Desertification Status Mapping of India-2nd Cycle

Technical Guidelines

Marine, Geo and Planetary Sciences Group, EPSA

Space Applications Centre (ISRO)

Ahmedabad – 380 015

April 2013

<u>**DOCUMENT CONTROL AND DATA SHEET**</u>

1.	**Report No**	SAC/EPSA/MPSG/DSM/TR-02/2013
2	**Publication Date**	April 2013
3	**Title**	DESERTIFICATION STATUS MAPPING OF INDIA 2nd cycle: Technical guidelines
4	**Type of Report**	Technical Report
5	**Pages, tables and Figures**	49, 21 and 23
6	**Author(s)**	Project Team
7	**Originating Unit**	MPSG/ EPSA/SAC/ISRO, Ahmedabad-15
8	**Abstract**	This document briefs on the desertification indicators, comprehensive classification system, methodology and legend for Desertification Status Mapping of drylands evolved and standardized for the country during cycle 1 of the project, in cold and hot regions of the country. The project is planned to be carried out under four heads. One is pertaining to desertification status mapping at 1:500,000 scale for entire country using AWiFS data, the second is related to desertification status mapping of selected vulnerable areas at 1:50,000 scale using LISS-3 data while the third refers to identification of areas vulnerable to desertification in one district in each state / U.T by using multi-parametric weighted index model and fourth deals with development of methodology for generation of action plans for combating desertification for selected watersheds at a larger scale. Change detection of the desertification status with the current and previous datasets will also be attempted both at 1:500,000 and 1:50,000 scales.
9	**Keywords**	Desertification, land degradation, vulnerability mapping, desertification combating plan
10	**Security Classification**	Unrestricted
11	**Distribution Statement**	Amongst Concerned

CONTENTS

1.0 INTRODUCTION

Desertification is the continuous degradation of land under the influence of natural and anthropological causes in arid, semi-arid and dry-sub humid conditions. Desertification affects two third countries of the world and one third of the earth's surface, on which one billion people live (one sixth of world's population). The causes for desertification are mainly improper management practices, overgrazing, tree felling, over cultivation etc. The vegetal degradation, erosion processes, water logging and salinization leads to loss of soil fertility, soil compaction and soil crusting. In addition to this, urbanization, mining and recreation will also have adverse effects on the land leading to desertification.

To assess the status of desertification for entire country is a herculean task and needs to be carried out using fast, accurate, cost effective and less laborious methods like satellite remote-sensing. For a long time, there existed no substantial base data on the status of desertification in India. Under the auspices of UNCCD-TPN 1 (United Nations Convention for Combating Desertification – Thematic Network Programme 1), a pilot project on Desertification Status Mapping (DSM) was taken up in 2001, at 1:50,000 scale covering about 16 study areas in both cold and hot desert regions of the country. 17 different organizations of the country participated in the programme and standards about the indicators of desertification, methodology, classification system etc. were harmonized. Finally the project was successfully completed and led to the operationalisation of DSM using remote sensing data. In view of non-availability of desertification/land degradation status map (DSM) for the country and also to fulfill India's commitment towards preparation of regional DSM under TPN-1 of UNCCD, the task of desertification/land degradation status mapping was taken up on 1 : 500,000 scale for the entire country using Indian Remote Sensing Satellite (IRS)-Resourcesat-1 AWiFS data of 2003-2005. For the first time, a national level spatial inventory has been carried out for the entire country giving information on various land degradation processes and their degree of severity. This national task has been executed by Space Applications Centre, Ahmedabad in collaboration with Central Arid Zone Research Institution (CAZRI), Jodhpur; National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Bangaluru; All India Soil and Land Use Survey (SLUSI), Delhi; M.P. Remote Sensing Applications Centre (MPRSAC), Bhopal; U.P Remote Sensing Applications Centre (UPRSAC), Lucknow; Jharkhand Space Applications Centre (JSAC), Ranchi, Birla Institute of Technology (BIT), Mesra, Ranchi; Orissa Remote Sensing Applications Centre

(ORSAC), Bhubaneshwar; Arunachal Pradesh Remote Sensing Centre (APRSAC), Itanagar; Jammu University (JU), Jammu; Jawahar Lal Nehru University (JNU), New Delhi; Institute of Remote Sensing (IRS) – Anna University, Chennai; Maharashtra Remote Sensing Applications Centre (MRSAC), Nagpur; University of Rajasthan (UOR), Jaipur; Directorate of Environment and Remote Sensing (DERS) – Srinagar; Earth Observations System (EOS), Indian Space Research Organization (ISRO), Bangaluru and Bihar State Remote Sensing Applications Centre (BIRSAC), Patna.

The DSM maps showed various processes of degradation like vegetal degradation water erosion, wind erosion salinization/ alkalization, water logging, frost heaving, frost shattering, mass-wasting, man-made etc. The two main processes of degradation observed were water erosion and vegetal degradation in forests and scrublands. Finally, a maiden Desertification Status Map of India at 1:500,000 scale was prepared. The study revealed that about 105.48 m ha is under various processes and severity of desertification, which is nearly 32.07 % of the total geographical area of the country. This means that nearly one-third of the country is under land degradation/desertification. A `Desertification & Land Degradation Atlas of India' has been brought out. Desertification is a dynamic process and needs to be assessed at regular intervals and it is in this context that desertification status mapping of India – 2nd Cycle has been taken by at the behest of MoEF, New Delhi.

Recently, the Hon. Minister of State for Environment and Forest, Shri Jairam Ramesh visited Space Applications Centre, Ahmedabad and appreciated the Desertification Status Mapping carried out earlier. He took keen interest in the maiden Desertification Status Map (DSM) of the country. It was informed to the Hon. Minister that 105.8 mha area of our country experiences land degradation/desertification of various types and severity. He opined that it is high time to carry out the second cycle of the DSM using latest satellite data as the previous results are now about 8 years old. He strongly suggested replicating the DSM of the India using latest satellite data and comparing the results with the ones achieved from the previous cycle so as to know the change in status of desertification over the years. The action was marked on SAC to submit a proposal in this regard as soon as possible.

The resourcefulness of the Indian Remote Sensing Satellite system (IRS) spans across variety of spatial, spectral & temporal resolutions, thus allowing resource / hazard mapping at National to Cadastral levels. The operationalisation of indigenously launching IRS series of satellites by ISRO has ensured un-interrupted supply of valuable satellite data over the years and continues to do so. Recently launched Resourcesat-2 (RS-2) satellite provides data from AWiFS sensor with improved swath and resolutions for regional mapping which aids in brisk yet accurate assessment of the desertification status of the entire country, while the LISS-III data from all the past missions, including RS-2, has immense potential to map the changes in the desertification status at much higher scale, for selected vulnerable areas / districts. GIS system provides the digital platform to store, integrate and analyze large and variant data sets to study the changes in DSM over the years.

The Desertification Mapping of India carried out by SAC, Ahmedabad in collaboration with 17 other governmental / academic institutions was a maiden attempt. This was a Herculean task carried out meticulously on war-footing mode. Prior to this, there existed no other work on the Desertification Status Mapping of India, including the cold desert in the Himalayan region. After this work, there has been a gap of about 8 years and desertification being dynamic phenomena, there is no information about the changes that have taken place in past 8 years. Thus, there exists an information gap and it is needed to repeat the feat again to have a near-decadal change assessment of the desertification status of the entire country.

2.0 OBJECTIVES

The main objectives of this project are:

- To map the desertification status of entire country (DSM) using AWiFS data (2012-13) on 1:500,000 scale
- To map the desertification status of selected vulnerable districts of India using LISS III (2012-13) data on 1:50,000 scale
- Desertification Vulnerability Modelling (DVM): To prepare Desertification Vulnerability Map on 1:50,000 for one district in each state
- Development of methodology for preparation of desertification combating plans at larger scale for selected watersheds

3.0 COLLABORATING AGENCIES

The pilot project was approved by the Ministry of Environment and Forests in February 2012. An in-house orientation cum training programme on the methodology and mapping procedures to be followed under this project was organized during April 30 to May 01, 2013. This programme was mainly, required for keeping the uniformity in approach and standards by various participating agencies. Status review meetings have also been carried out at SAC for the project. The first meeting was held on March 4, 2013.

A Technical guideline for Desertification Status Mapping (DSM), was prepared by the project team in discussion with all the participating organizations. Constructive suggestions for improvement of the technical guidelines have been received from the experts as well as from the participating organizations. More ever, the experience gained over the period of time has also guided us to improve upon in some of the aspects related to DSM. Keeping in view the above, the technical guidelines have been updated and revised in the present form.

Following table 1 displays the list of all collaborating agencies under this project.

Table 1: List of Collaborating Agencies

Sr No.	CA
1	APRSAC, Itanagar
2	Calcutta University
3	CAZRI, Jodhpur
4	CEPT, Ahmedabad
5	HARSAC, Hisar
6	IGNOU, Delhi
7	IRS, Chennai
8	JNU Delhi
9	Mizoram RSAC, Aizawl
10	MPCOST, Bhopal
11	MRSAC, Nagpur
12	Nagaland GIS & RS Centre
13	NBSSLUP, Banglore
14	NEHU, Meghalaya
15	ORSAC, Bhubneshwar
16	RSACUP, Lucknow
17	SLUCI, Delhi
18	SSCST Sikkim
19	Univ of Jammu, Jammu
20	Univ of Kashmir, Kashmir
21	Univ of Raj, Jaipur

4.0 STUDY AREA

In order to standardize the methodology for desertification status mapping, the representative sites for different types of desertification processes have been selected from each of the dryland regions i.e. arid, semi-arid and dry sub-humid in both cold and hot deserts of the country. The distribution of arid, semi arid and dry sub-humid regions (drylands) is shown in Fig. 1. The study areas are selected from each of the agro-ecological regions on the basis of the dominant process of desertification and the corresponding participating agencies are given as under (table 2).

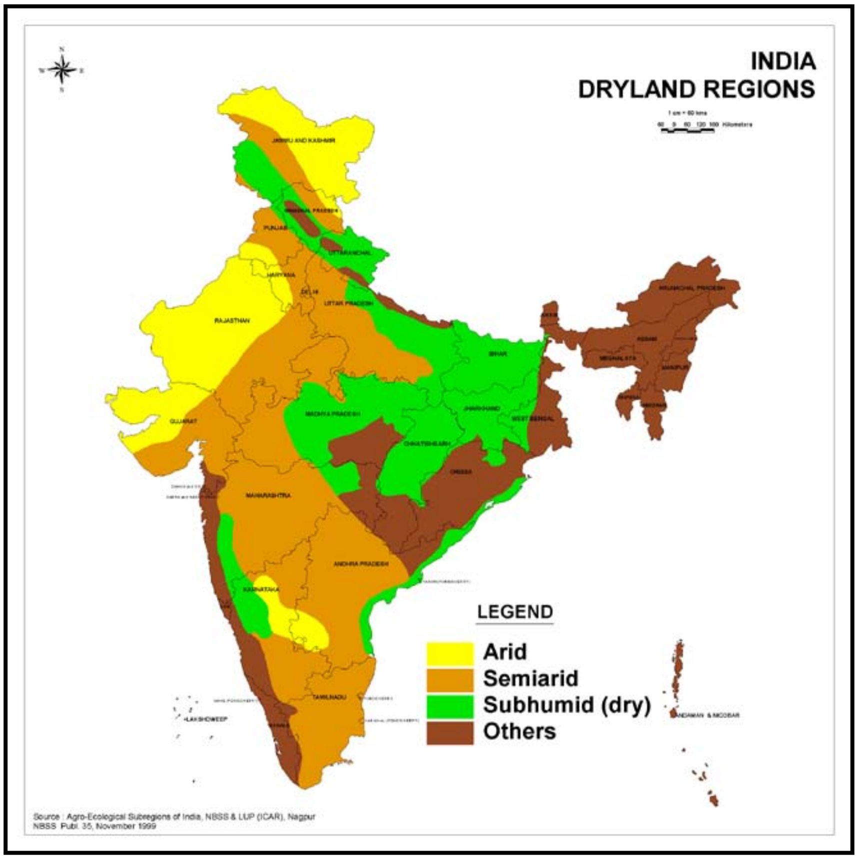


Figure 1. The concise dryland map based on the Agro-ecological sub-regions of India (NBSS&LUP, 1991).

