land and saline surfaces directly from the remote sensing measurements. The waterlogged land and saline surfaces have very distinct reflectance characteristics and can be identified with low \( \alpha \) - low NDVI and high \( \alpha \) - low NDVI, respectively. Well-developed saline efflorescence and crusts are always associated with high reflectance in visible and NIR on photographic data. However, reflectance reveals information of the first few millimetres of the top horizon and therefore, the possibility of underestimation exists. Reflectance of saline surface increases with increasing wavelength up to NIR and decreases in the middle infrared bands. However, the difference in spectral radiance of bare soil and saline surface in visible and NIR range is very small and therefore, the possibility of over estimation exists. Use of band 5 and 7 for determining threshold \( \alpha \) could reduce this error. The use of information in MIR and IR bands along with visible and NIR bands will provide precise information on soil surface with salt crust.

8.3.7 Identification of Waterlogged and Salt-affected Crops

A scatter-gram between surface albedo and NDVI is plotted for assessing severity of waterlogging and salinity in cropped area (Fig. 12). After evaluating the histogram of \( \alpha \) and NDVI, an approach,
based on a guiding principle that the surface albedo decreases with increase in waterlogging and increases with increase in salinity, has been developed. The reduction in crop condition is considered in both the cases. The various signatures are generated assigning the $\alpha$ and NDVI values. The signatures for bare soil and saline surface are assigned based on their spectral characteristics explained earlier.

The generated signatures are evaluated on plots of scatter-gram for all combinations of surface radiative property indicators ($\alpha$, SI1, SI2 and SI3), agronomical indicators (NDVI and LAI) and moisture indicator (A). It is observed that the scatter-gram between surface albedo and NDVI has high separability than all other radiative property indices. On evaluation of pixel by pixel values of NDVI and $\alpha$ colour composite, a kind of biased is observed due to the arbitrary selection of seed pixel and maximum likelihood classification procedure and therefore, another procedure was used to delineate and classify only waterlogged crops.

### 8.3.8 Methodology for Assessing Waterlogged Crops

The procedure consists of the following steps:

1. To suppress the non-waterlogged cropped land, apply an equation $\alpha_{\text{nor}} - \alpha_{(x,y)}$ on $\alpha$ image.
2. To suppress the non-cropped area, apply an equation $\text{NDVI}_{(x,y)} - \text{NDVI}_{\text{def}}$ on NDVI image and to suppress normal cropped area apply $\text{NDVI}_{\text{nor}} - \text{NDVI}_{(x,y)}$.
3. The suppressed $\alpha$ and NDVI images are recoded by assigning values 0 (for values $\leq 0$) and 1 (for values $> 0$) and multiplied in order to prepare a mask for waterlogged crops.
4. The mask is applied on $\alpha$ and NDVI image to select the waterlogged crops only.
5. Iso-data clustering operation was performed to generate the waterlogged crop classes based on average values of $\alpha$ and NDVI of the clusters (Table 10).
6. A linear regression is developed for waterlogged crop class number with $\alpha$ and NDVI and extrapolated for preparing waterlogged crop class.

$$\text{WLCCN} = 23.14 - 124.35 \times \alpha_{(x,y)} + 4.02 \times \text{NDVI}_{(x,y)}$$

where WLCCN is the waterlogged crop class number, $\alpha_{(x,y)}$ the distributed surface albedo, NDVI$_{(x,y)}$ the distributed NDVI.

### Table 10. Selection of average $\alpha$ and NDVI values obtained by iso-data clustering

<table>
<thead>
<tr>
<th>Waterlogged crop class number</th>
<th>$\alpha$</th>
<th>NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly waterlogged (1)</td>
<td>0.156</td>
<td>0.69</td>
</tr>
<tr>
<td>Moderately waterlogged (2)</td>
<td>0.161</td>
<td>0.57</td>
</tr>
<tr>
<td>Highly waterlogged (3)</td>
<td>0.147</td>
<td>0.46</td>
</tr>
<tr>
<td>Severely waterlogged (4)</td>
<td>0.142</td>
<td>0.38</td>
</tr>
</tbody>
</table>
8.3.9 Methodology for Assessing Salt-affected Crops

The scatter-gram between $\alpha$ with $\Lambda$ for assigned classes in first classification showed a decrease in $\Lambda$ for highly salt-affected crops. This indicated that the classification based on $\alpha$ and NDVI includes reduction in NDVI due to salt stress as well as water stress and in both cases $\alpha$ increases.

