AEOLIAN LANDFORMS AND IMPACT ON LAND UTILISATION: A GIS BASED STUDY OF NORTH EASTERN RAJASTHAN

Dissertation submitted to the
Jawaharlal Nehru University in partial fulfilment of the
requirements for the award of the Degree of

MASTER OF PHILOSOPHY

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DEDICATED TO

MY Parents & My

Guru

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25.07.12 **Prashant Kumar Arya**

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DECLARATION

I, Prashant Kumar Arya, hereby declare that the dissertation entitled "**AEOLIAN LANDFORMS AND IMPACT ON LAND UTILISATION: A GIS BASED STUDY OF NORTH EASTERN RAJASTHAN**" submitted by me in partial fulfilment for the degree of Master of Philosophy of Jawaharlal Nehru University, New Delhi, is my bonafide work and may be placed before the examiners for evaluation and it has not been submitted so far in part or in full, for any degree or diploma of this University or any other University.

(Prashant Kumar Arya)

FORWARDED BY

We Recommend that this dissertation be placed before the examiners for the evaluation.

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(Supervisor)

Prof. P.M. Kulkarni
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Chapter 1

Introduction

1.1 Background:

Landforms are the surface features of the earth, initial landforms are shaped by endogenic forces while sequential landforms are sculpted by exogenic forces[1]. Landforms reflect the influence of geology and climate on a regional/broad scale. The permutation of various elements (i.e. geology, climate, soil etc.) in the landscape develops the conditions in the form of flora and fauna. The study of Landforms is facilitated by considering four basic elements – structure, process, slope and drainage. The following questions after what that constitutes the basics of geographic analysis of landforms: what? (the form of the feature); where? (its distribution); why? (its origin); and so what? (its significance)[2]. There are many landforms which have been studied extensively. These researches provide the information regarding its genesis, morphology, and its processes. Additionally, these are very useful for knowing the complex landforms and its intricate processes.

An Aeolian study is one example of such landform research. Aeolian studies have historically received research attention because of its great importance in understanding the nature of arid ecosystem. It is interconnected with various sub-disciplines such as Physical science, Earth science and Geography. It includes the study of Aeolian processes and associated Aeolian landforms, deposits, and sedimentary features such as the study of wind erosion and it is controlled by tillage, crop cover, shelterbelts, and other management practices; and the study of mineral dust, dust

[1] Strahler A N & Strahler A H (1998), Physical Geography: Science & System of the Human Environment, Second Edition, Wiley and Sons, New Delhi. Survey Professional Paper 964, U. S. Govt. Printing Office, Washington (1976) pp. 384

[2] McKnight, T. L (1996): *Physical Geography: A landscape Appreciation*, Prentice Hall, New Jersey. pp. 384

emissions and the effects of fine particulate matter on climate and air quality[3]. Other issues which are explicitly used in Aeolian studies are atmospheric circulation; global climate modelling, sedimentology, mineralogy, dating techniques, remote sensing methods, and land use/land cover change, etc.[4]

The Aeolian studies provide the understanding about the Aeolian landforms, processes and their deposits. It provides an array of information regarding the environmental complexity of arid region.

1.2 Statement of Problem:

The importance of landforms must be understood in terms of their potential and restrains. Therefore, a study of land forms is vital for understanding the crucial impact on man and his environment. There are different types of landforms on earth, which has been examined in order to understand its natural development and its impact on human beings and vice-versa. For understanding any geomorphological landscape, it is important to first identify the landforms by proper identification by using suitable method and subject domain information. After identification it is important to quantify the landform on the basis of length, form and shape. Since, every landscape goes through some processes and which results into changes in landforms. These processes can be *Depositional* or *Erosional* in nature.

Aeolian landforms are one of such types of landforms which need to be studied extensively. These landforms are so dynamic due to the constructional forces (erosional agents, for instance wind) which are very active in such areas. The identification and mapping of Aeolian landforms and their significance in combating desertification and land degradation remains an important factor to be studied. Remote sensing data have become increasingly popular for geomorphological research because of their progressively increasing levels of detail and availability which have opened up new potentials for research. The core concern of this study is to examine the application of

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[3] Stout, J.E, Andrew, W and Gill, T. E (2009): "Publication trends in Aeolian research: An analysis of the Bibliography of Aeolian Research", *Geomorphology*, vol. 105, pp.6

[4] Bauer B.O. (2009), "Contemporary research in Aeolian geomorphology", *Geomorphology*, vol. 105, pp. 2

available DEM and GIS techniques for the identification and mapping of Landforms & its processes and its impact on land utilisation.

1.3 Significance of Aeolian Studies:

Over the centuries Aeolian studies have attracted attention due to its concern with the unique landforms and processes. An Aeolian process has influenced the populace and social front is quite evident, the influential nature of Aeolian processes on the environments also underlines to its significance. **Stout John E. et al. (2009)** had mentioned various factors which influenced the Aeolian studies are global conflicts, environmental disasters, technological innovations, political changes in government[5]. The significance of Aeolian studies has grown further due to the environmental disaster that Aeolian processes are affecting across the world. Due to Global warming and climate change the drought conditions have enhanced further in various regions of earth. This leads to the degradation of soil, prominent soil erosion and further desertification. Land degradation is one of the foremost menaces for land productivity and food production. Such incidences have seen in Sudan's Darfur region, Senegal, Somalia and many other countries which are affected by the drought and desertification. Countries having arid and semi-arid regions are continuously engaged in Aeolian studies for the combating its affects. This includes China, Mongolia, Africa and India as well. The Deserts in areas are invading in their neighbouring regions. Thus, Aeolian processes are linked with desertification, land degradation, and soil erosion. These problems need to studied in well depth and research has been carried out in throughout the world, which has grown the significance in Aeolian studies. Following are some stages of Aeolian studies which will show its growing significance.

1.3.1 Historical Significance of Aeolian Studies

According to **Stout John E. et al. (2009)**[6] the first publications that appear in Aeolian research are on 17th. From that period to now the Aeolian research has been influenced by many factors which have ramified the subject matter. The significance of

[5] Stout, J.E, Andrew, W and Gill, T. E (2009), *Op. Cit.*, pp.16

[6] *Ibid.* pp.-7

Aeolian studies has increase due to the response of major environmental and climatic events in the 20th and 21st century.

The significance of Aeolian studies had developed in the 18th and 19th century, which may be related to the influence of European colonial expansion. During that period several new colonies were situated in arid environments. People from various backgrounds went into the colonies and wrote about their experiences in which they occasionally mentioned about various Aeolian landforms that they had observed. Later various studies paid lot of attention to the issue of African dust plumes that drove across Europe. This issue has been studied extensively in order to understand the causality. It was further enhanced due to the '*Dust Bowl*' event on the great plains of North America. This event emphasised the soil erosion aspect especially by wind and improper agricultural practices. Later this event was studied as linked with wind erosion, which produced the significant work on wind erosion by **W. S. Chepil (1959)** in which he developed a suitable method of estimating relative susceptibility of farm fields to erosion by wind[7] and **Zingg & Chepil (1950)** who studied the intricate phenomena of the sorting of soil material by the wind and its relationship to possible changes in the productivity of agricultural land[8].

In 1970s the importance of Aeolian studies was further developed due to severe drought in Sub-Sahara which steered the concerns regarding the process and consequence of desertification in arid region. In this direction **Grove, A. T. (1969)**[9] studied the landforms and climatic change in the Kalahari and Ngamiland in which he described the climatic sequence with landform development. The exploration of oil and gas in the Middle East by Western countries also stimulated the Aeolian studies. A significant work in this regard was done by **Glennie (1970)**[10] in which he had worked on the present genesis of sea, sand and ancient Aeolian sandstone.

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[7] Chepil, W. S. (1959) "Wind Erodibility of Farm Filed", *Journal of Soil and Water Conservation*, Vol. 14, pp. 214

[8] Zingg, A.W., & Chepil,W. S. (1950), "Aerodynamics of wind erosion", *Journal of Agriculture Engineering*, Vol. 31, no. 6, pp.

[9] Grove, A. T. (1969), "Landforms and climatic change in the Kalahari and Ngamiland", *Geographical Journal*, vol. 135, pp.191-212

[10] Glennie K.W (1970) Desert Sedimentary Environments, Elsevier publishing company, Amsterdam.

In the 1972 National Aeronautics and Space Administration (NASA) had lunched remote sensing satellite known as *LANDSAT-1* which captured millions of images. These images were used for the mapping especially for quantifying the earth resource status. From that period Landsat and its series of satellites have been obtaining earth images and hence, a huge archive has been generated for further studies. In context of Aeolian studies, LANDSAT data has been used by various scholars for quantifying the Aeolian features and related studies. In this field **Breed C.S et al. (1979)** in which he attempted to link the wind, precipitation with the types of sand dunes in the eight desertic regions of the world using Landsat (ERTS)[11], **McKee, E. D et al. (1979)** classified the dunes in simple, compound and complex which was acquired from the Landsat (ERTS)[12]. The use of Remote sensing technique in Aeolian Geomorphology and in Geomorphology has been introduced by the noteworthy work of **Verstappen, H.T (1968[13], 1977[14])**.

1.3.2 Recent Significance of Aeolian studies

In 21st century Aeolian research has been revolutionized due to advancement in science and technology. The use of remote sensing technologies, Geographical Information System (GIS) and field-based measurements provides new insights into the Aeolian landforms and processes. The attention in Aeolian studies has been given to the processes and rates of wind erosion because of their impact on agriculture, especially in semi-arid regions, and the implications of dust emissions for air quality. Wind erosion has removes the organic matters and change the soil texture which lead the problems like desertification and land degradation. The impact of wind erosion also detected in

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[11] Breed, C. S. Fryberger, S.G. Andrews, S. McCauley F.L. Gebel, D. and Horstman, K. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), *A study of global sand seas*, Professional Paper US Geological Survey No. 1052, pp. 309-397.

[12] McKee, E. D. (1979): Introduction to a study of global sand seas. In E. D. McKee (Ed.), *A study of global sand seas*, Professional Paper US Geological Survey No. 1052, pp. 3-17

[13] Verstappen H.T (1966), " Landforms, water and land use west of the Indus plain", *Nature and Resources*, 2, pp.6-8

[14] Verstappen, H.T (1977): Remote Sensing in geomorphology, Elsevier, Amsterdam.

the air quality which changes the atmospheric properties and creating various problems regarding human health causing respiratory illnesses[15].

In Feb. 2000 the Shuttle Radar Topography Mission (SRTM) provides the digital elevation model of the earth surface. It covers the land mass between 60 degrees north latitude and 54 degrees south latitude and provides 30m elevation resolution[16]. This data provides information regarding elevation in order to map the height variability of the large sand seas and study the mega dunes[17].

1.3.3 Aeolian Studies in India

India has a total geographical area of 328.2 million hectares with drylands covering 228.3 million hectares or 69.6% of the total land area. Within the drylands, Arid area is 50.8 million hectares or 15.8% of total geographical area, Semi-arid is 123.4 million hectares or 37.6 % of total geographical area and dry sub-humid is 54.1 million hectares or 16.5 % of total geographical area[18]. Considering, the arid region of India, Rajasthan is one of such region, which is also known as the Great Indian Desert or Thar Desert of Rajasthan. This region is dominated by different Aeolian features, including the sand dunes and related landforms. Less rainfall, sparsely distributed vegetation and swift wind speed promotes Aeolian processes in this region.

In India, Central Arid Zone Research Institute (CAZRI), Jodhpur has done various researches in Aeolian studies and arid landscapes. Various renowned researches have been noticed such as **Singh, S. (1977[19], 1981[20]), Sharma, H.S (1987) [21], Kar, A.**

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15 Lancaster, N. (2009): Aeolian features and processes, in Young, R., and Norby, L., Geological Monitoring: Boulder, Colorado, Geological Society of America, p. 2.

16 Van Zyl. J.J (2001), "The Shuttle Radar Topography Mission (SRTM): a breakthrough in remote sensing of topography", *Acta Astronautica*, Volume 48, Issues 5–12

17 Blumberg D. G (2006), "Analysis of large Aeolian (wind-blown) bed forms using the Shuttle Radar Topography Mission (SRTM) digital elevation data", *Remote Sensing of Environment* 100, pp.180

18 MoEF (2011), Elucidation of the 4th National Report submitted to UNCCD Secretariat Ministry of Environment & Forests, Government of India, New Delhi, pp.294

19 Singh, S. (1977), Geomorphological Investigation of the Rajasthan Desert, Central Arid Research institute, Jodhpur, Monograph No. 7

(1993)[22], **Wadhawan, S.K (1994)**[23], and many more are some such works in this regards. Majority of studies in India is mainly on agricultural and sand control purposes[24]. While the main focus in India is to control the desertification processes and hence major attention was paid on the stabilising shifting sand dunes, restoring degraded forests through Afforestation, maintain the ground water reservoirs, improvements in bio-resources and farming system.