Table 2: Study areas and the corresponding collaborating agencies

S.No.	CA	1:500,000 using AWiFS	1:50K using LISS III	Modeling
1	APRSAC, Itanagar	Arunachal Pradesh	Tawang and Tirap	*To be identified*
2	Calcutta University, Kolkata	West bengal	Purulia and Bankura	*To be identified*
3	CAZRI, Jodhpur	Rajasthan	Pali and Jaisalmer	Pali
4	CEPT, Ahmedabad	Gujarat	Panchmahals, Bhavnagar, Sabarkantha and Surendranagar	Bhavnagar
5	HARSAC, Hisar	Haryana	Sirsa and Bhiwani	Hissar
6	IGNOU, Delhi	Jharkhand and Bihar	Bhabua, Samastipur, Sitamarhi, Bokaro, Giridih, Pashchim Singbhum and Leh (south) watershed	LEH watershed (south)
7	IRS, Chennai	Tamil Nadu and Kerala	Dharampuri, Theni, Tirunaveli, Virudhnagar, Kasargodh and Palkad	*To be identified*
8	JNU Delhi	Himachal Pradesh	Kangra, Kinnaur, Lahul-Spiti, Shyok, Nubra	Shyok and nubra
9	Mizoram RSAC, Aizawl	Mizoram and Tripura	Aizawl , Lunglei South Tripura, West Tripura	*To be identified*
10	MPCOST, Bhopal	Madhya Pradesh and Chattisgarh	Neemach, Dhar, Morena, Ratlam, Raipur, Durg and Rajnandgao	*To be identified*
11	MRSAC, Nagpur	Maharashtra, Goa	Maharashtra (Dhule, Ahmadnagar, Sangli) and Goa (North Goa)	*To be identified*
12	Nagaland GIS & RS Centre	Nagaland and Manipur	Kohima, Workha in Nagaland and Chandel, Charchandpur in Manipur	*To be identified*
13	NBSSLUP, Banglore	Andhra Pradesh, Karnataka	Bellary, Chamarajanagar, Anantpur and Mahabubnagar	Bellary
14	NEHU, Meghalaya	Assam and Meghalaya	Assam (Golaghat, Hailakandi, Kokrajhar) and Meghalaya (Jaintia hills, West Khasi hills)	*To be identified*
15	ORSAC, Bhubneshwar	Odissa	Bargarh, Mayurbhanj, Koraput, Kendujhargarh	*To be identified*
16	RSACUP, Lucknow	Uttarpradesh	Etawa, Kanpur Dehat, Chitrakut	-
17	SLUSI, Delhi	Uttarakhand, Punjab and Delhi	Chamoli, Garhwal, Pathankot, Hosiarpur	Chamoli
18	SSCST Sikkim	Sikkim	All four district of Sikkim	*To be identified*
19	Univ of Jammu, Jammu	Jammu region of Jammu & Kashmir state	Kargil	Kargil watershed
20	Univ of Kashmir, Kashmir	Ladakh and Kashmir regions of Jammu and Kashmir state	Badgan and Kathua	Kathua district
21	Univ of Raj, Jaipur		Ajmer and Dausa	-

5.0 DATA USED

IRS- Resourcesat- 2 AWiFS digital data of three different seasons viz. summer, kharif and rabi, will be used for preparing DSM of the country at 1:500,000 scale. There will be around 24 scenes (60 quadrants) of AWiFS covering entire India.

IRS LISS-III data of two different time series will be procured. During each of these years, three season viz. kharif, rabi & summer will be used. The dataset will be used for vulnerable areas mapping at 1:50,000 scale as well as for Desertification Vulnerability Modeling. In addition, various thematic layers viz climate, soil and socio-economic profile, prepared at 1:50,000 scale shall be used for vulnerability modeling.

6.0 THE CLASSIFICATION SYSTEM

A National level Classification System for the Desertification Status Mapping (DSM) using satellite data has been evolved based on literature, discussions with national and international experts and finally by consensus. The following steps were followed in standardizing the Classification System for DSM:

- Literature survey involving the study of published reports, papers in Journals and published maps.
- Discussions with various experts, national as well as international.
- Preparation of a tentative Classification System and Legend.
- Circulating the Classification System and Legend among various organization / experts in the country working in this field.
- Finally a brain storming discussion was organized at Space Applications Centre, Ahmedabad on Jan 29, 2002. The important organizations which participated in the discussion were - AISLUS, CAZRI, NBSS&LUP, NATMO, CRIDA (ICAR), IMD, EOS-NNRMS, NRSA, Directorate of Environment and Remote Sensing, J&K, Rajasthan University, Jammu University, JNU, State RS Centre Haryana, State RS Centre MP, RRSSC-Jodhpur and Space Applications Centre, Ahmedabad. After a detailed discussion, a consensus was arrived at a national level classification system for DSM which is also in tune with the classification system adopted by TPN-1 (UNCCD) at regional level.

The classification system adopted is a three level hierarchical classification system. This is given below:

Table 3: Comprehensive classification system

LEVEL 1: **Land Use/ Land cover**

The following categories have been identified as below -

Agriculture – Unirrigated	(D)	
Agriculture – Irrigated	(I)	
Forest / Plantation	(F)/P*	
Grassland/ Grazing land	(G)	
Land with Scrub	(S)**	
Barren / Rocky Area	(B/R)#	B(Sc) indicating Scree areas in Cold Deserts
Dune / Sandy Area	(E)	
Water body / Drainage	(W)	
Glacial / Periglacial	C/L	
Others	(T)	

(* Rocky areas within forest can be annotated as only Fv3-R in the map)

(** Vegetal degradation in Land with Scrub around periphery of notified forests can be delineated as SV)

(Encroachment in forest area esp. agricultural practices, is FV3)

(# Barren and Rocky areas to be delineated separately as B or R and shown in others category of the legend)

(All settlements should be hatched)

LEVEL 2: **Processes of Degradation** –

Types of processes resulting in degradation:

Vegetation Degradation	(v)
Water Erosion	(w)*
Wind Erosion	(e)
Water Logging	(l)
Salinization/ Alkalinization	(s/a)**
Mass Movement [in cold areas]	(g)
Frost Heaving [in cold areas]	(h)
Frost Shattering [in cold areas]	(f)
Man made	(m)

(*Gully/ ravines should be shown as Xw3, where x is the Land use/cover class of surrounding area.)
(** Salinization or Alkalinization should be shown as `s, or `a' separately. Where both occur, they should be shown together i.e. $\mathbf{s_x a_y}$, where **x** and **y** are respective degree of severities)

<u>LEVEL 3:</u> <u>Severity of Degradation</u> –

This level represents the degree and severity of the degradation:

Slight	1
Moderate	2
Severe	3

The severity levels in 1:500,000 scale maps (prepared using AWiFS) data would use only 2 levels of severity. The Severe (3) category mentioned above (for 1:50,000 scale) would be classified as `High' while the `slight' & `moderate' categories would be merged as `LOW' . So the final severity classes for 1:500,000 scale mapping would be as follows:

Low	1
High	2

The details on the severity classes for different desertification process are given as under:

Table 4: benchmarks (threshold values) for different severity levels of desertification processes

a) Vegetal Degradation

Vegetal degradation is observed mainly as deforestation / forest-blanks / shifting cultivation and degradation in grazing / grassland as well as in scrubland. At places, agriculture is observed within forest lands, this has also been classified under vegetal degradation within forest area. Figure 5 (Annexure 1) shows the satellite images and field photographs of vegetal degradation with varying severity levels.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Plant community	Climax or	Long lasting	Ephemeral

	slightly changed	secondary	secondary
Percentage of climax species	> 75	75-25	< 25
Decrease of total plant cover, %	< 25	25-75	> 75
Loss of forage, %	< 25	25-75	> 75
Loss of current increment of wood, %	< 25	25-75	> 75

b) Water Erosion

Water erosion is observed in both hot and cold desert areas, across various land covers and with varying severity levels. The sheet erosion (mostly within agricultural lands) and rills are categorized in slight category, the narrow and shallow gullies are categorized as moderate erosion, while the deep / wide gullies and ravines are classified as severe erosion. Figure 6, 7 and 8 furnishes the image and field characteristics of water erosion in hot and cold regions respectively.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Non-arable land			
Type of erosion (Depth and Width is in Meters)	**Sheet erosion** and / or **Single rills-** *(Depth < =0.5m and Width = 0.4-0.9m)*	**Rill erosion,** and/or **Formation of gullies-** *(Depth- 0.6-3.0m and Width- 1.0-3.5m)*	**Network of gullies/ Ravines -** *(In Gullies- Depth 3m –10m and Width 3.5-20.0m) In Ravine (Depth >10 m, width 20-40m)*
Density of channels, linear km per sq. km	< 0.5	0.5-1.5	1.5-3.0
Removal of top	< 25	25-50	> 50

soil horizon, %			
Arable land			
Removal of top soil horizon	< 25	25-50	> 50
Loss of yield of main crop, %	< 25	25-50	> 50

C) Wind Erosion

Wind Erosion pertains to the aeolian activities. It denotes the spread of sand by virtue of lift and drift effect of wind, even upto lofty altitudes of Himalayas. Various categories of sand cover and their severity are classified based on the depth and spread of sand sheet/ dunes and Barchans. Figure 9 shows the satellite image and field disposition of wind erosion .

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Non-arable land			
Sand Sheet in Cms	<30 cm per hummock Upto 100 cm over plains	< 50-150 cm/ stable dune and sandy hummock (East of 300mm Isohyet) <90-300 cm/ reactivated sand/ plant roots upto 40-100 cm (West of 300mm Isohyet)	<1-4 m dunes/ 100-300 interdunal sand/ Barchans 2-4 cm (mostly west of 300 mm Isohyte) 2-5 m active/ drifting dunes- Very Severe
Percentage of area covered with sand dunes	< 30	30- 70	> 70
Percentage of area covered with sod forming plants	50-30	30-10	< 10

Arable land			
Removal of top horizon, %	< 25	25-50	> 50
Blow-outs, percentage of area	< 5	5- 10	> 10
Loss of yield of main crops, %	< 25	25-50	> 50

d) Salinity/ Alkalinity

Salinization or alkalinization is fundamentally the chemical property of the soils. It occurs mostly in cultivated lands, especially in the irrigated areas. At places salinity is clearly observed on satellite images, while the alkalinization is not seen and is mostly inferred based on ground truth and soil sample analysis as well as information/ published maps. Figure 10, 11 & 12 show field disposition and corresponding satellite images of Salinization / Alkalinization in both un-irrigated and irrigated areas.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Soil salinity and Alkalinity	4- 8 ds/m < 15	8-30 ds/m 15-40	> 30 >40
Soil salinization, solid residue, in percentage	0.20- 0.40	0.40- 0.60	> 0.60
Salinity of ground water, g/litre	3-6	6-10	10-30
Salinity of irrigation water, g/litre	0.5- 1.0	1.0- 1.5	> 1.5
Seasonal salt accumulation, ton/ha	16- 30	30-45	45-90
Loss of yield of main crop, %	< 15	15-40	> 40

e) Water logging

The undrained land parcels tend to accumulate standing water for longer durations of time on the surface, this condition is called water logging viz ox-bow lakes, low lying areas, and even the shallow water tables. The severity of water logging is determined based on the period of time the water remains stagnant. Figure 13 shows water logging conditions.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Water logging	Seasonal (Affecting one crop) 4-6 months	Affecting two crops > 6 Months of submergence	Inland Marshes

f) Mass-Wasting

Mass movement is defined as a process of desertification which leads to the down slope movement of rock, regolith and debris through the action of gravity for example, Scree cones. Figure 14 shows the satellite images and ground pictures for mass movement.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Mass-Wasting	Talus Cones	Small boulders at scarp face	Very big size boulders present from ridgeline upto foothill

g) Frost Shattering

Frost shattering is defined as a freeze and thaw action operating mostly in periglacial environment. When water, that filters through the crevices and pores in rock freezes, it expands by almost ten times. This puts enormous pressure on the surrounding rocks as at -22^0 C, ice can exert a pressure of 3000 kg on an area half a square inch. The process is most active where the periglacial environment exists, usually in areas adjoining glacial margins; with long cold winters and short mild. Frost shattering as observed on satellite image is shown in Fig. 15 along with ground photo.

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Frost Shattering	Supra-glacier material of small pebbles	Supramaterial of large boulders	Huge blocks on scarp face

h) Frost Heaving

Frost heaving is defined as a process of intense frost and freezing of water operating in glacial and periglacial environment and evolves peculiar forms of rock, regolith and soil, for example, in frost heaving, a typical irregular pattern ground are seen (Fig. 16)

Status criteria	Desertification classes		
	Slight	Moderate	Severe
Frost Heaving	Loose material present along valley wall	Big bolders present along valley wall	Huge sandy debris present along valley wall

i) Man Made

All those land degradation processes which is induced directly or indirectly by human intervention and are not natural, are categorised as Man Made desertification processes, it includes. (Mining/Quarrying, Brick Kiln, Industrial Effluents, City Waste, Urban Agg etc.) This occurs across various land use/ land cover classes (Fig. 17)

DSM maps for the state of Jammu and Kashmir and Rajasthana are given in the figures 18 and 19 showing the land use, the processes involved and the severity of degradation in such parcel of DSM units mapped using satellite data.

Each polygon in a typical DSM map shows three things viz. the landuse/ land cover, the process of degradation and the severity of land degradation represented by a three digit map annotation code, the first two digits being alpha and the third one numeric, in that order respectively. The first alphabetic digit is always in capital, which depicts the landuse/ land cover, followed by the second small letter alphabetic digit depicting the process of land degradation. The third and final numeric digit represents the severity of degradation.