As $\Lambda$ is a measure of relative water availability in the command, it is included for improved classification of salt-affected crops. An equation is designed to scale up the crop class taking into account the fact that increase in $\alpha$ and decrease in NDVI represents increase in salinity. Also a scale-down factor is included to take into account the decrease in salinity due to decrease in evaporative fraction. The equation to classify the salt-affected crops class number (SACCN) is expressed as:

$$SACCN = \frac{\alpha_{(x,y)} - \alpha_{dat}}{\alpha_{nor,avg}} * \frac{NDVI_{nor,avg} - NDVI_{dat}}{NDVI_{(x,y)}} \frac{\Lambda_{nor,avg} - \Lambda_{(x,y)}}{\alpha_{nor,avg}}$$

where SACCN is the salt-affected crop class number, $\alpha_{nor,avg}$ the average surface albedo for normal crop, $NDVI_{nor,avg}$ the average NDVI for normal crop, $NDVI_{dat}$ the minimum NDVI value for crops, $\Lambda_{nor,avg}$ the average evaporative fraction for normal crop, $\alpha_{(x,y)}$ is the distributed evaporative fraction.

The application of equation is not straightforward as it gives error due to algebraic limitation and therefore, applied in parts to classify the salt-affected crops. The signatures are evaluated on scatter-gram between crop class with $\alpha$, and NDVI in different combinations. This showed a good response in all categories.

8.3.10 GIS Application

A map of the project area was digitised through Arc-Info package of GIS and transformed to real world coordinate system to extract the command area of Bhilaut distributary and the four watercourse commands at tertiary level. The digitised map has been used to create the polygons and extracting information from various images for the command of Bhilaut distributary (Bt), tertiary unit at head of Bhilaut distributary (Bt1), tertiary unit at tail of Bhilaut distributary (Bt3), tertiary unit at head of Asan minor of Bhilaut distributary (Btal) and tertiary unit at tail of Asan minor of Bhilaut distributary (Bta3). The statistics for the analysis of variability in water supply, crop condition/yield and waterlogging/soil salinity in cropped land have been generated.

8.4 Results

The analysis of waterlogged crop image has shown severely waterlogged crops close to the vicinity of branch canal and distributary (Fig. 13a). A total 14 percent area suffers from various degrees of waterlogging in the Bhilaut distributary. At tertiary level, the spatial distribution of waterlogged crops indicated higher area under severe waterlogging at the lower reach of watercourse located at the head for Bt1 and Bta1. The waterlogged crop area reduces at the tail end of the distributary and minor for Bt3 and Bta3.

A total of 23 percent area was found suffering from various degrees of soil salinity in the cropped land of the command of Bhilaut distributary (Fig. 13b). The crop affected with different salinity
Figure 13. (a) Waterlogged and (b) soil salinity affected crop area in the Bhalaut distributary command
levels at tertiary level indicated an increase in cropped land affected from soil salinity at the lower reach of the watercourse command. The statistics of area under different level of salt-affected crop at different location of the watercourse command indicated an increase in salt-affected crop in tail ends both in case of Bhalaut distributary, Bt3 and at Asan minor, Bta3.

8.5 Conclusions

- The presented approach based on surface radiative properties, biomass depression and moisture indicator seems promising for identification and assigning the extent and severity of waterlogged/salt-affected cropped land using remote sensing data along with geographical information system.

- The analysis, based on this approach, indicated relatively higher area under waterlogged crops close to the head of the distributary than tail reaches, whereas an increase in crop area affected from soil salinity with respect to distance from head of the distributary/watercourse.

- Based on the image characteristics, a total 14% area under crops suffers from various degrees of waterlogging, whereas 23% area suffers from different levels of salinity in Bhalaut distributary.

8.6 Recommendations

- The presented approach has been applied on one satellite data set. It is recommended that the approach may be validated and used on temporal RS data for waterlogging/salinity identification and assessment under cropped condition.

- Looking to the small area under consideration in a distributary command, the study needs to be carried out at the level of branch canal where higher variation of waterlogging/salinity on cropped land is expected.