The application of Remote Sensing techniques and its uses in India bring the new era of applied research. The use of this application helps many earth science departments such as the soil survey, Ground water boards, and Forest department to quantify the changes. After getting support from Indian Space department (ISRO) it becomes viable for Indian scholars to work on the new fields[25]. The remote sensing satellite images provide the synoptic view of a large area and it helps in identification of many geomorphic features such as Aeolian landforms and its related processes. Through this technologies various thematic maps has been generated to show the current status of the study area. Remote sensing techniques have been found a significant tool to identify the features, monitor, and quantify the processes. The other work regarding the Aeolian related aspects in India and its applicative work are done by **Sharma K.D et al. (1989)**[26], **NRSA (1995)**[27], **Singh (1988)** [28] and many more. The

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[20] Singh S (1981), "Types and formation of sand dunes in the Rajasthan Desert" in the Sharma H.S (Ed.), Perspectives in Geomorphology - Vol.2, Concept Publishing company, New Delhi, pp.165-182

[21] Sharma, H.S (1987), Tropical Geomorphology: A Morphogenetic Study of Rajasthan, Concept New Delhi.

[22] Kar, A. (1993), "Aeolian Processes and Bedforms in the Thar Desert", *Journal of Arid Environments*, Vol. 25, Issue 1

[23] Wadhawan, S.K (1994), "Dune Dynamics and evolution of Aeolian in parts of Jaisalmer District, Rajasthan, India", *Journal of the Indian Society of Remote Sensing*, Vol. 22

[24] Breed, C. S. Fryberger, S.G. Andrews, S. McCauley F.L. Gebel, D. and Horstman, K. (1979), *Op. Cit.*, pp-377

[25] Dikshit, K.R (1991), "The Status of Applied Geomorphology" in Sharma, H.S (ed.) *Indian Geomorphology: selected papers from the 2nd Conference of the Indian Institute of Geomorphologists on Environmental Geomorphology*, Concept Publication, New Delhi.

[26] Sharma K.D., Singh S., Singh N. and Bohra D.N., (1989), "Satellite remote sensing for detecting the temporal changes in the grazing lands", *Journal of Indian Society of Remote Sensing*, 17(4), pp. 55-59.

[27] NRSA (1995), "Report on Area Statistics of Land use/Land cover Generated using Remote Sensing Techniques". Hyderabad, pp.71

work on Aeolian studies is still continue and over the period of time it also providing some new insight of Aeolian Landforms.

1.4 Role of Remote Sensing and Geographic Information System (GIS)

For decades, Remotely-sensed data and Geographical Information Systems (GIS) have been used successfully for the mapping surface structures and therefore represent an integral part in various disciplines, especially in Geomorphology. In order to study the geomorphology of a particular area or a region; there are two possible ways of understanding it. Firstly, the field study through which we can get the empirical observation. Secondly, we can use some analytical tools such as GIS & RS (remote sensing). These tools help us in order to identifying the existing changes in the terrain.

"Remote sensing is a Recording device for the acquisition of information of an object or phenomena without coming physical contact of the object or phenomena under study"[29]. The advancement of remote sensing brings new scope of information about the earth surface. The early aerial remote sensing or airborne radar techniques were very specific in nature. Due to weather conditions, positioning errors and smaller coverage etc. are making so many problems in this respect. While satellite radar based remote sensing provides the greater height, an extensive coverage and the quality of resolution. Such technique produced images on the bases of variable electromagnetic radiation from the diverse surface of earth.

"The Dutch Geomorphologists led by **H.T .Verstappen** are the leader in the utilisation of remote sensing techniques. **Verstappen, H.T (1983)** in his book '*Applied geomorphology: geomorphological surveys for environmental development*' advocates the application of geomorphology in the field of earth science (topographic and thematic maps), environmental studies, rural development, urban problems and engineering"[30]. In the present study it is very much evident that the utility of remote sensing for

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[28] Singh, S. (1988), "Remote Sensing in Monitoring Desertification Processes under Different landforms (Ecosystems) of the Indian Desert", In Tewari, A.K (ed.) Desertification: Monitoring and Control, Scientific Publishers, Jodhpur.

[29] Singh, S. (1988), *Op. Cit.,*pp.55

[30] Dikshit, K.R (1991), *Op. Cit.,*

monitoring the Aeolian Landforms and its processes is a best tool. The satellite images provide a synoptic view of geomorphic features which helps in understanding the spatial distribution and detect the changes.

Geographic Information System (GIS), which is basically a comprehensive analytical tool for capturing, storing, manipulating, integrating, organizing, analysing and displaying geographical data, has developed as complementary field to geography. In the present study the usage of GIS is very crucial for analytical purpose. It can compute various parameters into one geo-database and hence which evaluate various aspects.

1.5 Objectives of the Study

The study related to identification and Mapping of Aeolian landforms and its impact on land utilization has following objectives.

1. To identify the Aeolian landforms on the basis of shape and form in the study area using HRS and generate a landform classification map.

2. To explicate the Aeolian processes related to the environmental aspects such as wind, temperature and precipitation as well as their derivatives.

3. To study the distribution of Aeolian Landforms in different land use classes and to analyse the impact of afforestation and agricultural practice on the Aeolian landforms.

4. To study the dynamic impact of Aeolian landforms and processes on the land utilisation practice and the pattern of land cover.

1.6 Research Question

1. The significance of landforms must be understood in terms of their potential and restrains regarding land utilization. The identification and mapping of such landforms is expected to provide an array of information regarding the environmental complexity.

2. The core issue of identification and mapping of Aeolian landforms is to link them with the processes involved in their temporal evolution with respect to the apparent processes. Whether there has been a shift in the characteristic processes involved is the chief subject of investigation here.

3. What is the spatial pattern of landform distribution in the micro level study of study area?

4. What kind of process is responsible of the various shape, form and pattern of landform?

1.7 Data Base:

Following dataset has been used for analysis:

I. ***Cartosat -1***: Cartosat- 1 is a first Indian Remote Sensing satellite moving in a sun-synchronous orbit. It carries a Panchromatic (PAN) Cameras that took black and white picture of the earth. It provides stereoscopic images which are further used for cartographic applications. This data generates Digital Elevation Model (DEM), Ortho Image products, and other value added products for various applications of Geographic Information System (GIS). The swath covered by these high resolution PAN cameras is 30 km and their spatial resolution is 2.5 meters.

II. ***Carto (DEM):*** The Cartosat-1 Digital Elevation Model (Carto DEM) is developed by the Indian Space Research Organization (ISRO). There are two set of sources, where Carto DEM has been generated and taken. The first source is generated through Orthorectification process. A Cartosat-1 and DGPS point has been used to generate Digital Elevation Model. While for further verification Carto Dem has been downloaded from *Bhuvan*[31] – An Indian earth observation visualisation system product of National Remote Sensing Centre, Indian Space Research Organisation (NRSC/ISRO).

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[31] http://www.bhuvan.nrsc.gov.in

III. ***LISS III:*** The LISS III (Linear Imaging Self Scanning Sensor) is a multi-spectral camera operating in four spectral bands, three in the visible and near infrared and one in the SWIR region. LISS III camera has a SWIR band (1.55 to 1.7 microns), which provides data with a spatial resolution of 23.5 m. LISS-III data are well suited for agricultural and forestry monitoring tasks.

IV. ***Landsat5:*** Landsat TM5 multispectral data (bands 1-5 and 7) and equipped with a multispectral scanner (MSS) and thematic mapper (TM). MSS is an optical sensor designed to observe solar radiation, which is reflected from the Earth's surface in four different spectral bands. Data cover the visible, near-infrared, shortwave, and thermal infrared spectral bands of the electromagnetic spectrum. The spatial resolution of Landsat 5 is 30 meters (120 meters Thermal). The Data set has been downloaded from USGS (US Geological Survey) Global Visualization Viewer (**GloVis**)[32] site.

V. **Meteorological Data:** The meteorological data's of *Wind*, *Temperature* and *Rainfall* have been taken from Indian Meteorological Department, Pune, India.

TYPE OF DATA	TIME PERIOD	STATIONS
Wind (Wind seed & Direction)	From 2000 to 2009	Churu and Pillani
Temperature	From 1956 to 2010	Churu and Pillani
Rainfall	From 1956 to 2010	Churu and Pillani

1.8 Methodology:

The study has been undertaken based on three successive stages which are:

1. Primary data collection based on field observations and capturing of Ground Control Points (GCPs);
2. Post-processing of D-GPS data,
3. Processing and analysis at GIS.
4. Land Use & Land Cover.

[32] http://glovis.usgs.gov

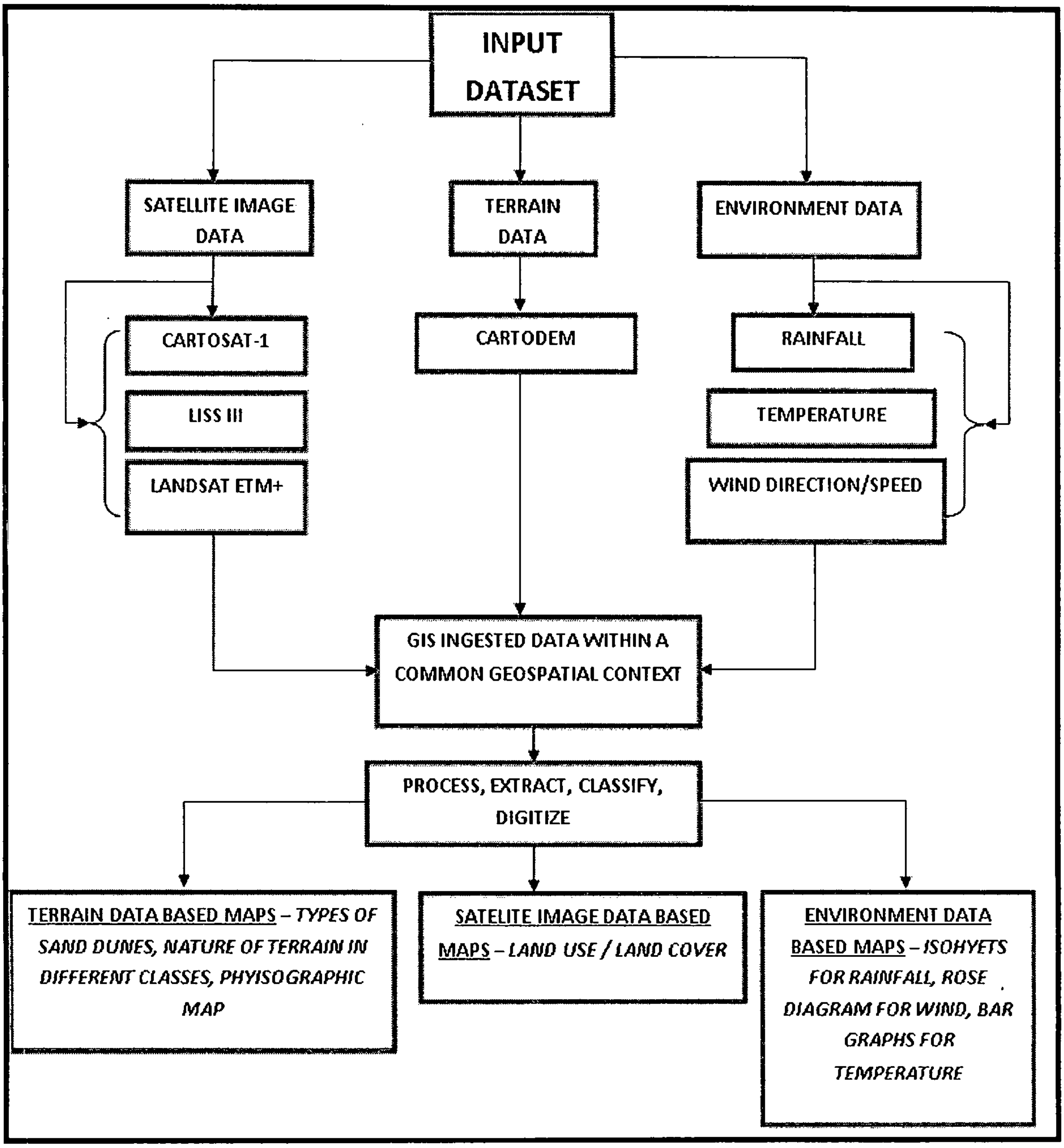


Fig. 1.1: Input of Data sets and uses

The following instruments and softwares have been used for data collection, data processing and data analysis.