7.0 INTERPRETATION KEY

Sr. No.	Land Use/ Land Cover	Tone	Size	Shape	Texture	Pattern	Location	Association
1	Urban	Dark Bluish Green in the Core and bluish on the perephery	Small to Big	Irregular And Discouninous	Coarse and Mottled	Clustered to Scattered and Non-contiguous	Plains plateaus, on hill slopes, deserts, water front, road, rail, canal etc.	Surrounded by Agricultural lands, Forest Cover, Wastelands, Network of River, Road and Rail etc.
2	Kharif	Bright red to red	variabl e	Regular to irregular	Medium to Smooth	Contiguous to Non-contiguous	Plains, hill slopes, valleys, cultivable wastelands etc.	Amidst rainfed arable lands
3	Rabi	Pink	variabl e	Regular to irregular	Smooth	Contiguous to Non-contiguous	Plains, valleys, Etc.	Amidst irrigated (canal,tank, well etc.) arable lands, proximity to rivers/streams etc.
4	Forest	Dark red To Dark Brown (Subject to Canopy cover	variabl e	Irregular discontuous	Smooth to Mottled	Contiguo to Non-contiguous us	Mountain slopes, isolated hills and foot slopes and within notified forest areas	Hill slopes having skeletal soils, different forest types/ sub-types and where abiotic interference
5	Grassl and/ grazin g land	Light red To Light Brown	variabl e	Irregular	Coarse to Mottled subject to the vegetation	Contiguous to Non-contiguous	Plains,uplands, hill slopes/foot slopes, close to river/stream	Amidst agricultural lands, drylands and lands fenced from cultivation
6	Land with scrub	Light red	variabl e	Irregular	Coarse to Mottled	Contiguous , Dispersed in patches	Terrain with varying lithology and landorms	Gentle relief with moderate slope in plains and foot hills and surrounded by agricultural lands
7	Barre n/	Greenish blue to yellow	variabl e	Irregular	Very Coarse	Linear to contiguous &	Steep isolated hillocks,hill	Barren and exposed rock / stony wastes,

	Rocky area	(Subject to varying rock type)			To Coarse and Medium	dispersed	slopes/crest,platea u and eroded plains	lateritic outcrops, mined areas and quarried sites, boulders.
8	Dune/ sandy area	White to light yellow (Subject to Moisture content) and red for vegetation	variabl e	Regular to Irregular	Smooth to Mottled (Subject to Vegetation)	contiguous, to Linear	Deserts, river beds and coastal onshore plains	River sand, shifting desert sands, sand dunes, coastal beach/ dune sands and river bed/ natural levees.
9	River/ Strea m	Light Blue to Dark blue	Long Narrow to Wide	Irregular, Sinuous	Smooth to medium	contiguous, Non-linear to dendritic/ sub-dendritic etc.	Natural Rivers/ streams (perennial and non-perennial)	Drainage Pattern on Hill slopes, flood plains, uplands etc. Also with vegetation along the banks and in river bed.
10	Water Body	Light Blue to dark Blue (subject to weeds/ vegetation)	Small/ Mediu m to Large	Regular to Irregular	Smooth to Mottled Subject to vegetation	Non-contiguous dispersed, linear for canals	Tanks and lakes in low lands/ plains, reservoirs surrounded by hills and across rivers, canals in plains	Amidst cultivated lands, low lands, reservoirs with hilly terrain and rivers, canals with irrigated arable lands
10	OTHE RS Urban	Dark Bluish Green in the Core and bluish on the perephery	Small to Big	Irregular And Discouninous	Coarse and Mottled	Clustered to Scattered and Non-contiguous	Plains plateaus, on hill slopes, deserts, water front, road, rail, canal etc.	Surrounded by Agricultural lands, Forest Cover, Wastelands, Network of River, Road and Rail etc.

Table 5: interpretation key

8.0 METHODOLOGY

8.1 Desertification Status Mapping

The methodology has already been developed and operationally used during the DSM project carried out earlier. In the proposed study, about 24 scenes (60 quadrants) of multidate AWiFS satellite data will be digitally interpreted through on-screen digitization method by employing ARC GIS software. As a reference, desertification status maps prepared earlier at 1:500,000 scale using AWiFS satellite data of 2003-05 will be used and changes in degree of severity will be incorporated. Limited ground checks will be carried out throughout the country.

The proposed study area includes the Arid, Semi-arid and Sub-humid regions as well as the North-East region of the country. There after DSM for some selected vulnerable districts will be carried out. It is proposed to study the vulnerable regions of India like the drought prone areas, regions of high degradation etc. Visual interpretation at 1:50,000 scale will be carried out using temporal LISS-III data so as to compare the change in the status of the desertification in these areas over the years. Desertification Vulnerability modeling will also be carried out for a district each in every state possible. Development of methodology for combating plan will be attempted at few places on larger scale, in selected micro-watersheds.

Preparation of DSM is an ordered process of certain logical steps carried out using visual interpretation of satellite data, mainly IRS-LISS-III geo-coded FCC paper prints, followed by ground truth, data collection at selected points and then finalization of preliminary DSM.

To start with, firstly a **study area** is selected from agro-ecological regions and areas susceptible to land degradation through various processes like wind erosion, water erosion, salinization, man-made, water logging, frost shattering, mass wasting and frost heaving and vegetal degradation etc. This is done through the available background information.

Once the study area is finalized, a suitable set of **satellite data**, preferably IRS-LISS -III geo-coded FCC are acquired for at least three different seasons viz. summer, kharif and rabi.

A reconnaissance survey is conducted in and around the study area to grossly assess the type, extent, cause and possible consequences of the problem with regards to ground conditions. This helps in standardizing the interpretation key through image signatures of various land degradation processes and their varying severity. The interpretation key generated for level-1 in classification system of the DSM is given in Table-5. A lot of collateral data as well as socio-economic profile of the area are collected from the district headquarters/ study area in forms of maps, published reports, statistical data etc. Ancillary information in the form of related map and data is also acquired from other concerned organizations/institutions.

Once having collected all the relevant and necessary information about the area, the visual interpretation is carried out using latest multi temporal satellite data. Interpretation of satellite data of three seasons (Summer, Rabi and Kharif) is carried out to delineate the degraded land cover, the process of degradation and its severity for dryland regions consisting of Arid, Semi-arid and Dry sub-humid regions in both cold and hot desert areas. Detail methodology for preparation of desertification status map is given in fig. 2.

The field proforma is given in Table 6 and has to be filled up at each location during ground truthing. The location for soil sample is selected randomly or systematically (grid wise) for subsequent soil sample analysis.

Examples for different kinds of land use class and desertification processes as seen on satellite images along with their field photos are given in Annexure-I.

A comparison of the DSM-1 and DSM-2 maps will be made for the purpose of `change-detection' , if and where it may occur .

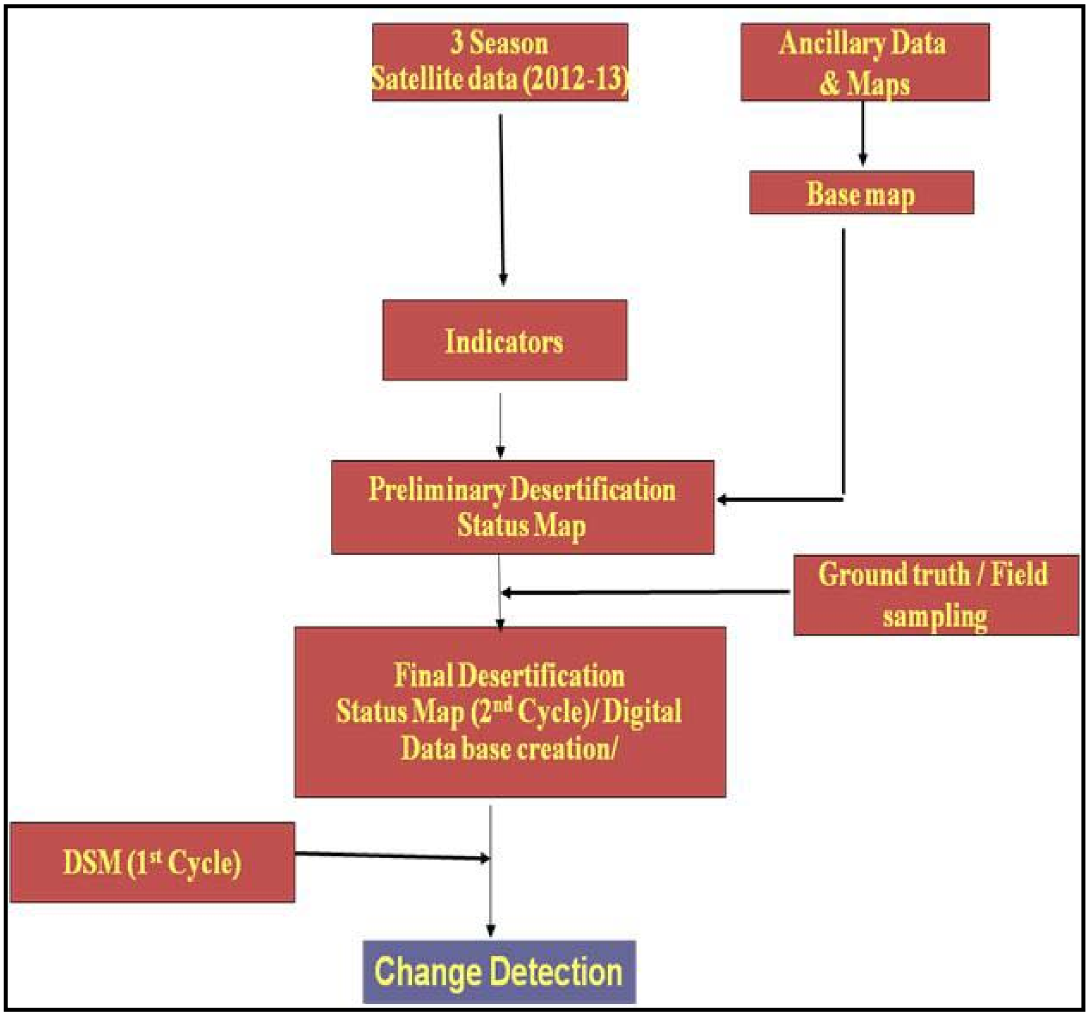


Figure 2: Detailed methodology for Desertification Status Mapping (2nd cycle)

Table 6: Field proforma

Station No.	Land use / cover	Process of Degradation	Severity	Remarks

Ground water well (Type)	Total Depth	Water Level	Static Water Level	Quality of Ground water (Potable / Non-potable)	Pump (HP/ Hours of Pumping)	Remarks

Soil Sample Location	Type of Soil	Colour of Soil	Remarks

8.2 Desertification Vulnerability Modeling

Land degradation involves complex set of processes, which interact in space and time leading to decrease in land productivity. Thus, it is necessary to identify the various indices, which can be used to identify the desertification vulnerable areas. Since, climate, soil, vegetation and land use play a significant role in desertification of any area, hence, in this work, all of these indices are considered: Climate index (CI), soil index (SI), Vegetation index (VI) and land use index (LUI). These indices are combined through geometric mean to form an index called Environmental Vulnerability Index (EVI). EVI is defined as:

$$EVI= (CI*VI*SI*LUI)^{1/4} \ldots\ldots\ldots\ldots\ldots(1)$$

Where, CI=Climate Index, VI=Vegetation Index, SI=Soil Index, LUI=Land Use Index

These indices are themselves derived from a variety of spatial inputs. These inputs have to be taken in the form of spatial layers and have to be integrated in GIS environment to provide environmentally vulnerable areas for desertification. However, man's intervention leads to significant changes in the environment, thereby making socio-economic factor as another major input to assess vulnerability to desertification. Hence, Socio economic index is also introduced. Thus, the final index of desertification vulnerability is defined as:

$$DVI=(CI*VI*SI*LUI*SEI)^{1/5} \ldots..(2)$$

Where, DVI=Desertification Vulnerability Index and SEI is the Socio-economic Index.

The flow chart shown in fig. 3 clearly explains the methodology employed to compute EVI and finally DVI.

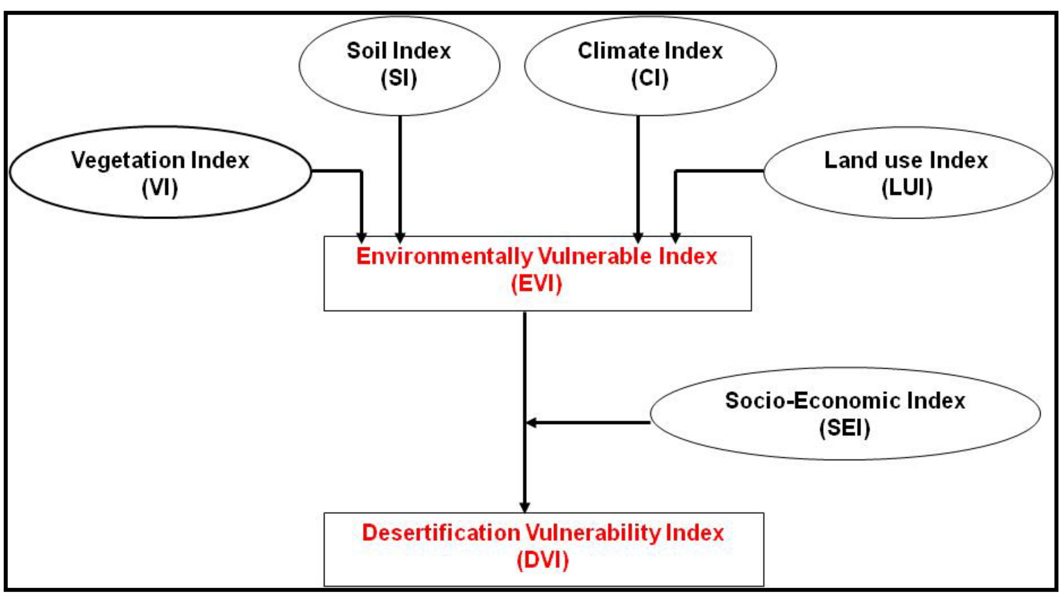


Figure 3: Flow Diagram of the methodology

The source of inputs required to compute CI, VI, SI, LUI and SEI are shown in table 7.

Table 7: illustration of the source of input parameters for different indices

(all maps to be prepared at 1:50,000 scale)

Index	Inputs	Source
Climate	Precipitation, air temperature	Weather Bulletin, AWS Data integrated to generate spatial map
Soil	Soil texture, parent material, slope	NRDB or other thematic map source
Vegetation	Erosion protection, drought resistance, fire risk, plant cover	LISS-3 data
Land use	Land use	LISS-3 data
Socio-economic	Poverty, Unemployment, Illiteracy, Population	Census of India

INPUT INDICES

1) Climate index

This index involves aridity as well as precipitation. Aridity will be computed through Bagnouls-Gaussen bioclimatic aridity index (Kosmas et al 1999). It is defined by equation (3)

$$BGI=\Sigma\ (2Ti-Pi).k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, Ti=mean air temperature for i th month in degree Celsius, Pi=total precipitation in month i in mm, k= proportion of month during which 2Ti-Pi>0.