- **Use of Instruments:** During Field visit the following instruments were used for data collection purposes.

a) ***Hand-held GPS:*** The hand-held Global positioning system or GPS is looks or shape can be comparable with a mobile phone. GPS contains a single receiver; therefore it has a frequent distortion by the errors source which leads to reduce the accuracy of the position. These kinds of GPS are least accurate and simplest as well. Its accuracy varies between 1 to 10m[33].

b) ***Differential Global Positioning System (D-GPS):*** D-GPS is a much more complex system than the hand-held GPS. It acquires sub-metre level accuracy. It works on the different measurement techniques, which minimized the errors. It contains two parts, one is a **base station** or *reference receiver* and another is a **rover** or *receiver* connected through the radio link.

Base station assesses the information of computed and calculated range values by approximating the range of satellites should be after being located at a known point. The difference between computed and calculated range values are known as corrections. The real time differential corrections are transmitted to the rover receiver (through radio) by the base station, and the rover receiver uses them to correct its measurements. The corrections formats of D-GPS are stated by the radio Technical commission for Marine Services (RTCM). The radio beacon which is put up nearby the coastlines of several countries has a powerful transmitter, which is located at old radio stations. The beacon station has a Range of 100-150Kms, while the frequencies which are used by the D-GPS signals are medium frequency (300 kHz.). The D-GPS or Differential code-phase GPS have an accuracy of < 1m.[34]

For the main analysis and processing of satellite data D-GPS points or GCPs have been taken. While hand-held GPS points have taken to see the variation in the Z value. The comparative evaluation in field and post processing has shown the best results, while using D-GPS. Following, results between GPS and D-GPS ground control points (GCPS) have revealed the clear image, about the use of D-GPS GCPs.

[33] Pavlopoulos. K, Evelpidou. N, Vassilopoulos. A (2009): Mapping Geomorphological Environments, Springer Verlag Berlin Heidelberg, pp. 20

[34] Ibid. pp. 21

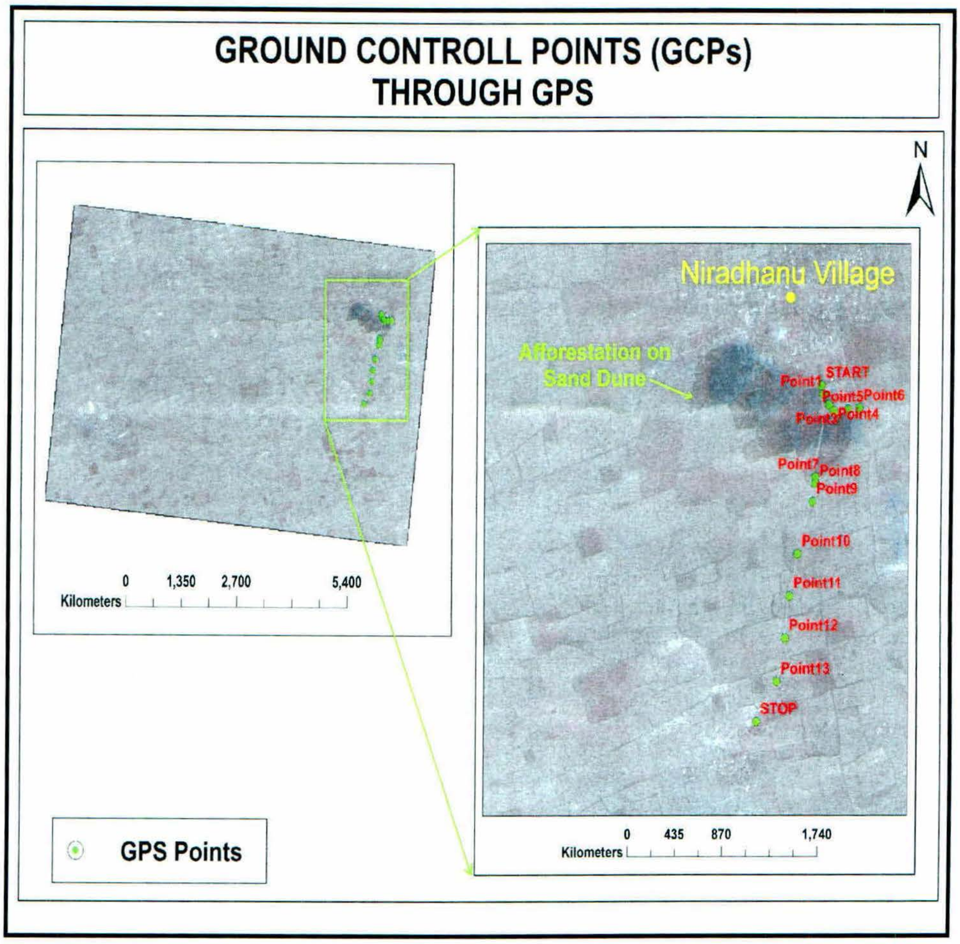


Fig. 1.2: Track records of GPS from Nirdhanu Village

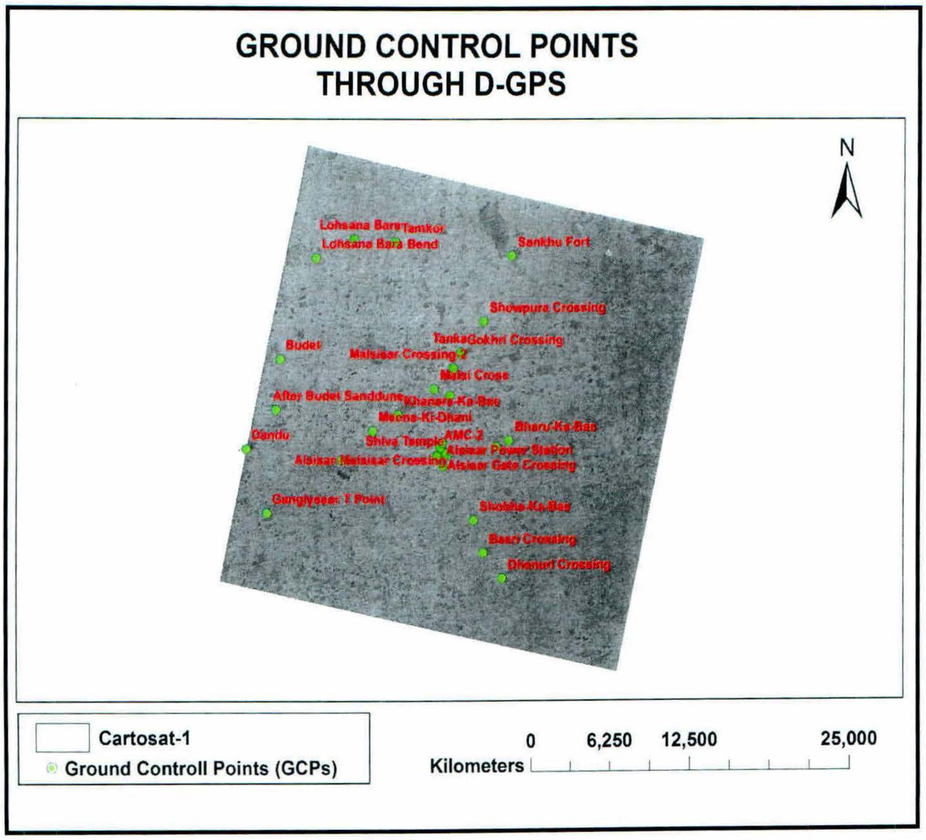


Fig1.3: Ground Control Points from D-GPS

Distance in meters	DGPS	GPS
0	251	286
172	252	288
344	250	289
516	250	292
688	250	297
860	255	297
1032	258	297
1204	252	288
1376	249	288
1548	243	292
1720	244	294
1892	246	290
2064	247	288
2236	246	286
2408	244	283