BGI along with rainfall can be used to assess the climatic index, as follows:

$$CI= (rainfall*BGI)^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The quantization for BGI for the purpose of computing desertification vulnerability index is given in table 8.

Table 8: Quantization of Bagnouls-Gaussen bioclimatic aridity index

Class	BGI range	Score	Comment
1	<50	100	No risk
2	50-75	120	Low risk
3	75-100	140	Moderate risk
4	100-125	160	High risk
5	125-150	180	Very high risk
6	>150	200	Desert

Similarly, quantization of rainfall is done and is shown in table 9.

Table 9: Quantization of rainfall

Rainfall (mm)	Score
>650	100
250-650	160
<250	200

2) Soil index

Soil has a great effect on biomass production and hence is a dominant member of the ecosystem that affects the productivity. Soil Index is computed through the following steps:

$$SI = (\text{Soil texture}*\text{parent material}*\text{slope})^{1/3} \ldots\ldots\ldots\ldots\ldots(5)$$

Parent material

Soils derived from different parent materials responds differently to erosion, supporting vegetation growth and hence to desertification process. The parent material of soil formation as against their ability to desertification is given in table 10.

Table 10: Parent material of soil formation

Class	Parent material	Score
1	Shale, Schist, basic ultra basic, conglomerates, unconsolidated	100
2	Limestone, marble, granite, gneiss, siltstone, sandstone	150
3	Marl, limestone	200

Soil texture

Texture is an important parameter that governs the erodibility as well as the water holding capacity of the soil, thus, indirectly affects biomass production. Table 11 shows the score of different soil texture vis-à-vis desertification vulnerability.

Table 11: Soil texture

Class	Soil texture	Score
1	Coarse	100
	Medium	120
3	Medium fine	140
4	Fine	160
5	Very fine	200

Slope

Erosion becomes acute when slope angle exceeds a critical value and then increases logarithmically. The effect of slope (in terms of scores) on desertification vulnerability is tabulated in table 12.

Table 12: Slope

Description	Slope (%)	Score
Flat	<6	100
Very gentle	6-12	120
Gentle to moderate	13-24	140
Slightly steep	25-30	160
Steep	31-35	180
Very steep	>35	200

3) Vegetation index

The dominant biotic land component critical for desertification is the vegetative cover. Vegetation cover is very crucial for run-off generation and can be readily altered depending on the climatic conditions and the period of the year. Key indicators of desertification related to the vegetation can be considered in relation to: (a) fire risk and ability to recover, (b) erosion protection offered to the soil, (c) drought resistance, and (d) percentage plant cover (equation 6).

$$\text{Vegetation Index} = (\text{Erosion protection} * \text{drought resistance} * \text{fire risk} * \%\text{plant cover})^{1/4} \quad \ldots\ldots\ldots\ldots(6)$$

Fire risk

The occurrence of forest fires is amongst the most serious environmental problems. In addition to the loss of vegetation, forest fires induce changes in physio-chemical properties of soils such as water repellency, loss in nutrients and increased runoff and erosion. Plants react to fire in very different ways. They possess numerous fire-related adaptations. Table 13 shows the risk of fire occurrence to the available vegetation type and the corresponding scores used for DVI.

Table 13: Risk of fire w.r.t. Vegetation type

Description	Type of vegetation	Score
Low	Horticulture, fallow land, agricultural crops, Plantation	100
Moderate	Scrubland, grassland, deciduous, evergreen forests, Forest plantation	160
High	Coniferous forest, pine forest, Mixed forests, Scrub forest	200

Erosion protection

Vegetation and land use largely control the intensity and the frequency of erosion. Table 14 shows the capacity of various vegetation types to prevent erosion.

Table 14: Vegetation types and their effect on erosion protection

Description	Type of vegetation	Score
Very high	Mixed/evergreen forests, Plantation, coniferous forest	100
High	Pine forests, grasslands	120
Moderate	Deciduous forests, scrubland, Horticulture	160
Low	Agricultural crops, fallow land, unproductive Land	200

Drought resistance

The main response of the plants to increased aridity is the reduction in leaf area index. Some vegetation like the evergreen forests have high potential of erosion protection as against annual agricultural crops as is shown in table 15.

Table 15: Vegetation types and their effect on drought resistance

Description	Type of vegetation	Score
Very high	Forests	100
High	Grasslands, Scrubland	120
Moderate	Degraded forests, Cropped area, Horticulture	160
Low	Shifting cultivation, fallow land, unproductive land	200

Plant cover

Many studies showed that the variation in runoff and sediment yields in drainage basins is attributed to the vegetation cover and land use management changes (Williams and Reed, 1972; Patton and Schumm, 1975; Newson, 1985). A value of 40% vegetative cover is considered critical below which accelerated erosion dominates in a sloping land. It shows that degradation begins only when a large portion of the land's surface is denuded, then it proceeds with an accelerated mode that cannot be arrested by land resistance alone. Following table 16 shows the effect of plant cover on desertification vulnearbility.

Table 16: %Plant cover

Description	% Cover	Score
High	>40	100
Low	10-40	180
Very low	<10	200

4) Land use index

The rapid increase in population and thus poverty resulted in the sharp increase of the cultivation of sloppy areas and marginal land resulting in greater erosion and finally greater risk of desertification. The land use classification in context to desertification vulnerability is shown in table 17.

Table 17: Land use classes and their score for desertification vulnerability

Land use class	Score
Closed forest	100
Open forest	115
Grassland	120
Scrubland/degraded forest	140
Cropped area, Horticulture	160
Salt affected land, Fallow land/barren land, Shifting cultivation	180
Rocky land	200

All the input indices namely Soil index (SI), climate index (CI), vegetation index (VI) and land use index (LUI) are categorized as low, moderate, high and very high. Based on the geometric mean of these indices, scores for the composite index, EVI are evolved and classed as “Not affected”, “low risk”, “moderate risk” and “high risk”. The quantization for EVI are given in table 18.

Table 18: Quantization of EVI

Index	Quantization	Comment
Environmentally Vulnerable Index (EVI)	100-125 126-150 151-175 176-200	Not affected Low risk Moderate risk High risk

5) Socio-economic Index

Cultivation on marginal lands, inappropriate management practices, herding and tree felling/deforestation for fire wood gathering have all been cited in the definitions as major causes of desertification. In other words, society and its economic conditions directly or indirectly influence every piece of land. Socio-economic factors are often responsible for desertification and are so entwined that to separate them is a useless endeavor.

Population pressure is a major contributor and a cause to variety of sick features of the society. Unemployment and illiteracy also pose a serious threat to the environment in conjunction with poverty. Hence, to develop socio-economic index, all these factors have to be carefully analyzed. Equation 7 shows the method of obtaining SEI (Socio-Economic Index).

$$SEI = (\text{Population pressure} * \text{Unemployment} * \text{Illiteracy} * \text{Poverty})^{1/4} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

The entire study area has to studied at sub-divisions level. Table 19 shows the scores for this index:

Table 19: Socio economic index

Parameter	Method of computation	Criteria	Score
Population pressure	Population density of sub-division	1. Low (<170 persons/sq km) 2.Medium (170-285 persons/sq km) 3. High (>285 persons/sqkm)	100 150 200
Unemployment	Census data	% of non-worker population 1. 0-33% 2. 34-60% 3. 61-100%	 100 150 200
Illiteracy	Census data	% of illiteracy 1. 0-40% 2. 41-60% 3. 61-100%	 100 150 200
Poverty	Census data (Analysis of fuel for Cooking, assets and Construction material of House)	Check for 60% or higher Population using/having: 1) Fuel for cooking LPG Kerosene Crop residue/cow dung Firewood/No cooking 2) Asset No asset Two wheeler/ bicycle Four wheeler 3) Construction material Concrete/brick Tin shade Anything else	 100 150 175 200 200 150 100 100 150 200

Based on DVI, the whole area is classed into “Not affected”, “low risk”, “moderate risk” and “high risk” zones. The quantization for DVI is given in table 20.

Table 20: Quantization of DVI

Index	Quantization	Comment
Desertification Vulnerability Index (DVI)	100-125 126-150 151-175 176-200	Not affected Low risk Moderate risk High risk

8.3 Combating desertification

One of the objectives of this project is to develop methodology for generation of action plan for combating desertification. By employing on on-screen digitization method and through the use of multi-date satellite data along with ancillary information and collateral data various thematic maps, e.g. Land use/ land cover, ground water prospect, land capability and slope are prepared. Realizing the importance of adopting an integrated approach, and recognizing the mutual interdependence of natural resources, thematic information is integrated in GIS environment. In order to integrate various themes, firstly, land use/ land cover layer is integrated with ground water prospect layer. The resultant of these two themes is unionized with slope and finally with land capability. The resultant coverage has the basic information of all the four themes- land use/ land cover, ground water prospect, land capability and slope and referred in resource data base. Various map units known as composite land development units (CLDU) are created in this composite layer. Overall methodology for combating desertification is given in fig 4. Based on the CLDU characteristics various measures are suggested for conservation and protection of natural resources. The decision rules, given in Table 21 are used to suggest the appropriate action plan for each of the CLDUs (Anon.1995).

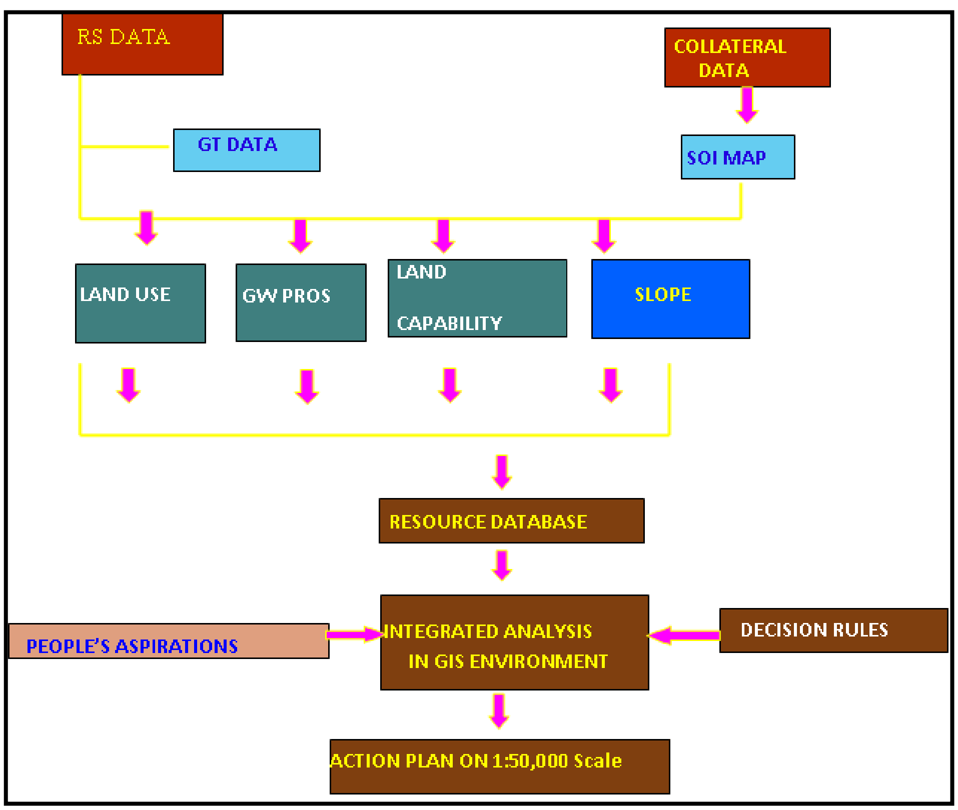


Figure 4: Methodology flowchart for generating action plan for combating desertification

Table-21: Decision rule for generation of action plan for combating desertification

Sr. No.	Land Use/ Land Cover	Ground water Prospect	Slope In per cent	Land Capability	Measures
1	Scrub Forest	Poor	5-10	VI	Afforestation with proper soil and water conservation
2	Kharif+Rabi, Dense Forest	Good	3-5	III	No action
3	Open Forest	Moderate-Poor	5-10	VI	Protection and Gap Filling
4	Open Forest	Moderate	>35	VI	Afforestation with staggered trenches
5	Crop land in Forest	Moderate	0-3	III	Agro-forestry with contour bunding
6	Kharif Crop	Moderate	0-3	III &IV	Double cropping with ground water exploration
7	Kharif Crop	Moderate	3-5	IV	Agro-horticulture with groundwater irrigation
8	Double Crop	Good-Moderate	0-1	III	minimal action - farm ponds
9	Land with scrub & Land without scrub	Moderate - Poor	10-15	IV	Silvipasture
10	Barren rocky/Stony waste/ Sheet rock area	Poor	5-10 & 10-15	VIII	Natural regeneration
11	Wasteland Salt affected land	Moderate	3-5	III	Drainage treatment
12	Open Forest	Moderate - Poor	3-5	VI	Afforestation with contour bunding

Various thematic maps, e.g., land Use/ land Cover, slope, land capability and ground water prospect maps are prepared by using multi-date IRS-1D, LISS-3 data and ancillary information (fig. 18,19, 20 and 21). Later on, spatial database is created for these themes GIS environment. After creating spatial database of various themes, these coverages are unioinised to create composite land development units. Based on decision rule, these CLDU's are converted into action plans for Land Resources Development as referred in Table 21. These action plans are later on transferred onto cadastral maps for implementation (Dhinwa et al., 2010). The measures suggested for combating desertification is shown in fig. 22 and 23.