Table 1.1: Ground Control Points of GPS and D-GPS

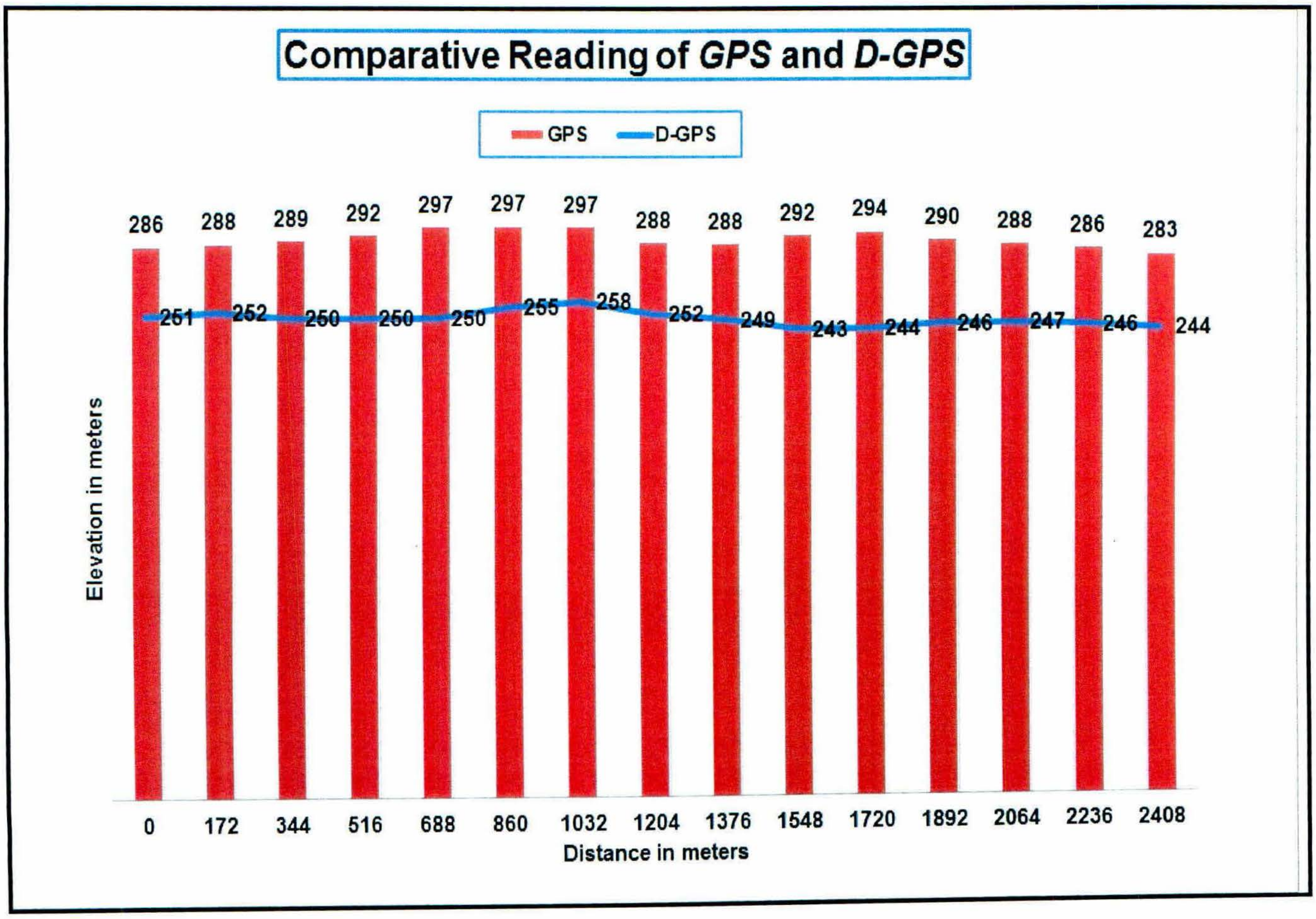


Fig. 1.4: Graph of comparative analysis in between GPS and D-GPS

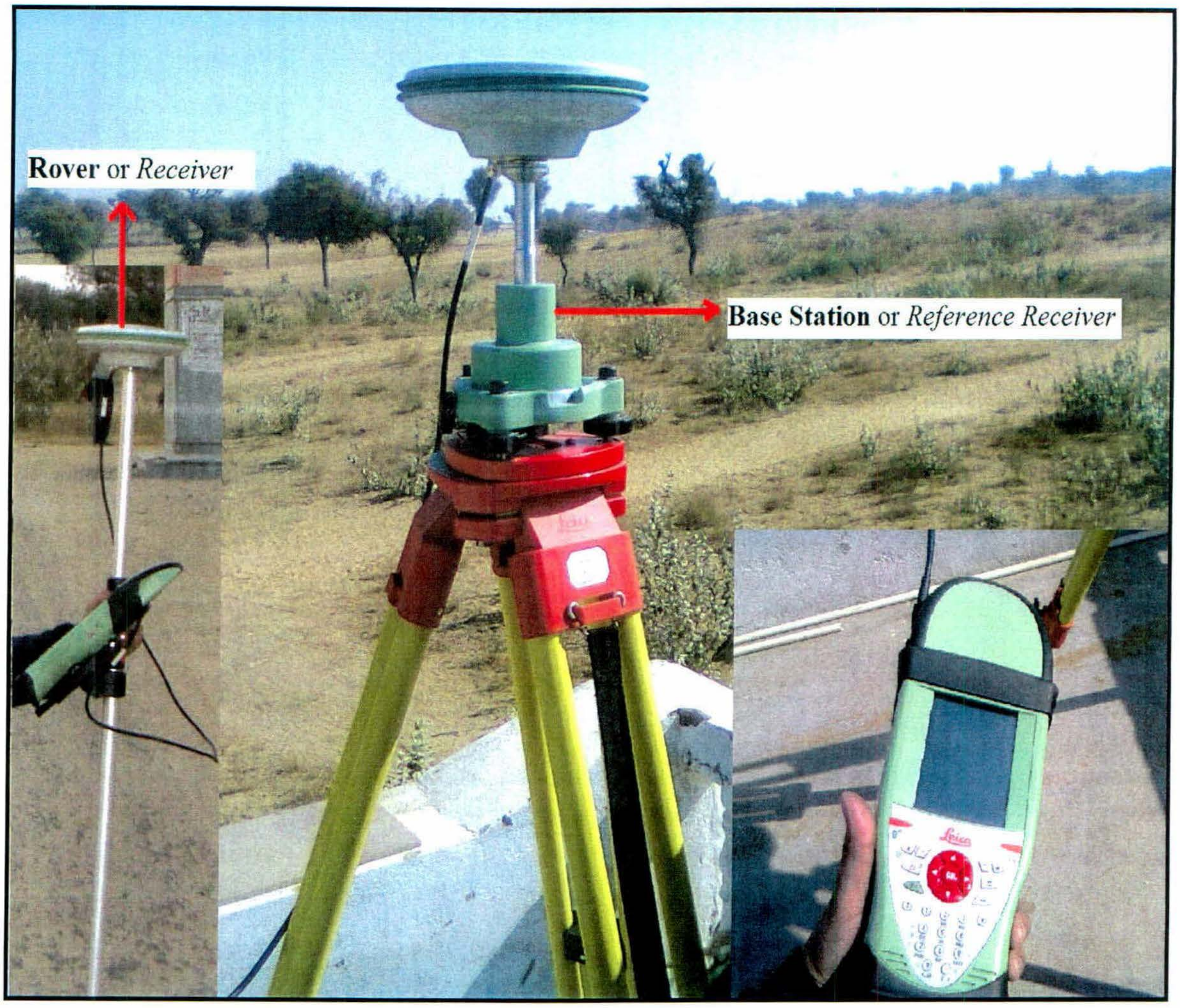


Fig. 1.5: Differential Global Positioning System (D-GPS)

- ## Software Used:

The following softwares were used for data processing and analysis:

I. ***ArcGIS and Arc Scene v.10*** **-** This was also used to compliment the display and processing of the data and for three dimensional analysis.

II. ***Erdas and LPS (Licea Photogrammetry Suite) 2010*** - This was used for Orthorectification of Cartosat and constructing of DEM. This Software also used for the further development of land use land cover analysis and subsequently used for change detection analysis of the study area.

III. ***Origin Pro 8.6*** **-** It was used for processing Wind speed and Direction of data and also used for Wind Rose Diagram.

• Input data

This study has been divided into macro and micro level studies. For the macro level scale due to unobtainability (due to its cost) of Cartosat-1 data, the digital elevation of this level has been taken from the *Bhuvan*[35] – An Indian earth observation visualisation system product of National Remote Sensing Centre Indian Space Research Organisation (NRSC/ISRO). On this site CartoDEM of 2.5 resolutions is readily available and downloadable. The macro level study of dunes classification has been done through this data. While, for micro level study Cartosat-1 data was available, but it need to orthro-rectification and related processes for generating DEM.

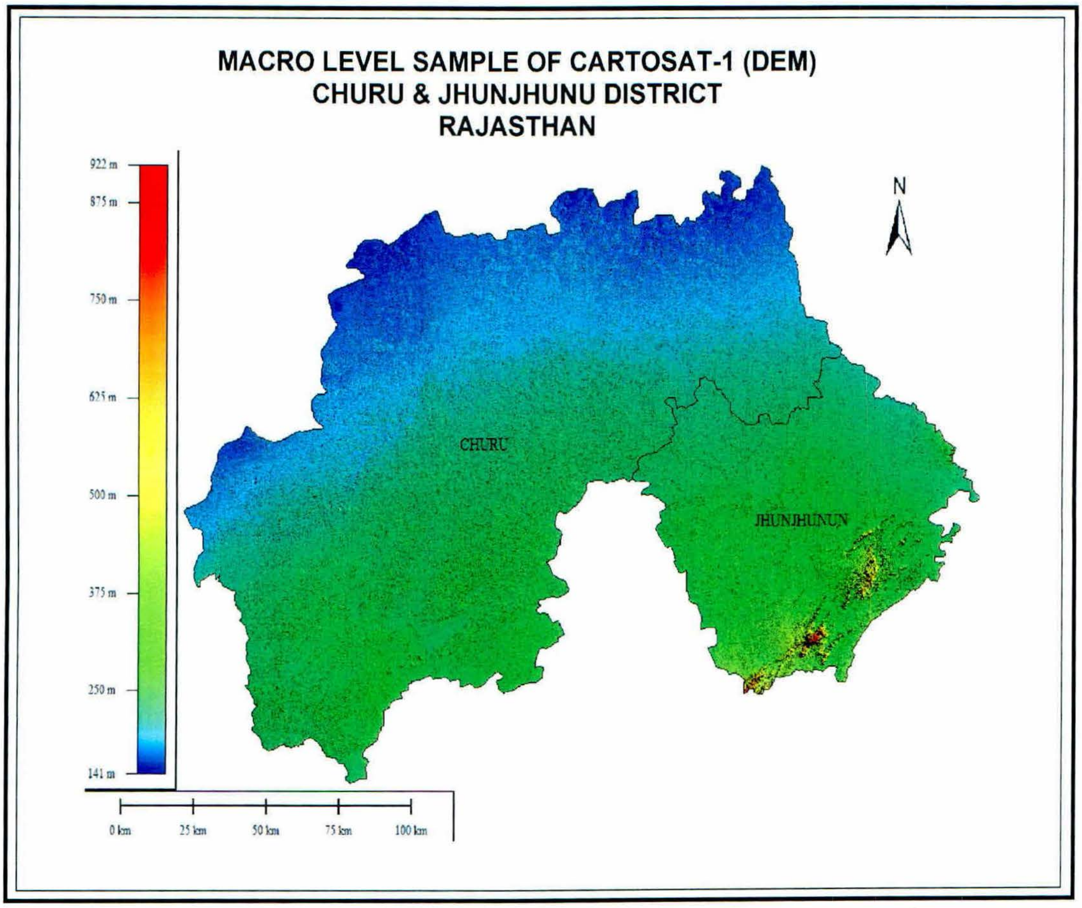


Fig. 1.6: CartoDEM dataset of District Churu and Jhunjhunu acquire form Bhuvan Site.

[35] http://www.bhuvan.nrsc.gov.in

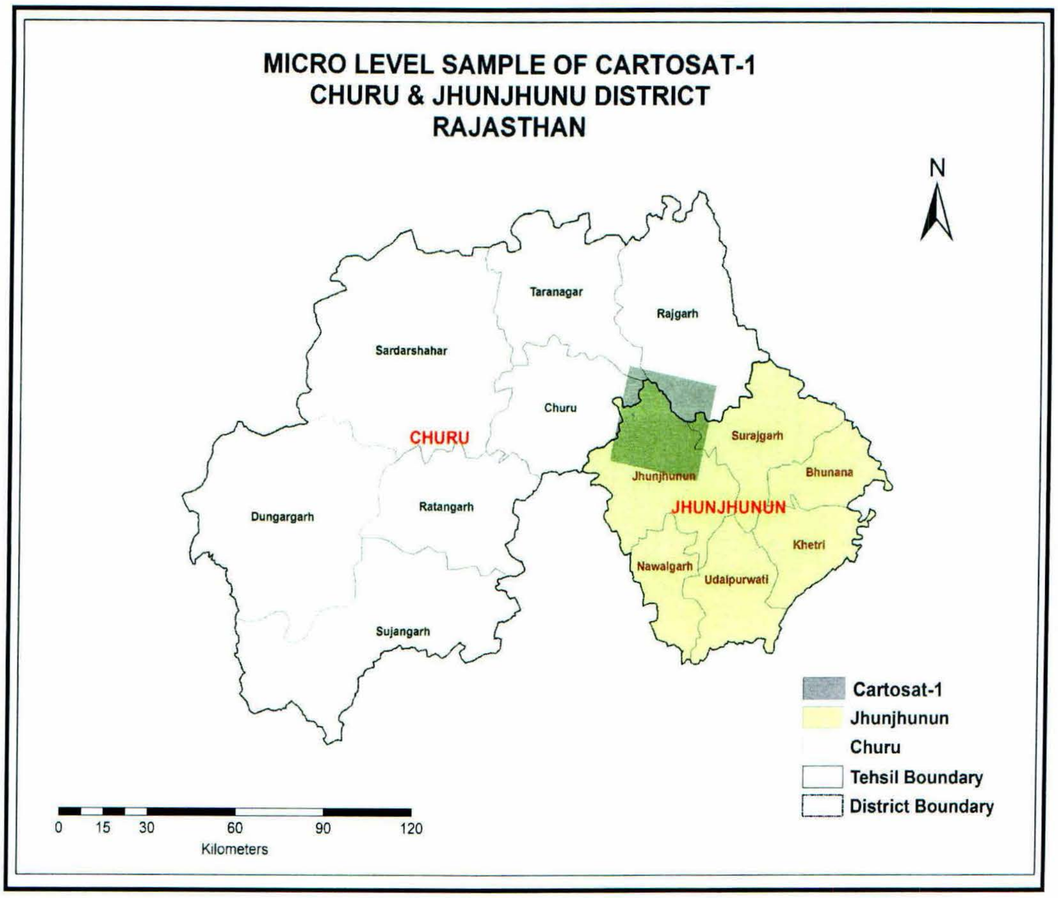


Fig. 1.7: High resolution Cartosat-1 panchromatic images cover few tehsils of District Churu and Jhunjhunu

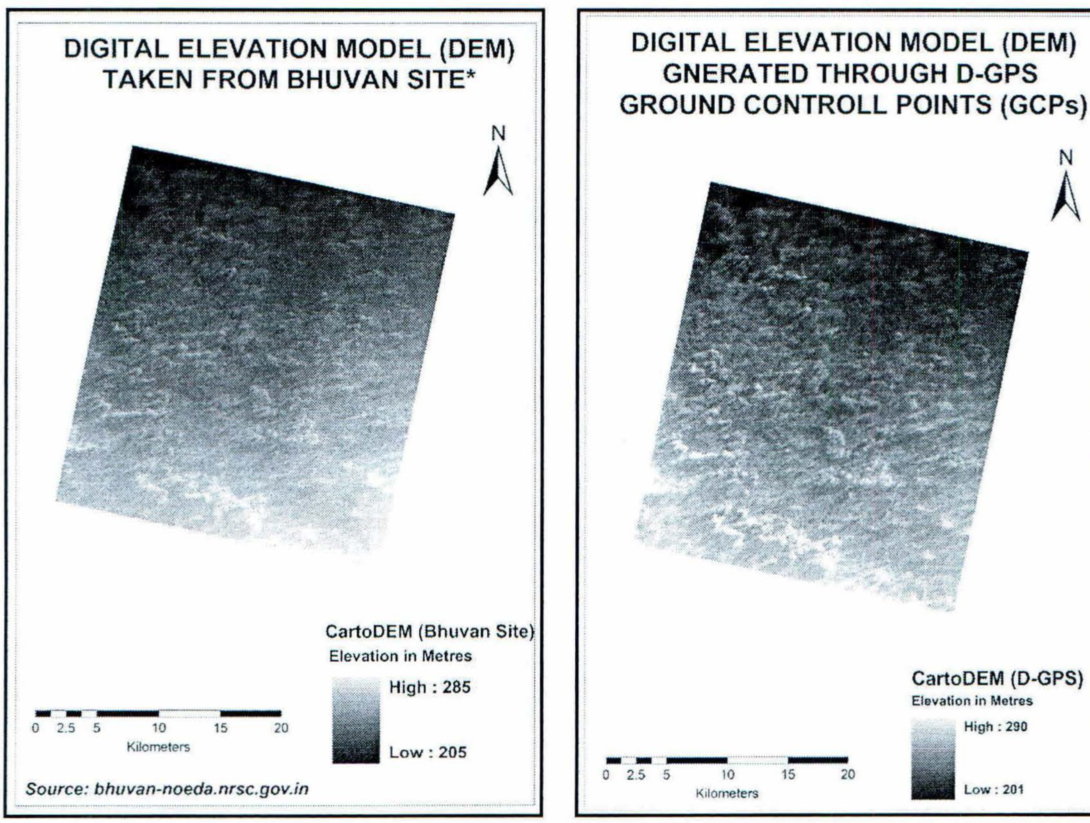
• Field Verification and Data Collection

For better knowledge of study area, field visit has been carry out for better visualisation of study area. In the study area, the boundary between Churu and Jhunjhunu has been taken as a field site for better understanding of the local morphology. In order to create a Digital elevation modal (DEM) of this area, various ground control points (GCPs) have also collected for this purpose.

• Data Processing

In the post-processing of D-GPS data, 29 ground control Points (GCPs) have been taken from the study area, in order to rectify the CARTOSAT image. These GCPs are taken from Differential Global Positioning System (D-GPS) have been used for the perfect height value or Z value. The geographic co-ordination and altitude were collected by D-GPS, the base station situated in two different areas. The altitude is not related to mean sea level, but they are relative to the geodesic of base station. The acquisition time of a point taken through D-GPS was from few seconds to 1 minute.

The distribution of points was well scattered, through which Digital elevation Model (DEM) has been created. After orthro-rectification of CARTOSAT image a DEM has been created for visualising the natural terrain of study area. Finally, post-processing analysis provides a less error based data, which further assist the information of various landforms and its patterns. After finalising the making of CartoDEM, RGB combination was diffuse from LISS III in high resolution Cartosat image. After diffusing RGB information, Cartosat image provide useful information regarding the land use and Land cover in a high resolution format.



(a) (b)

Fig. 1.8: A comparative difference between DEM (a) DEM taken from Bhuvan site (b) DEM generated through Panchromatic Cartosat data

- ## Data Interpretation and Analyses

In order to fulfil first objective, CartoDEM and fuse Cartosat image has been used for identifying the various types of sand dunes. From CartoDEM types of sand dunes was demarcated on the basis of shape, size, it was later superimpose on a diffused Cartosat image. This provides a perfect picture regarding the existing pattern of types of sand dunes in the study area. This is followed by generation of final map generated with types of sand dunes, area it cover and aerial coverage. In addition, meteorological data such as wind, temperature and rainfall also segregate and processed. With this data, an attempt will be made to establish a link between these factors (especially wind) with the shape of dunes in the study area.

Lastly, in order to see the impact of Aeolian environment on land utilisation; Land use and Land Cover method will be used to see the change detection in the study area with respect to zonal topography in different land use classes.

- **Land use/land cover mapping**

For the purpose of the land use/land cover (LULC) mapping of the study area, hybrid classification method has been used. Since the area is huge, it has been difficult to provide minute information of land use and land cover and its change. Land use and Land Cover method has proven as the best technique for quantifying the land use & land cover practice. Whereas on a practical ground LULC method suffers with some sort of problem, this includes the Signature mixing problem which causes inaccuracies in the mapping. Such problem can be noticed in the hilly regions (Aravalli hills in this case), where the reflectance value between the shadow areas of hilly area shows the same reflectance values with water. The supervised classification is accomplished with the field based knowledge. Following table show the land use and land cover classes, which were generated.

Table 1.2: Land Use and Land Cover Classes

S.no	Classes
1	Crop Land
2	Fallow land
3	Forest Cover
4	Plantation
5	Waste Land
6	Scrubland
7	Settlement
8	Water Bodies

1.9 Location & Extent

Churu and *Jhunjhunu* is located between 28° 19' N to 28° 06' N latitude and 75° 01' E to 75° 20' E longitude, covering an area of about 22,986 sq. km. It is surrounded by Hanumangarh district (Rajasthan) in its north, Sikar & Nagaur district (Rajasthan) in south, Bikaner district (Rajasthan) in west and Bhiwani and Mahendragarh district (Haryana) in east. Administratively, Churu and Jhunjhunun divided into 13 tehsils, 7 tehsils (churu, ratangarh, sujangarh, dungargarh, sardarshahar, taranagar and rajgarh) in Churu and 6 tehsils (Jhunjhunu, surajgarh, bhunana, khetri, udaipurwati and nawaigarh) in Jhunjhunun respectively. Total population of Churu district was 2,041,172 persons 2011, Census), while in Jhunjhunun has 2,139,658 persons (2011, Census) with a sex o of 938 Female per 1000 males in Churu and 950 Female per 1000 males in unun. The urban population of Churu and Jhunjhunu was 27.87% and 20.64% ely.

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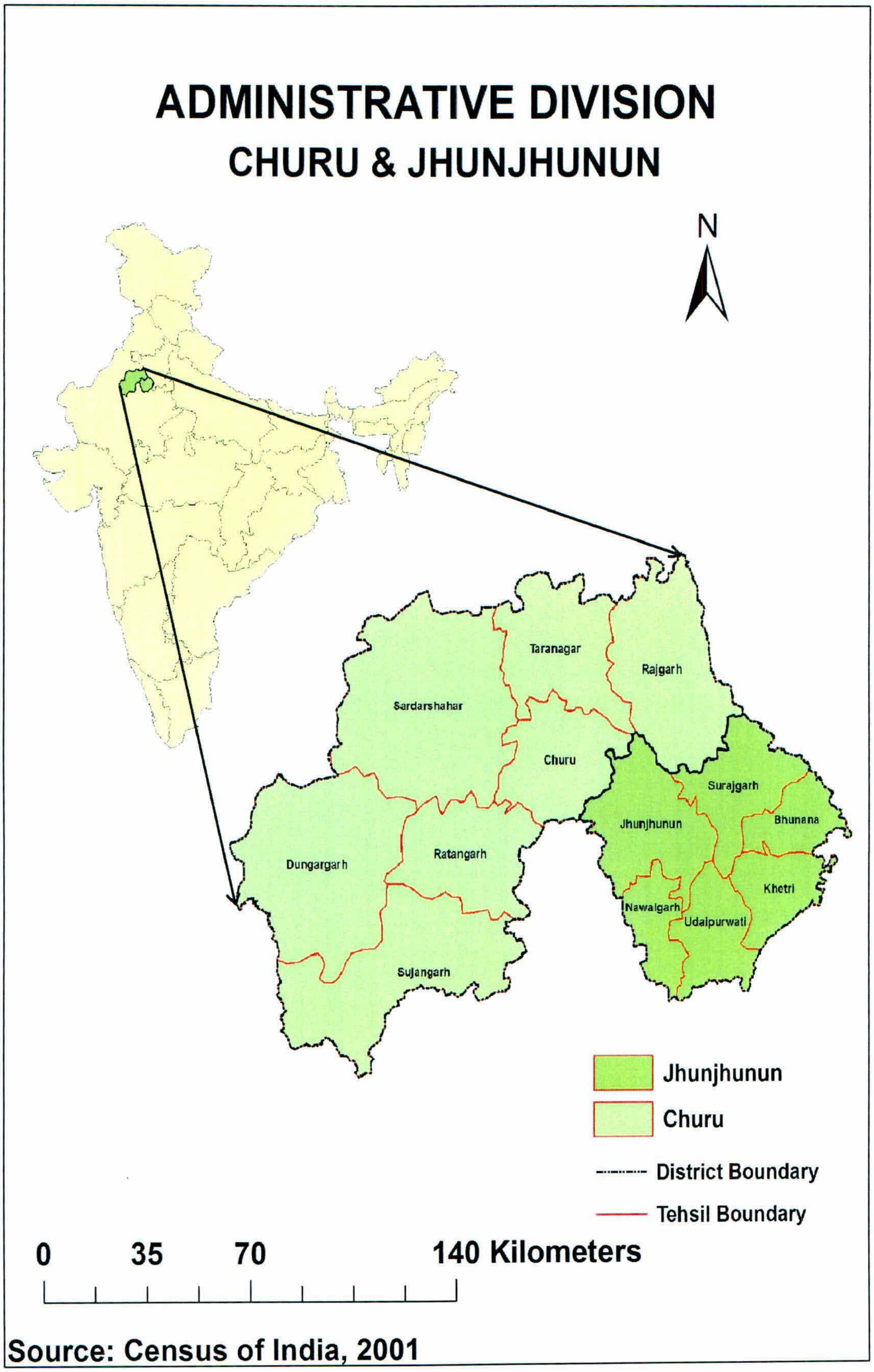

Fig. 1.9: Location of the Study Region.

1.10 Physiographic Background

***Physiography*:** Churu district characterized by 6 to 30 meter high longitudinal dunes trading north-east to south-west direction. It is situated about 400 meters above from the mean sea level[36]. Due to arid condition and lack of water availability the encroachment of sand is very extensive this area, sometime sand dunes intrude on the agriculture land and metaled roads. There is no river system in the district except kantli which grows in the hill near khandela in Sikar district and it gets vanished in the sands on the border district of Churu.

In Jhunjhunu district, a range of Aravalli hill is situated in the extreme south of this district. This piece of hill portion is located in the udaipurwati tehsil and it is further extended up to east of khetri tehsil. The elevation of this district is between the 300 to 450 meters above from mean sea level. In the south of Lohagarh Village maximum peak 1051 meters found[37]. Constant mining and deforestation leads to active sand shifting, and bare slope, which leads to further hazards related to land degradation. There are four major streams, namely Dohan, Chandravati, Udaipur Lohagarh Ki Nadi and Sukh Nadi. There is no lake in the district but scared tanks are well distributed throughout the district.

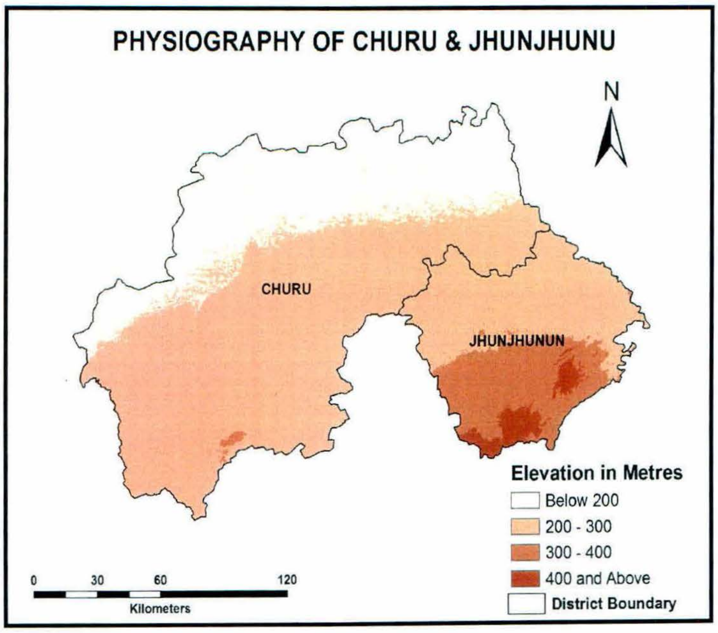

Fig. 1.10: Physiography of the study region

[36] Tomar, R.P (1991): District census Handbook, Churu, Census of India.

[37] Tomar, R.P (1991): District census Handbook, Jhunjhunu, Census of India.