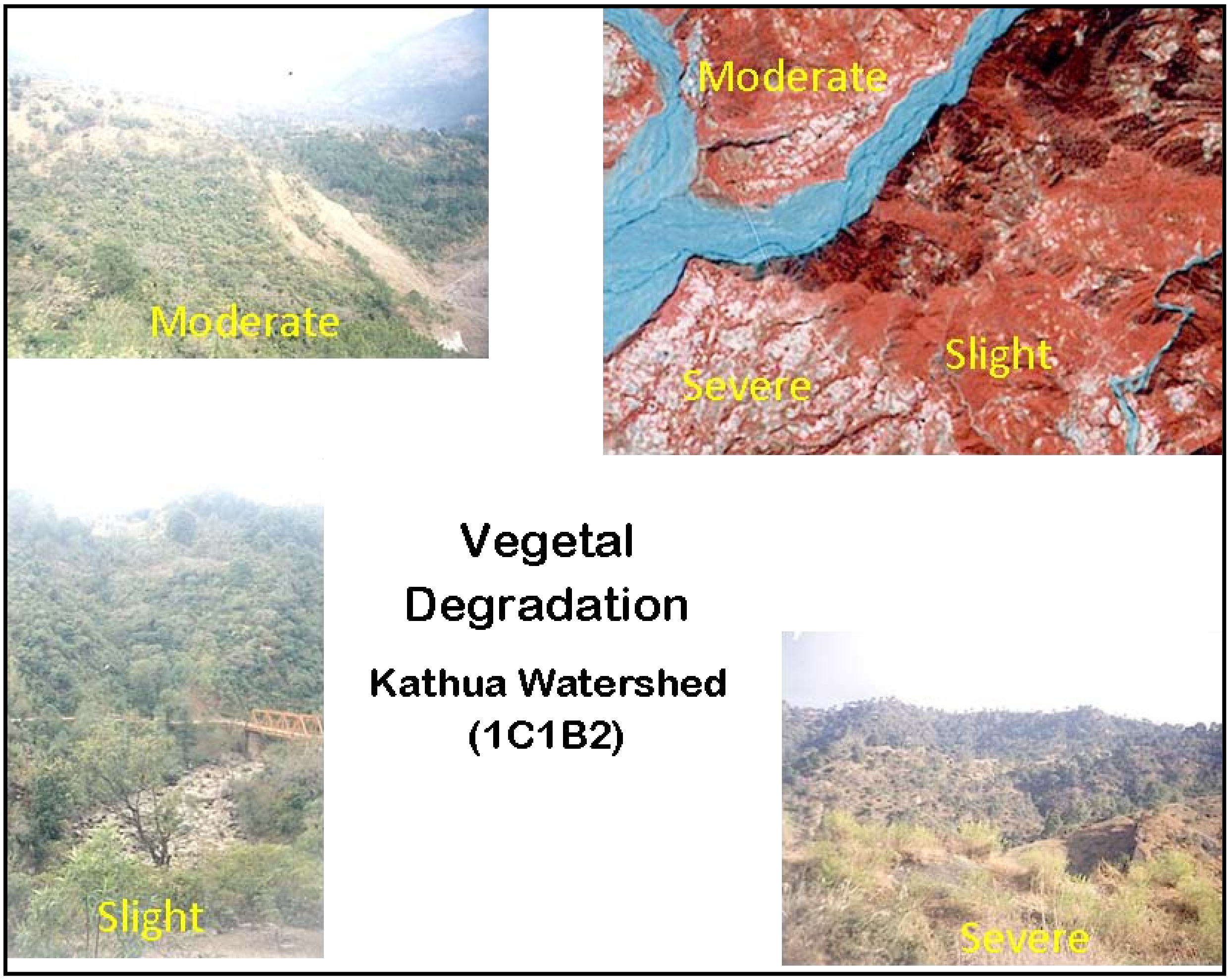


Figure 5: vegetal degradation (field photo along with satellite imagery)

Agriculture Unirrigated–Water Erosion – Moderate - (Dw2)

Figure 6: Moderate water erosion in un-irrigated agricultural areas.

Agriculture Unirrigated –Water Erosion – Severe - (Dw3)

Figure 7: Severe water erosion in un-irrigated agricultural areas

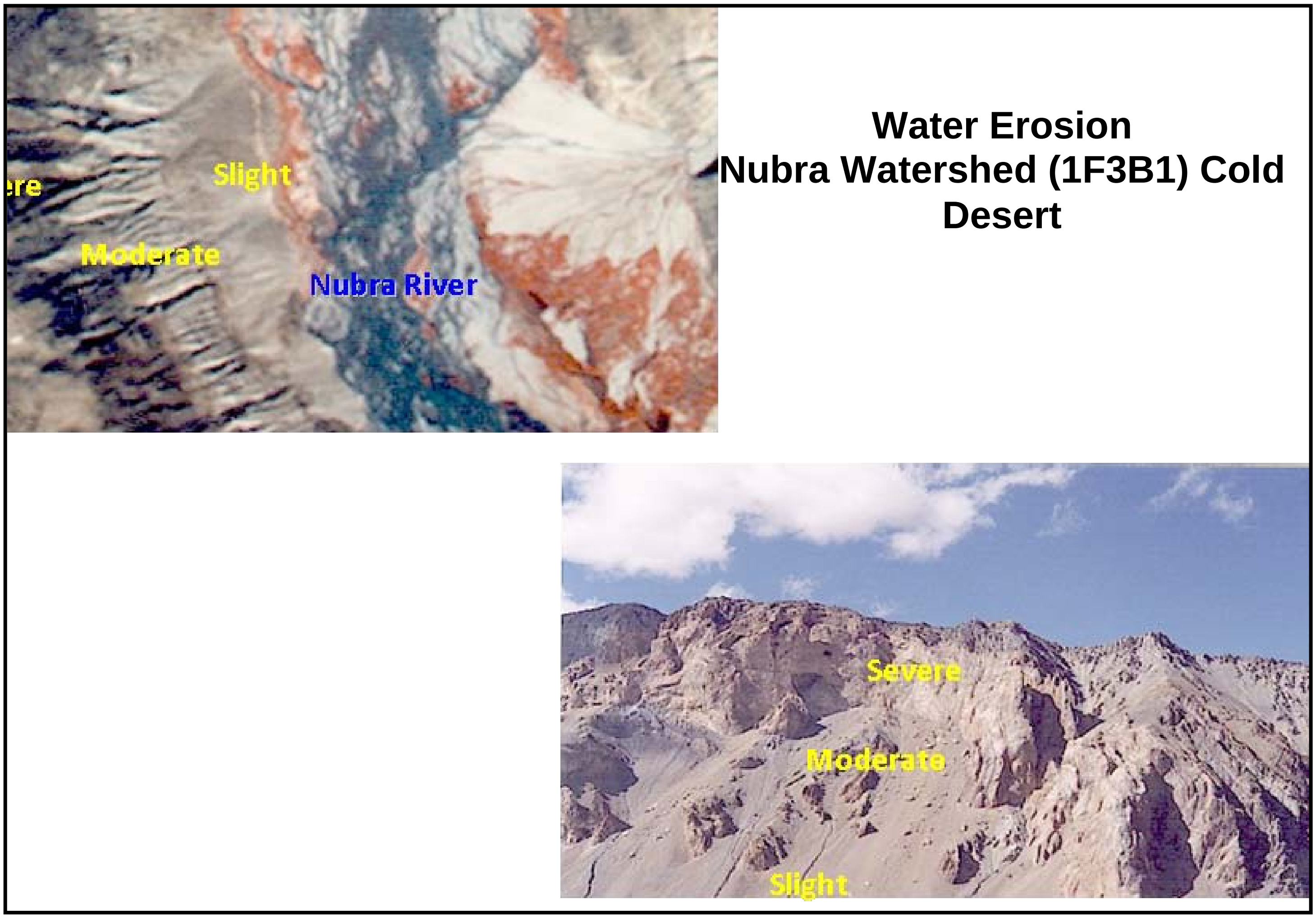


Fig. 8. Water erosion in cold desert areas

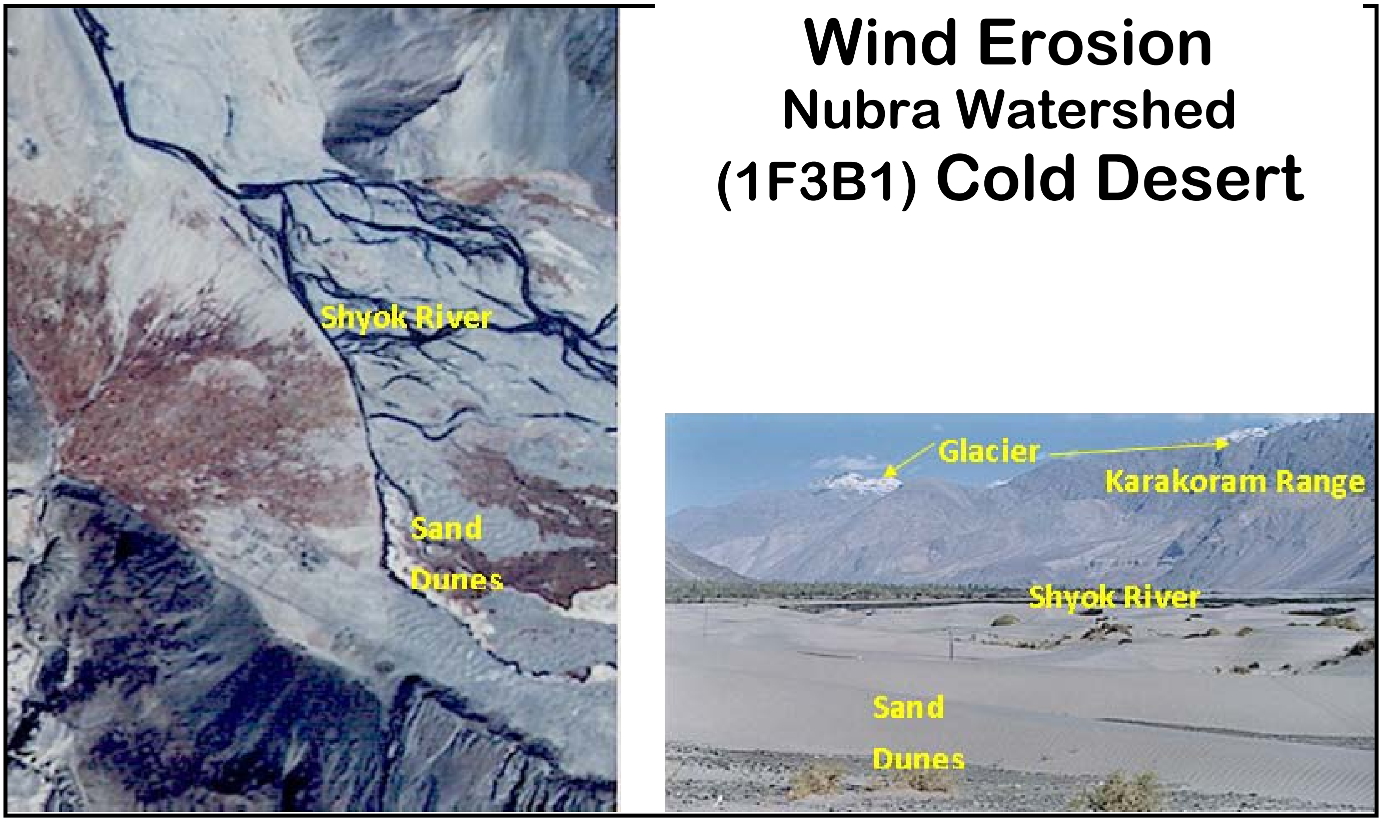


Figure 9: Wind erosion in cold deserts

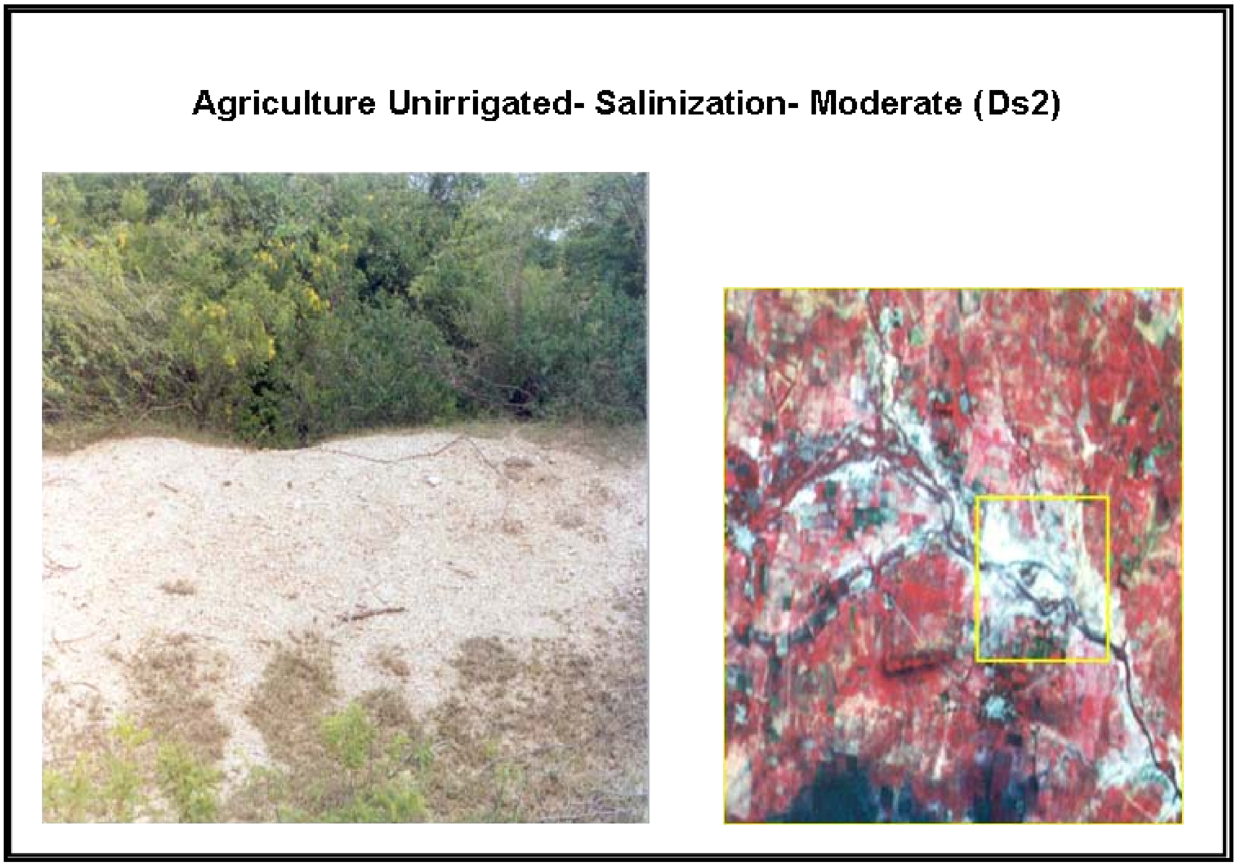
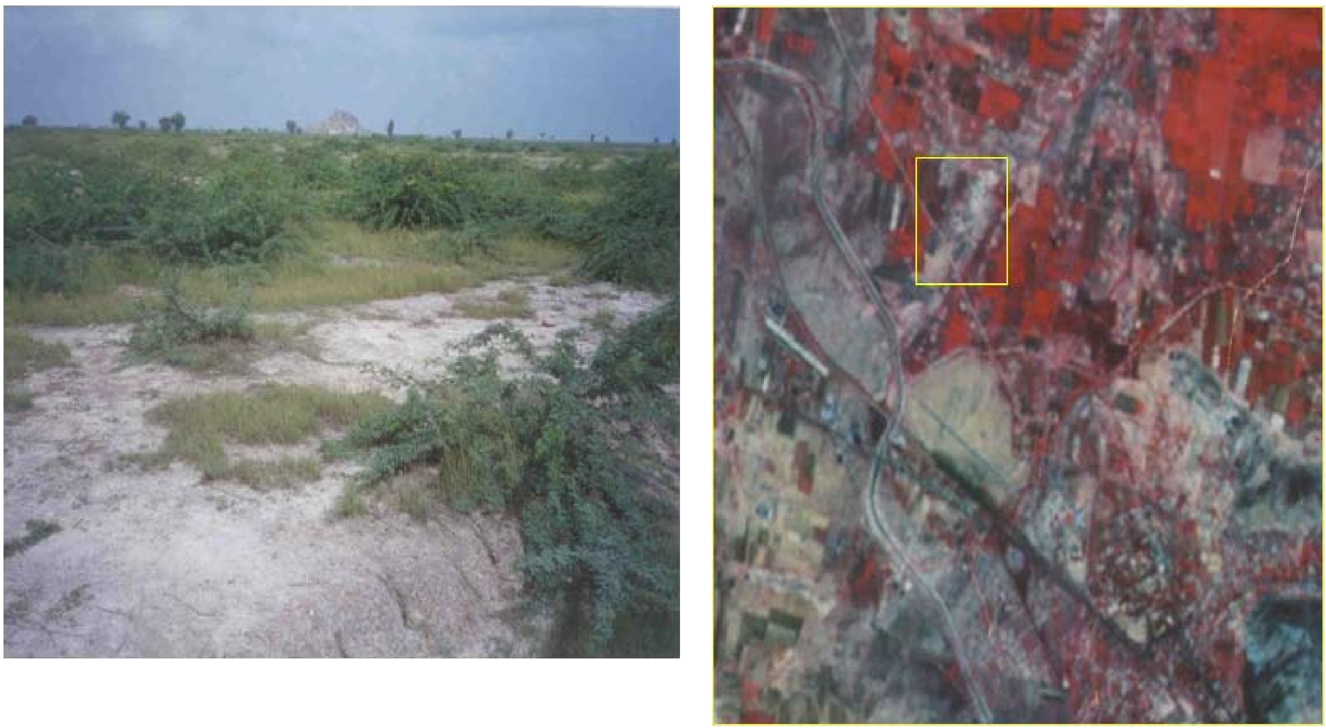


Figure 10: Moderate salinization in un-irrigated agricultural areas.

Agriculture Irrigated –Salinization – Moderate - (Is2)



Figur 11: Moderate salinization in irrigated agricultural areas.

Agriculture Irrigated–Salinisation – Severe - (Is3)