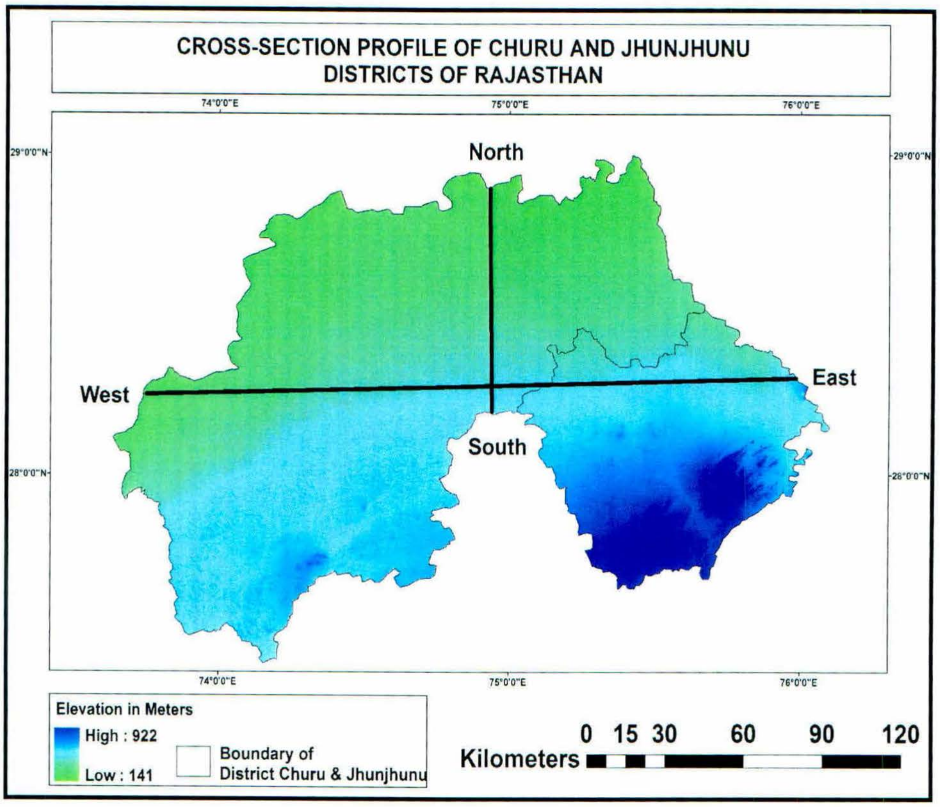

Fig. 1.11: Locational Cross Sectional Profile of the Study Region

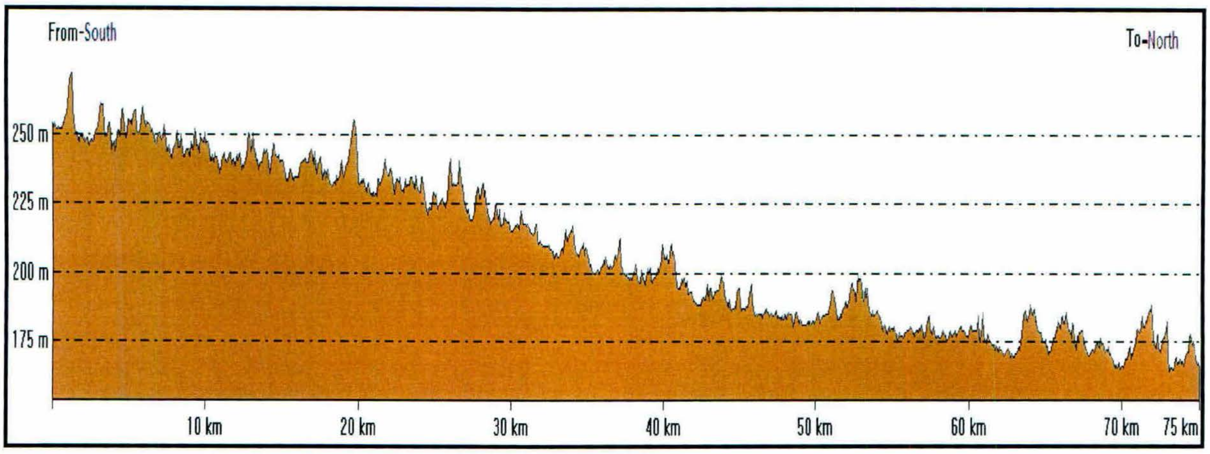

Fig. 1.12: Cross Section Profile of Elevation from South to North Direction

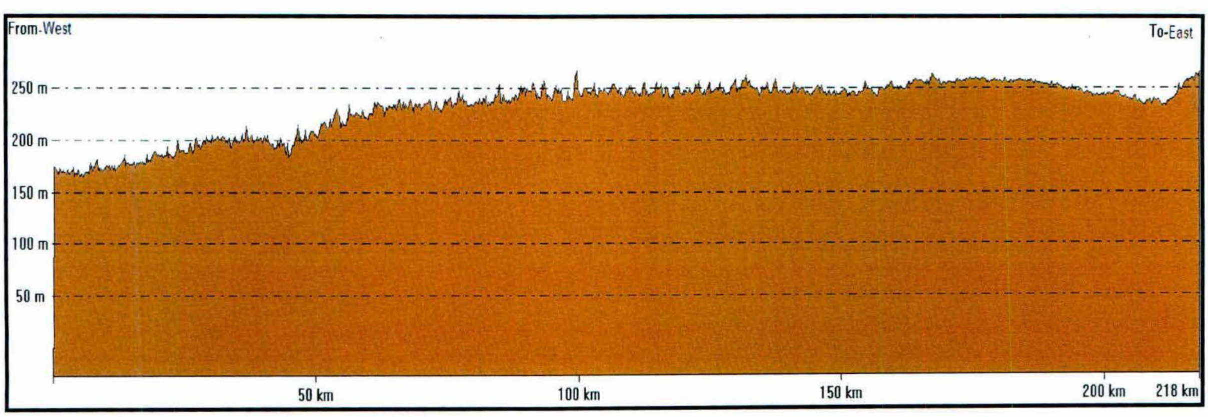

Fig. 1.13: Cross Section Profile of Elevation from West to East Direction

Geology: A major portion of Churu district is thickly covered with sand, which is covered by the wind-blown sand. But in some places rock exposures have been found both in eastern and western portion. Sand stone is an important rock of this region which actually quarried out about 1.6 km west where it crops up. Majority portion of region is covered with sand and no information regarding the nature of rocks below, is available[38].

Jhunjhunun district is formed by wind-blown sand. There is a linear out crop of Aravalli mountain system which is stretched form NNE to SSW direction. The length of this mountain system is about 70kms, while its width is about 20 kms in north and 5 kms in southern side. Other small isolated outcrops of the rocks are Delhi Supergroup and Malani Igneous suite. The district is well known for copper, majority of copper lie in kehtri tehsil. Apart from copper, other minerals such as calcite, Dolomite and iron ore also found in this district.

Climate: The climate of the study region is semi-arid and arid. The climatic condition in *Churu* is arid and hot, this part of the study region comprises with the variations of temperature and scanty rainfall. The summer period is from April to June is followed by Southwest monsoon season from July to mid-September. After mid-September to October period of post-monsoon occur, this is later followed by the period of winter from November to March. The minimum and maximum of normal annual temperature recorded are 12.6 °C and 38.3 °C respectively. While, the normal annual rainfall in Churu is 36.3 cm was recorded. The average annual pattern of rainfall is decline from east to west.

[38] Sehgal, K.K (1970): Rajasthan District Gazetteers: Churu, Barat Printers, M.I. Road, Jaipur.

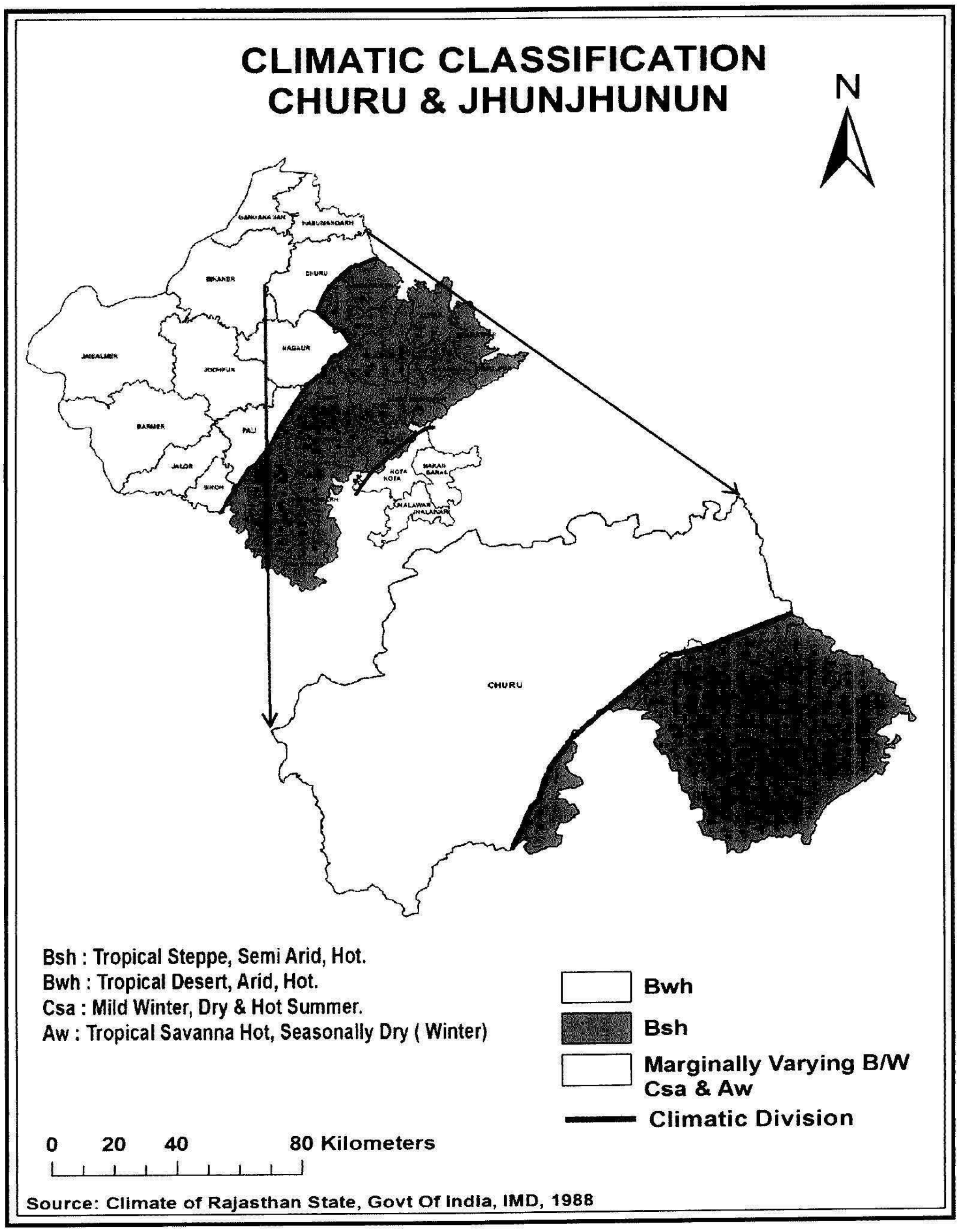

Fig. 1.14: Climatic Condition of the Study Region

In *Jhunjhunun* the climatic condition is semi-arid. 'The district has a dry climate with a hot summer. In summer sand storms are a characteristic feature. The cold season starts by about the middle of November and continues till about the beginning of March. Thereafter, hot season follow and it extends up to the end of June. The south-west monsoon is from July to mid-September'[39]. The minimum and maximum of normal annual temperature recorded are 12.7 °C and 37.2 °C respectively. While, the normal annual rainfall in Jhunjhunun is 35 cm was recorded. The average annual pattern of rainfall is decline from east to west.

[39] Tomar, R.P (1991): District census Handbook, Jhunjhunu, Census of India.

Vegetation: The vegetation cover in *Churu* district is very much sparsely distributed. As this district is situated in arid region, the favourable condition for vegetation growth in this area is hindered distribution of vegetation. Extreme temperature in summers and winters, lack of water and scanty rainfall are some reason for their poor vegetation cover. Moderate rainfall during rainy season provides grass and fodder in this region. The forest cover of Churu District is 0.53 per cent (2011)[40]. Important trees in this district are Acacia nilotica (Kikar), Azadirachta indica (Neem), Balanites roxburghill (Hingota), Capparis apphylla (ker), Dalbergia Sissoo (shisham), Prosopis Spicigera (khejra), Salvadora Oleoides (Jal-Pilu), Salvadora persica (Jal-Khara), Tecomela Undulata (Rohira) and Ziziphus Mauritiana (Ber). Important grasses in this area are Cenchrus catharticus (Bhurat), Lasiurus seindicus (sewan), Cymbopogon jwarancusa (Bura), Aristida mutica (Lampra), Saccharum Griffithii (kucha), Panicum turgidum (Murat).

In District *Jhunjhunu*, the vegetation cover is well distributed as compare to district *Churu*. The reason behind such variation is due to rainfall, which decreases from east to west. The forest cover in District Jhunjhunu is 3.29 per cent (2011)[41]. Important trees in districts are 'Jant' or Khetri (prosaic specigera), which is found in abundance and utilised for animals folder, checking soil erosion and cooking fuel for domestic purpose. Other species are Neem, Akara, Babul, Shisham, Pepal, Ber, Hingotia, Karli, Mango trees etc.