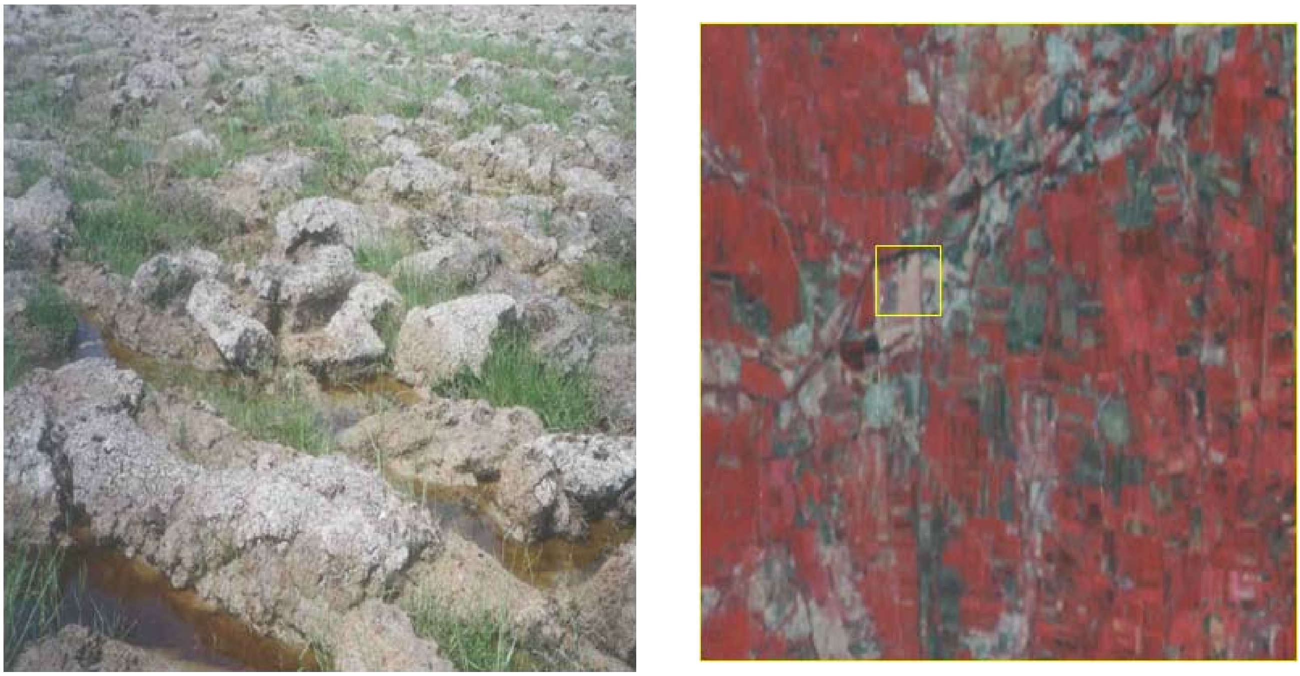


Figure 12: Severe salinization in Irrigated agricultural areas

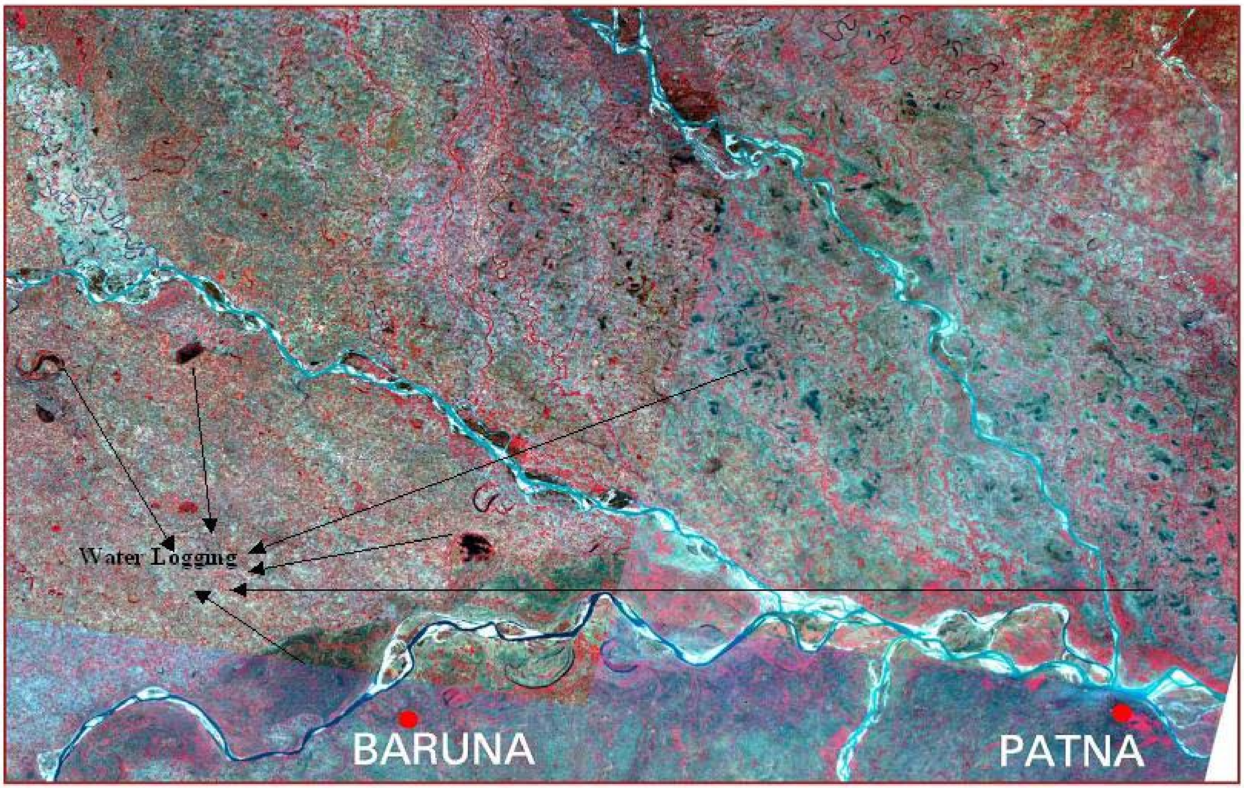


Figure 13: Water Logging in low lying areas of Indo-Gangetic plains of Bihar

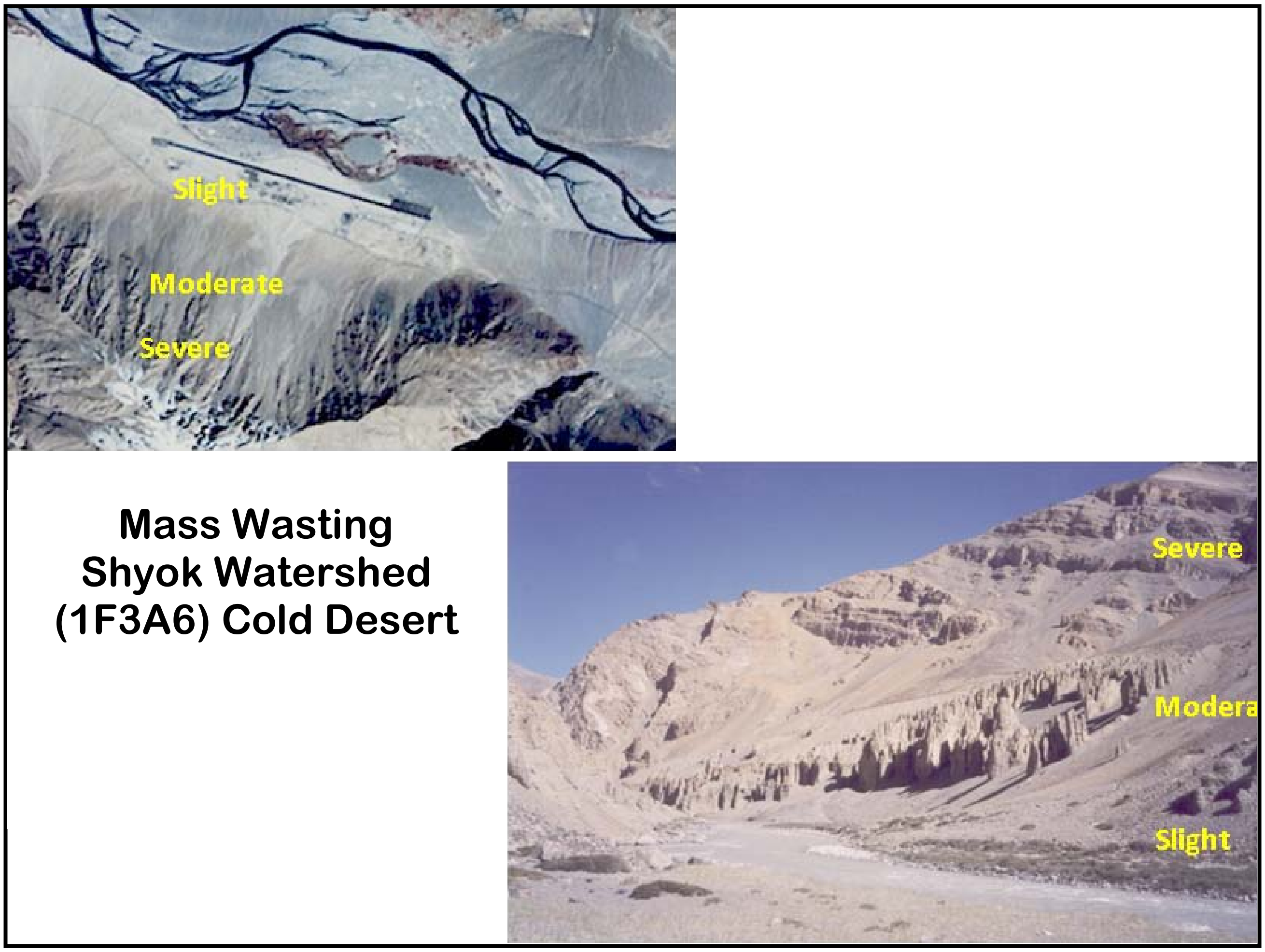


Figure 14 : Mass wasting in cold deserts

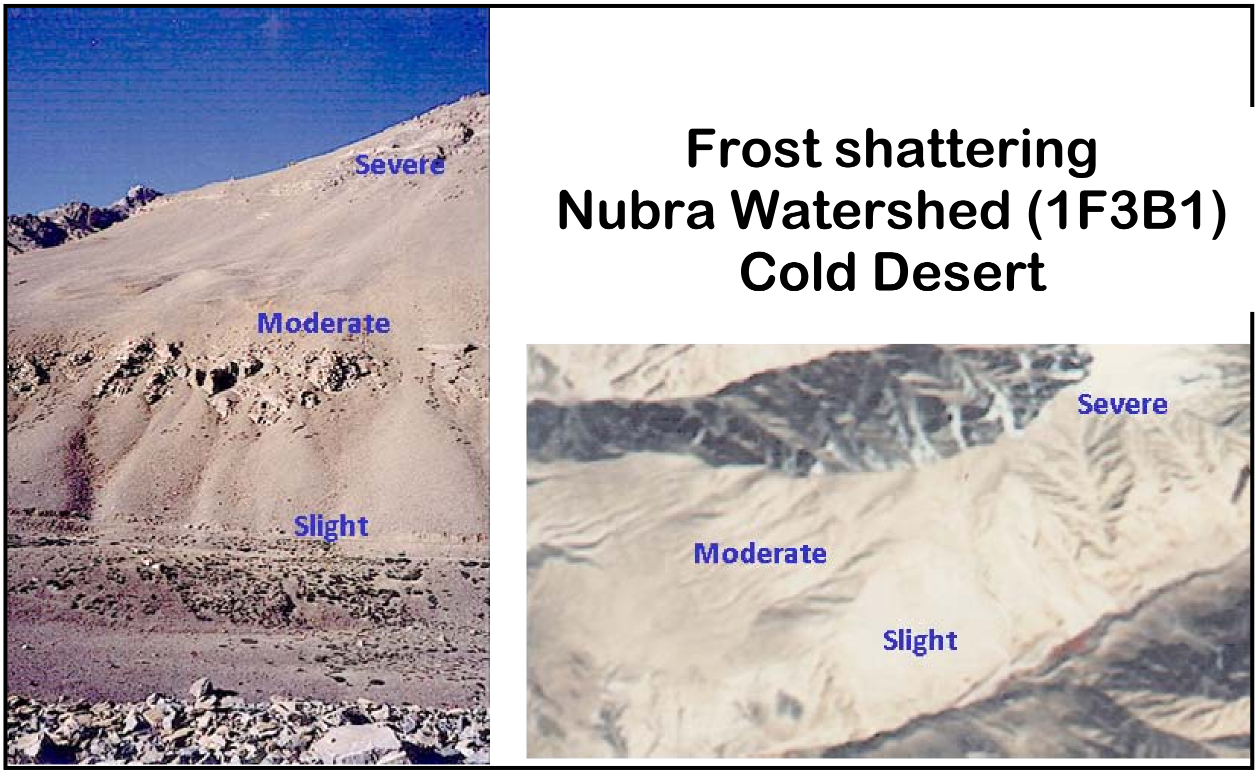


Figure 15: Frost shattering in cold deserts

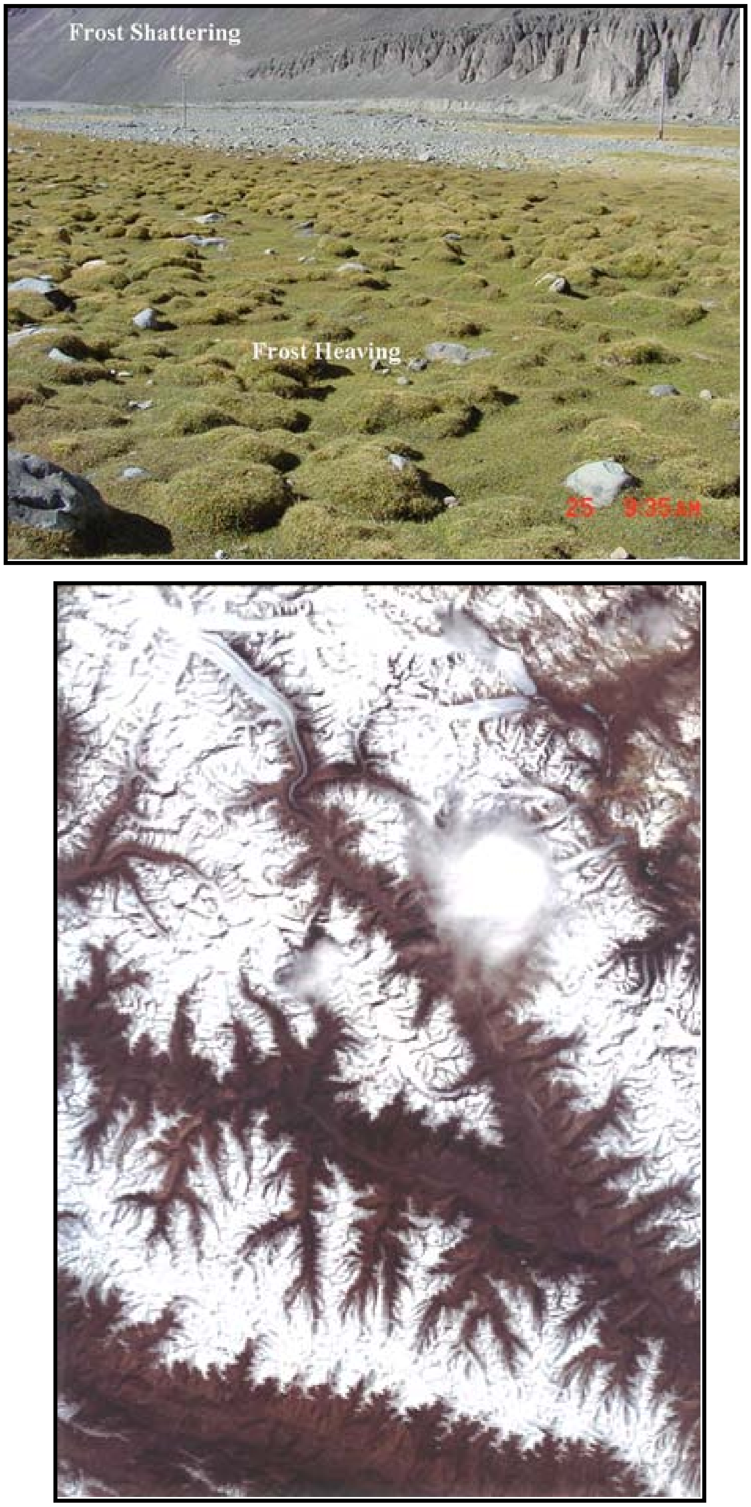


Figure 16: Frost heaving in cold desert (RESOURCESAT-1, AWiFS)

Agriculture Unirrigated – Manmade –Severe – (Ds3)

Figure 17: Severe man-made degradation in un-irrigated agricultural areas

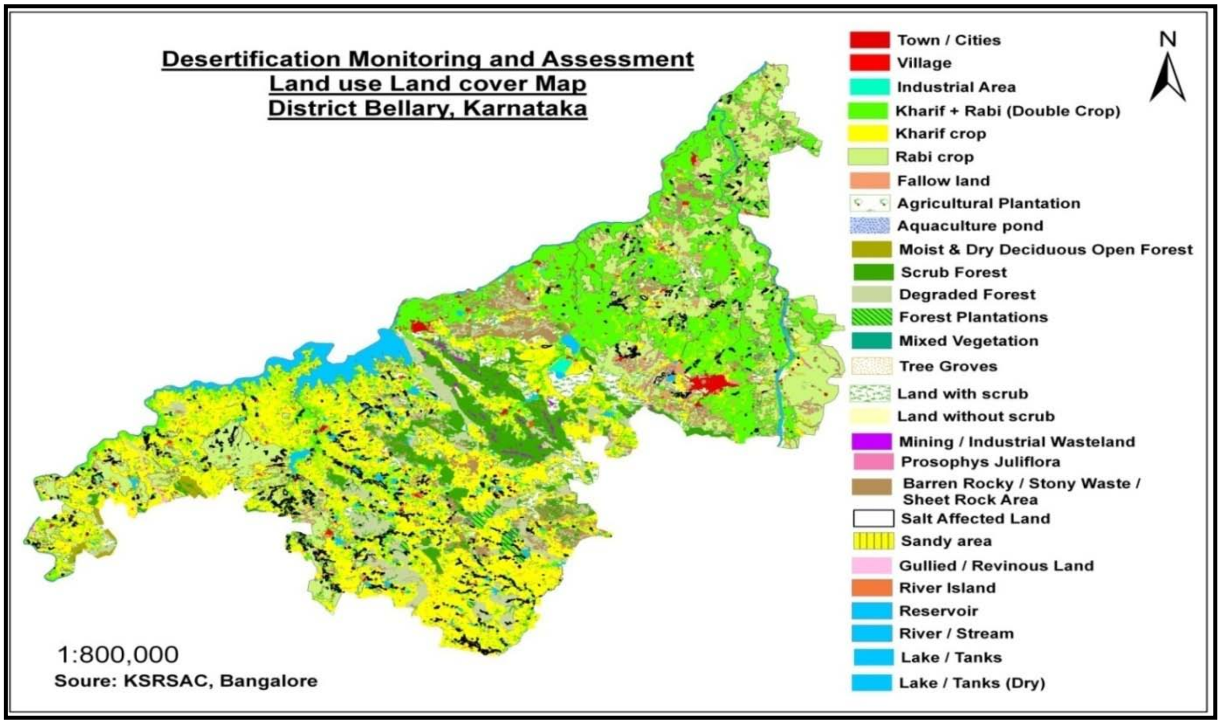
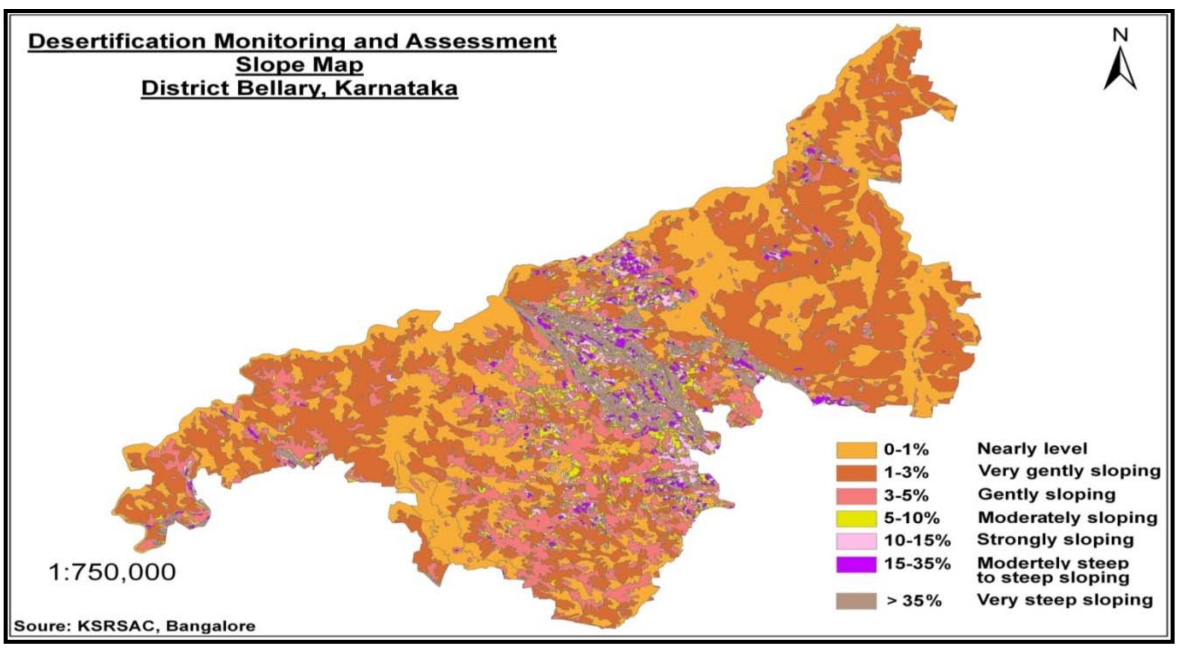