1.11 Organisation of Study

The present study has been envisaged with an aim of mapping the Aeolian landforms and processes. It also tries to analyse its impact on land utilisation practice. In the present study District Churu and Jhunjhunu of Rajasthan have been considered as study region, and further sample areas from within the study region have been carved out for micro level study. This study is a sincere attempt to explore the factors affecting Aeolian landforms and provide a detailed explanation which has been distributed into six chapters. The outline of the main chapters is as follows:

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[40] State forest report (2011), Forest Survey of India, Ministry of Environment & Forests, Government of India

[41] Ibid.

***Chapter 1*: Introduction** - The study begins with an introductory note stating the background, statement of problem, explaining the significance of the topic as to why it requires a detailed analysis. Later on, the role of remote sensing and GIS as also highlighted, and its utility in Aeolian studies also described. The objectives and research questions which are to be addressed have been outlined, followed by a brief description of the study region, and database on which the study has been based and the broad methodology adopted at each step of the present study.

***Chapter 2*: Literature Review** – In this chapter the theoretical framework which forms the basis of the present study has been underlined. The available literature relating to classification of sand dunes and its driving variables, Remote Sensing and GIS Application in Aeolian Landforms and Combating Strategies (Aeolian landforms related problems, "Desertification") have been reviewed which forms the inevitable backbone of the present study.

***Chapter 3*: Aeolian Landforms and Processes** – In this section begin with an Aeolian Environment in which a brief description about the Aeolian processes and landforms has been described. In the next portion Aeolian landforms and processes in India has been emphasized. In this segment Thar Desert of Rajasthan has been briefly described with sample study, which has been taken for the visualisation of micro level Aeolian features. In this chapter, Field survey observation also included with field photographs and field generated data (CartoDEM).

***Chapter 4*: Types of Aeolian landforms and its Driving variables** – In this chapter, identification of different types of sand dunes has been categorized. Afterward, different variables such as Wind, rainfall and temperatures have been analysed separately in order to see its impact on Aeolian landforms.

***Chapter 5*: Aeolian Landforms and its Impact on Land Utilization** - In this segment, the data relating to two time periods (December 1998, *Landsat 5* and 2010, *LISS III*) have been considered, through which Land use and Land cover map has been generated. In this section, through change detection method, impact on land utilisation has been monitored and an effort has been made to analyse the role of

Aeolian landforms in it. In this chapter another analysis has done for understanding the nature of terrain in different land use classes (Settlements, Agriculture area, Forest cover, and Water Bodies, Wasteland, Grassland areas). Under this portion of analysis, an elevation generated map has been developed to know the expansion of Aeolian landforms in different land use classes. Lastly, in this chapter, various combating strategy of Aeolian landforms related problems like "Desertification, Land degradation" etc. is also taken into account.

Chapter 6: **Conclusion with findings** – Finally, this study will wind up with the final outcomes with findings.

Chapter 2

Literature Review

The identification of Aeolian landforms and its processes has been subject to intensive research work. Such intensive work provides an assistance to determine the impact of physical events associated with Aeolian processes such as land degradation, desertification etc. on the social environment. Researches undertaken in Aeolian studies generally deal with a plethora of issues such as wind erosion, Aeolian Dust and Aeolian geomorphology[1].

Gary, M. et al. (1972) in ***Glossary of Geology*** defines Aeolian (Æolian) as "pertaining to the wind; especially said of rocks, soils, and deposits (such as loess, dune sand, and some volcanic tuffs) whose constituents were transported (blown) and laid down by atmospheric currents, or of landforms produced or eroded by the wind, or of sedimentary structures (such as ripple marks) made by the wind, or of geologic processes (such as erosion and deposition) accomplished by the wind".

India has a total geographical area of 328.2 million hectares with drylands covering 228.3 million hectares or 69.6% of the total land area. Within the drylands, Arid area is 50.8 million hectares or 15.8% of total geographical area, Semi-arid is 123.4 million hectares or 37.6 % of total geographical area and dry sub-humid is 54.1 million hectares or 16.5 % of total geographical area[2]. Considering, the arid region of India, Rajasthan is one of such region, which is also known as the Great Indian Desert or Thar Desert of Rajasthan. It is located in the western part of Rajasthan and cover the total area of 1, 96,150 Km^2. The districts of western zone such as Bikaner, Barmer, Jodhpur, Jaisalmer, Pali, Jalor, Sriganganagar, Churu, Nagur, Sikar and

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[1] Stout, J.E, Andrew, W and Gill, T. E (2009): Publication trends in Aeolian research: An analysis of the Bibliography of Aeolian Research, Geomorphology 105, 6–17

[2] MoEF (2011), Elucidation of the 4th National Report submitted to UNCCD Secretariat Ministry of Environment & Forests, Government of India, New Delhi, pp.294

Jhunjhunu lies in got arid[3]. This region is dominated by different Aeolian features, including the sand dunes and related landforms. Less rainfall, sparsely distributed vegetation and swift wind speed promotes Aeolian processes in this region. Current study region lie in between the district of Churu and Jhunjhunu of Rajasthan.

A brief survey of literature reveals that numerous studies have been undertaken to identify and map Aeolian landforms and its related processes. Some of these studies are remotely sensed observations from aerial and space platforms. Majority of them relates to agricultural and sand control purposes[4]. While the other works deal with the control of desertification processes, stabilising shifting sand dunes, restoring degraded forests through Afforestation, maintain the ground water reservoirs, improvements in bio-resources and farming system.

2.1 Classification of Sand Dunes & its driving variables

So as to identify and mapped the Aeolian landforms several studies has been made to classify dunes on the basis of shape, form, orientation of slip-faces comparative to the prevailing wind, sand shift direction, and degree of mobility (**Breed & Grow: 1979[5], McKee: 1979[6], Pye & Tsoar: 2009[7], & Mabbutt: 1977[8]**). In this regard a very suitable classification has been done by **McKee (1979)** on the basis of two descriptive attributes, firstly on the basis of shape or form of the sand body and secondly on the basis of position and number of slipfaces. On that basis sand dunes were classify into three classes such as, basic or simple, compound and complex

[3] Krishnan, A., (1968), Delineation of Different Climatic Zones in Rajasthan and their variability, Indian Journal of Geography 3, pp. 33-40

[4] Breed, C. S. Fryberger, S.G. Andrews, S. McCauley F.L. Gebel, D. and Horstman, K. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), *A study of global sand seas*, Professional Paper US Geological Survey No. 1052, pp.377

[5] Ibid. pp. 309-397

[6] McKee, E. D. (1979), Introduction to a study of global sand seas. In E. D. McKee (Ed.), *A study of global sand seas*, Professional Paper US Geological Survey No. 1052, pp. 3-17

[7] Pye and Tsoar (2009), Aeolian Sands and Sands Dunes, Springer pp. 185-248

[8] Mabbutt, J.A (1977), *Desert Landforms: An Introduction to Systematic Geomorphology*, Cambridge, MIT Press/Canberra, ANU Press

dunes or *'Mega Dunes'.* In simple dunes structure an inter-sandunal space distinguished various units of individual dunes forms. Compound dunes comprise the conjoined of two or more same types of dunes into one structure. The complex dune comprises the merged of two or more simple types of dunes into one unit. **Lancaster, N. (2009)**[9] has mentioned about the Aeolian dunes self-organisation pattern, which depends upon the wind regime and the supply of sands. He stated that the sand dunes occur in four main morphologic types, crescentic, linear, star and parabolic dunes. In his work he relate the dunes types with wind regimes and specify the direction of wind is the main controlling factor of dune type.vtc The further effort has been noticed in the work of **Pye & Tsoar (2009)**[10], where he divided simple dunes into three basic groups, such as those whose development is related to topographic obstacles, those which can be regarded as self-accumulated (autogenic dunes), and those whose development is strongly influenced by vegetation (phytogenic dunes).

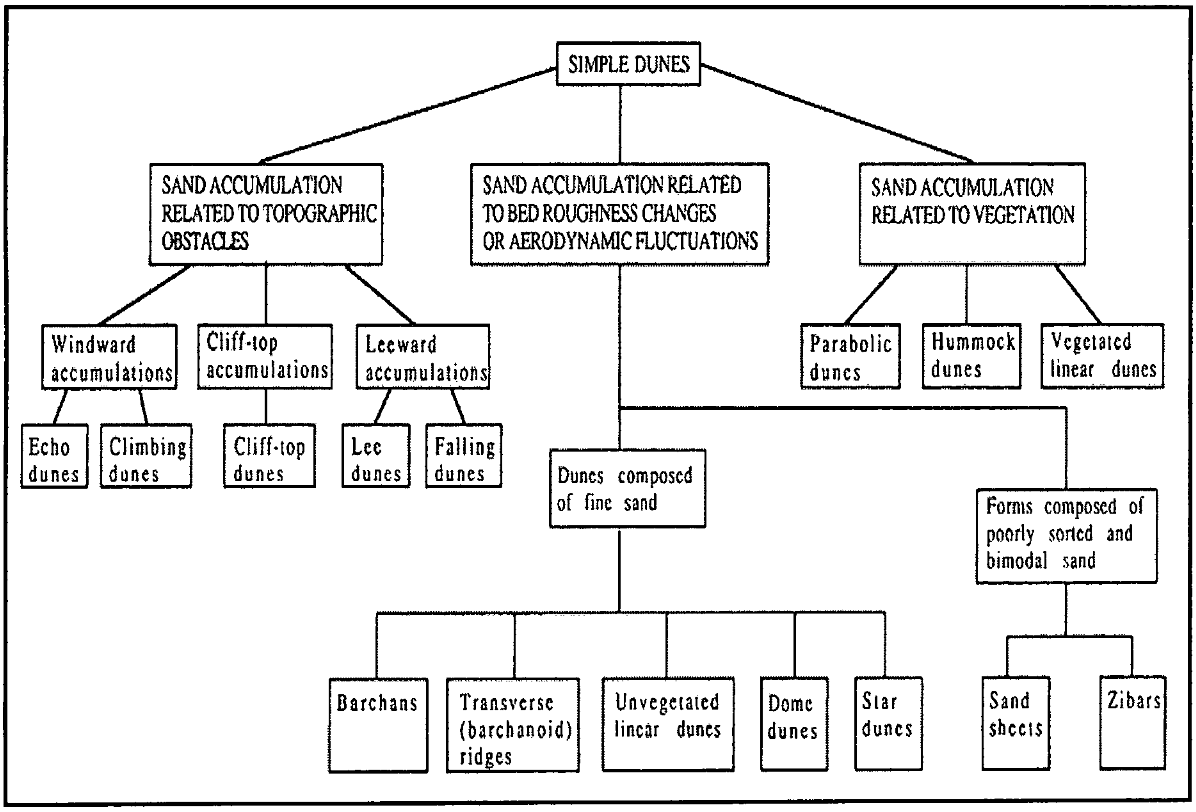

Fig.2.1: Classification of major sand dunes adopted from Pye & Tsoar (2009)

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9 Lancaster, N. (2009), Aeolian features and processes, in Young, R., and Norby, L., Geological Monitoring: Boulder, Colorado, Geological Society of America, p.3

10 *Ibid.*

Numerous Studies are done in order to identify and map the status of Aeolian landforms. Some of these studies have been used remote sensing techniques in order to quantify the change in the Aeolian features. In 1972, National Aeronautics and Space Administration (NASA) has lunched the Earth Resources Technology Satellite (ERTS-1) now known as Landsat 1 used for study of dune morphology and sand sheets in eight desert regions on earth. **Breed and Grow (1979)**[11] mapped Sand dunes using the ERTS-1 satellite imagery based on the external shapes and slip face orientations. **Warren, A. and Allison, D. (1998)**[12], who has used Landsat MSS image in order to relate the scales of climatic stability and scales of dune size. While they have used the directional maxima of reflectance analysis for measure the dunes spacing. Later on such dataset bring the new scopes in the Aeolian research. Various analyses have been done with the help of these datasets. **Walker (1986)**[13] categorize dunes according to their shapes and the relative positions of their slip faces, and classified them as linear, crescentic, dome, star, or parabolic dunes and used it as global applicable purpose.