Figure 18: Land Use/ Land Cover Map

Figure 19: Slope map



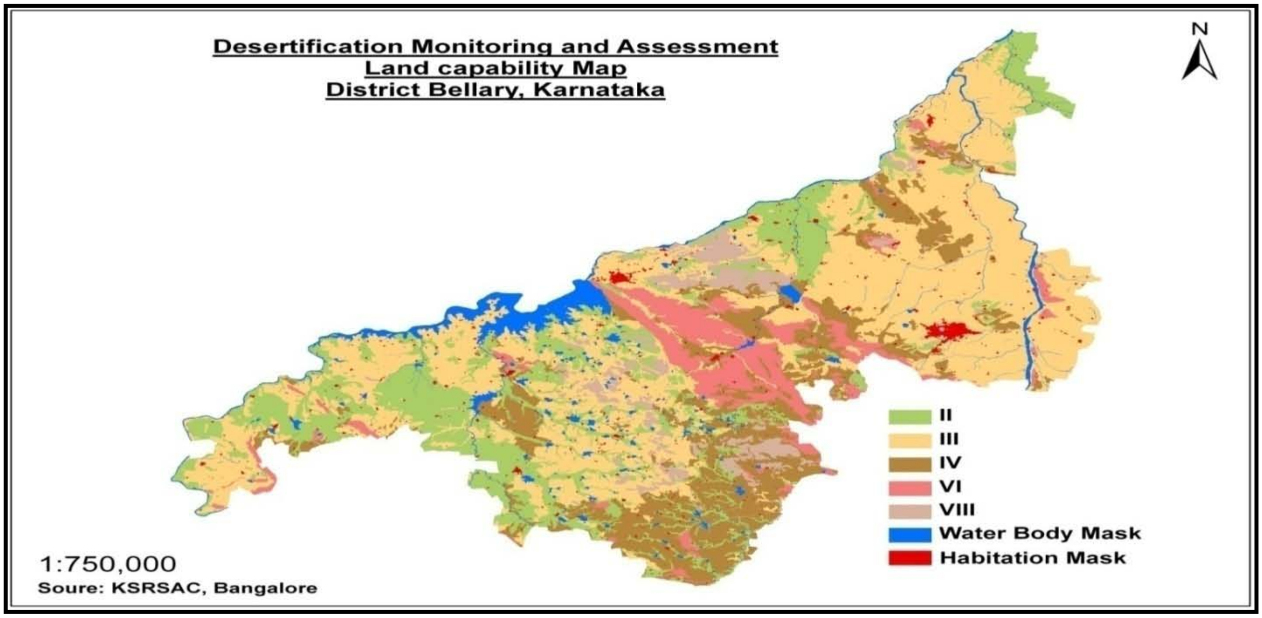


Figure 20: Land capability map

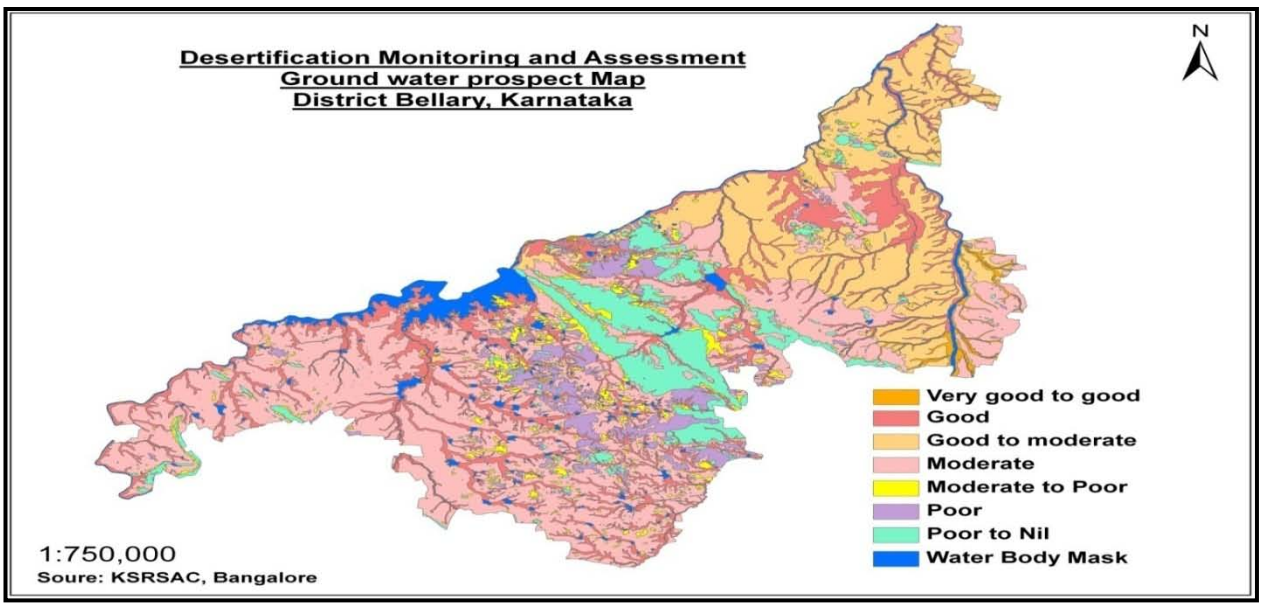


Figure 21: Ground water prospect map

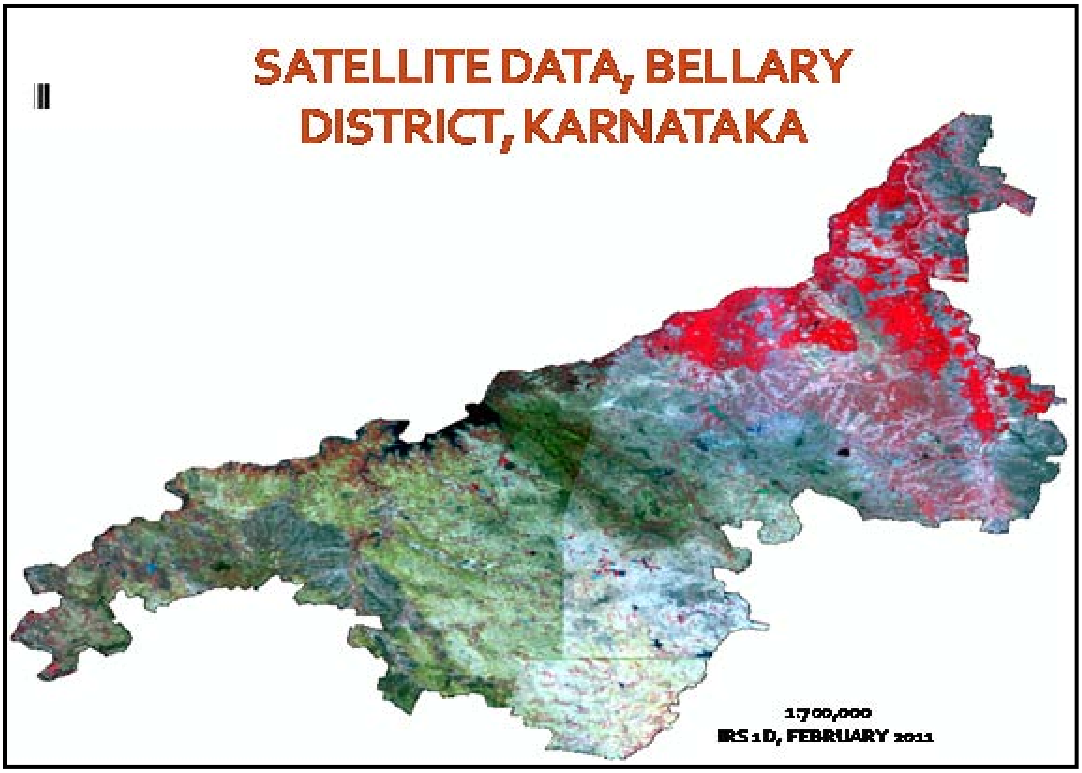


Figure 22: LISS II, FCC, District Bellary, Karnataka

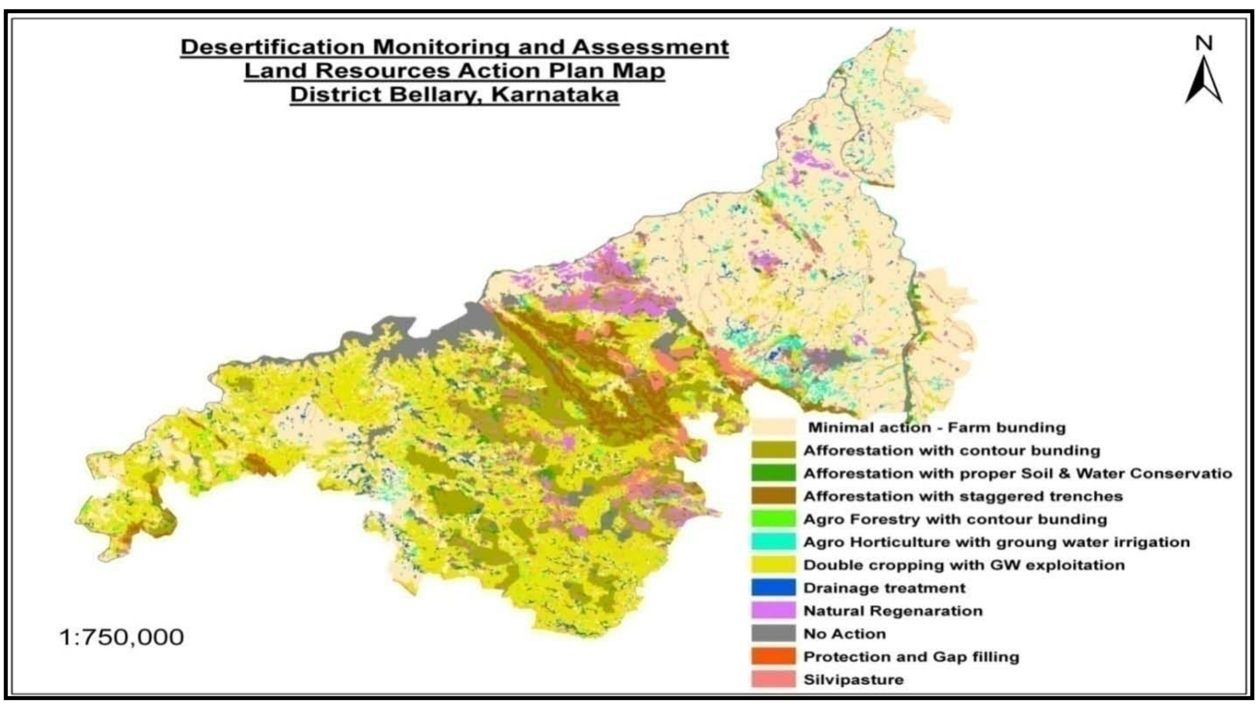


Figure 23: Land Resources Action Plan Map

ACKNOWLEDGEMENT

This technical guideline is an outcome of the detailed brain storming discussions / consultations with the scientists from a large number of organizations in the country who are involved in desertification monitoring and assessment project. The methodology, classifications system and the legend have been finalized after consultation of literature and the deliberations of the brain storming discussions. We are very much thankful to the organizations, 1) Central Arid Zone Research Institute (CAZRI), Jodhpur, 2) National Bureau of Soil Survey and Landuse Planning (NBSS&LUP), Nagpur / Bangalore, 3) All India Soil & Land Use Survey (SLUSI), New Delhi, 4) India Meteorology Department (IMD), Pune, 5) National Remote Sensing Agency (NRSA), Hyderabad, 6) National Atlas and Thematic Mapping Organisation (NATMO), Kolkata, 7) Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, 8) Ministry of Environment and Forests (MOEF), Government of India, New Delhi, 9) University of Rajasthan, Jaipur, 10) Jammu University, Jammu, 11) Jawaharlal Nehru University, New Delhi, 12) Directorate of Environment & Remote Sensing, Government of Jammu and Kashmir, Srinagar/Jammu, 13) Institute of Remote Sensing, Anna University, Chennai, 14) EOS-NNRMS, Bangalore, 15) RSAC, MP Council of Science and Technology, Bhopal, 16) Regional Remote Sensing Service Centre (RRSSC), Jodhpur, 17) Haryana Remote Sensing Applications Center, Hissar, and 18) Space Applications Centre (ISRO), Ahmedabad for their contributions in finalizing the classification system and the methodology for Desertification Status Mapping.

We are also grateful to Dr A S Kiran Kumar, Director SAC and Dr. J S Parihar, Deputy Director EPSA, SAC for their keen interest and guidance in this programme.

REFERENCCES

Anon. (1995). Integrated Mission for Sustainable Development – Technical Guidelines, National Remote Sensing Agency, Hyderabad

Dhinwa,P.S.,Pathan.S.K. and Ajai (2010),Action Plan for combating desertification in dry sub-humid region of Kathua district(J&K), Journal of Geomatics,Vol 4, No.1 , 43-48

Velayutham, M., Mandal, D.K., Mandal, C., Sehgal, J., 1999, b; Agro-ecological Subregions of India for Planning and Development, NBSS & LUP, NBSS Pub. 35, Nagpur