Singh et al (1972)[14] has categorised the Aeolian sand dunes of Rajasthan. The categorisation was based on the field observation, relative age and stabilisation. There are three categories

1. Old dissected dunes of intermediate types and sand shields

2. Stabilised parabolic, longitudinal and transverse dunes

3. Active small-scale barchan, scrub-coppice and low-longitudinal ridges dunes.

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[11] *Ibid.*

[12] Warren, A. and Allison, D. (1998), "The palaeoenvironmental significance of dune-size hierarchies" Paleogeography, Palaeoclimatology, Palaeoecology, 137 (3-4), pp.289-303

[13] Walker (1986), "Chapter 8: Eolian landforms" in Nicholas M. Short, Sr. and Robert W. Blair, Jr. (ed.) Geomorphology from Space (NASA publication), pp.14

[14] Singh S., Ghose B, Vats P.C (1972), Genesis, Orientation and distribution of sand dunes in arid and semi-arid regions of India, Central Arid Zone Research Institute (CAZRI), Jodhpur, Annual Report, pp.: 50-53

Landforms and landscape geomorphology are a direct response to environmental boundary conditions and form important and characteristic of recent or past climatic conditions[15]. As same Aeolian land forms are driven by some environmental variables which are the results of current landforms. The Environmental variables (wind, rainfall, temperature) are constantly shaping Aeolian landforms, which lead them to such a complex landforms structure. **Fryberger and Gary (1979)**[16] used sand dune maps and compared them with meteorological data such as wind regime. Combining these dataset and relate the relationship between the wind regime and dunes types. Further, **Wilson (1973)**[17] **and Fryberger and Gary (1979)**[18] describe about the impact of regional topography on wind regime. These impacts on wind regime seem as directional variability and airflow acceleration. **Mainguet & Callot (1978)**[19] also mention the important role of regional topography in demarcating the boundaries of sand seas. Aeolian landforms are shaped by its processes which include erosion, transportation, and deposition of sediment by the wind. These processes vary in diverse environments such as coastal, hot and cold deserts and agricultural fields **Lancaster (2009)**[20]. "In arid regions, fluvial processes function much less frequently and more episodically than the Aeolian processes, but their impacts on landforms and society are large, as noticed on several occasions in the Thar Desert, especially after the high-intensity rainfall events for short period of time during the summer monsoon"[21] .

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[15] J. B¨udel (1984), Climatic Geomorphology, Princeton University Press, Princeton.

[16] Fryberger, S.G. and Gary, D. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052. Pp. 137-166

[17] Wilson, I. G (1973), Ergs, Sedimentary Geology, 10(2), pp. 77-106

[18] *Ibid.*

[19] Mainguet M. (1984), A Classification of Dunes based on Aeolian dynamics and the sand budget. In Deserts and Arid lands (ed.) by El-Baz, The hague Martinus Njjhoff Publishers, pp. 31-58

[20] Lancaster, N. (2009), *Op. Cit.*,pp. 1

[21] Moharana P.C and Kar A (2010), Quantitative Measurement of Arid Fluvial Processes: Results from an Upland Catchment in Thar Desert, Journal Geological Society of India, Vol. 76, pp. 86-92.

2.2 Remote Sensing and GIS Application in Aeolian Landforms

Remote Sensing techniques and its uses bring the new dimensions in the applied research. The use of this application helps many research fields. The application of remote sensing and GIS (Geographical Information System) not only investigating the trends and evaluating the changes, but it also helps in the management decision making process. After Landsat series various satellite images provide a broad view of a large area, which helps in the identification of many geomorphic features such as Aeolian landforms and its related processes. Through this technologies various thematic maps has been generated to show the changing pattern, current morphology etc. Following are some techniques and tools which are very useful for the research purposes. Recent remote sensing satellites from ISRO i.e IRS-P6, Cartosat-1 and Cartosat-2 offers an opportunity to harness its potential for identification and analysis of Aeolian features.

2.2.1 Land use and land cover

The initiation of satellite imagery during 1970's and 80's not only offer assistance in various fields but it also introduce different kinds of remote sensing techniques. These techniques have been developed further and have proved to be of immense valuable. These Techniques includes the accurate land use land cover maps and monitoring changes at regular intervals of time. Land use land cover technique is not only cost and time effective but it also provides information of inaccessible region with the help of satellite data. Previous methods of land use land cover mapping was very customary, labor intensive, time consuming and are done in an infrequent manner. Such maps are also difficult to update and hence they will soon become out-dated with the passage of time. Monitoring the change with passage of time has quite difficult to monitor in the conventional method of surveying[22]. The Land use and

[22] Olorunfemi J.F (1983), "Monitoring Urban Land – Use in Developed Countries -An aerial photographic approach", *Environmental Int.*9, pp. 27 – 32

Land cover application in remote sensing are efficiently implement and used by **Anderson (1971)[23].**

From the time when the first remote sensing satellite (Landsat-1) launched in 1972, than onwards land use land cover studies were carried out. In India National Remote Sensing Agency (NRSA) used the Landsat multi Spectral Scanner data of 1980-82 for waste land mapping of India. Mapping shows that around 16.2 per cent of waste land in India was projected. Similarly, In India Central Arid Zone Research Institute (CAZRI), Jodhpur has done various assessments on Land use mapping. These mapping offer very useful information regarding the intensification of agriculture which caused tremendous reduction in natural biomass. Such reduction of biomass leads to further spurt of wind erosion/ deposition hazard. These studies suggest for sustainable organisation of lands which will further management of sand dunes movements. The study of District Churu, based on spatio-temporal mapping of land use was carried out by CAZRI, they have developed the variety of maps which includes wasteland mapping **CAZRI (1998)** [24] and land use and land Cover mapping **CAZRI (1990)**[25]. In the present study region extensive research has been conducted on the mapping of desertification or on land use land cover. **Ajai et al.: (2009)**[26], **UNEP: (1992), NBSS&LUP: (2001), MoEF: (2001, 2011).** The other noticeable work regarding land use and land cover and its applicative work have been done by **NRSA (1995)**[27], **Balak Ram and Chauhan, J.S. (1997)**[28], **Balak Ram and Gheesa Lal (1998)**[29], **Balak Ram et al. (2003)**[30]

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[23] Anderson, J. R. (1971), Land use classification schemes used in selected recent geographic applications of remote sensing. PE and RS, 37(4): 379-387.

[24] CAZRI, (1988), Short note on Wasteland Maps, Churu district, Rajasthan, CAZRI, Jodhpur, p.18

[25] CAZRI, (1990), Report on Land use/land cover, Churu district, Rajasthan, CAZRI, Jodhpur, p.26

[26] Ajai, A. S. Arya, P. S. Dhinwa, S. K. Pathan and K. Ganesh Raj (2009), "Desertification/land degradation status mapping of India", *Current Science,* Vol. 97, No. 10

[27] NRSA (1995), Report on Area Statistics of Land use/Land cover Generated using Remote Sensing Techniques, Hyderabad, pp.71

[28] Balak Ram and Gheesa Lal, (1997), Landuse and agriculture in Indian arid ecosystem, *In Desertification Control in the Arid Ecosystem of India for Sustainable Development* (Eds.) Surendra Singh and Amal Kar, Agro Botanical Publishers (India), Bikaner, pp. 80-92

[29] Balak Ram and Gheesa Lal, (1998), Land use. In Fifty Years of Arid Zone Research in India (Eds.) A.S. Faroda and Manjit Singh, CAZRI, Jodhpur, pp.127-139

2.2.2 Digital Elevation Model (DEM)

After 1980s new dataset become available that includes higher resolution satellite imagery, digital elevation data which provide further scope for quantifying the sand dunes morphology. There are different types of Digital Elevation Model (DEM) which vary from resolution to type of sensor it use. Such DEM includes *Shuttle Radar Topography Mission (SRTM)*, which was launched in February, 2000 by National Aeronautical space Administration (NASA) in an international effort to get the digital elevation models in order to map all terrestrial topography between 60-N and 56-S. This would later provide a near global Digital Elevation Model (DEM) of the land masses with an absolute accuracy of at least +/-16 m and a posting every 30 m[31]. SRTM resolution is 90 m global while it has 30 m resolution over USA. Another, elevation model is *Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER)* lunched in December 1999. It is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI), and Japan Space Systems (J-spacesystems). The resolution of images ranges between 15 to 90 meters. The application of such data set is used in different geomorphological analysis which includes Aeolian landforms. The signature of the dune types in SAR amplitude data as a function of polarization and wavelength and the applicability of SRTM (Shuttle Radar Topography Mission) dataset in order to study the large compound or complex desert dunes mostly, longitudinal and barchans dunes[32]. The analytical opportunities offer by ASTER GDEM (Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) to the spatial study of global sand dunes

[30] Balak Ram, Gheesa Lal, Chauhan, J.S. and Malakar, A.R. (2003), Cartographic appraisal of land use for sustainable development in Churu district, Rajasthan, using remote sensing and GIS, Indian Cartographer 23, pp. 16-25.

[31] Warren. A. and Allison, D. (1998), "The palaeoenvironmental significance of dune-size hierarchies, Paleogeography, Palaeoclimatology", *Palaeoecology*, 137 (3-4), pp.289-303

[32] Blumberg D. G (2006), "Analysis of large Aeolian (wind-blown) bed forms using the Shuttle Radar Topography Mission (SRTM) digital elevation data", *Remote Sensing of Environment* 100, pp. 179

is also applicable in this regards[33]. There is variety of DEM generation methods which includes interpolation of topographical maps, stereo-matching from satellite image or from aerial photographs, by airborne laser scanning, or with the interferometric synthetic aperture radar (InSAR).

Due to the complexities in sand dunes, the studies of dunes fields demand the use of high accuracy data. Meanwhile, the quantification of Horizontal dimensions of landforms (coastal dunes) can be measured from the satellite imagery, but quantifying vertical dimensions is difficult[34]. Various technologies have offer the new aspects to study the sand dunes systems, this includes Differential Global Positioning System ***(D-GPS)*** which provides sufficient accuracy to monitor dune fields for X, Y and Z. Thus, use of D-GPS provides GCPs with the less error and better Z value, which will help to generate DEM from high resolution stereo imagery such as Cartosat-1 with two improved fore and aft PAN cameras with better than 2.5m spatial resolution. In order to generated accuracy of DEM from such imagery depends upon some factors which includes, number of input GCPs (Ground control Points), spatial resolution of output DEM. It also requires the use of geometric model (rigorous physical sensor model). The high resolution Cartosat-1 images are being released to users with only RF (rational function) coefficient. The RPC model was computed for each image and supplied in a text format with the Cartosat-1 datasets. *CartoDEM* can be generated with the use of tie point only or it can be improvement by extracted DEMs quality by applying horizontal shift on reference DEMs from the available Global DEMs or other source DEMs[35]. In order to acquire vertical accuracy in DEM, the RMS error is reduced to within pixel with the Ground control points (collected through DGPS) and

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[33] Hugenholtz, C. H. And Barchyn, T. E. (2010), "Spatial analysis of sand dunes with a new global topographic dataset: new approaches and opportunities," *Earth Surface Processes and Landforms*, vol. 35, no. 8, pp. 986-992

[34] Andrews B.D., Gares P.A. and Colby J.D., (2002), "Techniques for GIS modeling of coastal dunes", *Geomorphology*, no 48, pp. 289-308

[35] B. Gopala Krishna, Amitabh, Srinivasan, T P, Srivastava, P K (2008), Dem Generation from High Resolution Multi-View Data Product, the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1, Beijing, pp. 1099-1102

tie points. Results area further enhanced after image matching and Orthorectification[36].

2.2.3 3D Visualisation

Three dimensional models or 3D Visualisation is another aspect of remote sensing application which is very useful in terms of real world experience. The three dimensional modelling are basically a digital computer models which can be used in landscape design and planning and other disciplines for visualization of proposals, evaluation of alternatives, and stimulation of impacts[37] . This model is a combination between geotechnical and GIS[38]. "The three dimensions or 3-D stereo intersection is executed using the previously computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to 3-D data. Cartographic coordinates (planimetry and height) in the user-defined map projection system are determined for the measured point with a least square intersection process based on the geometric model equations and parameters[39]. The result is an irregular grid in the map projection system, which is transformed to a raw regular DEM"[40].

Two Dimensional or 2D Maps does not provide a clear picture of change, such maps only provide information of spatial location in the form of 'X' and 'Y' axis or latitude and longitude basis. Thus, there is a need to use Information technology (IT) as a tool to construct three dimension or 3D view for visualising the landscape in a three dimension space (X, Y and Z axes). Overview the data in three dimensions gives new standpoints. 3D viewing can provide visions that would not be easily

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[36] Tiwari P.S, Pande H, Punia M, and Dadhwal V.K (2008), Cartosat-1: Evaluating Mapping Capabilities, International Journal of Geoinformatics, March, Vol.4, No.1.

[37] Punia M & Pandey D (2006), 3D Landscape Modelling using Java 3D/YRML, Joumal of the Indian Society of Remote Sensing, Vol. 34, No. 4, pp. 397-402

[38] Ahmad F, Hamir R, Mohd S, Yahaya S, (2002), " Slope stability analysis using GIS technique", (viewed on 28/10/2011) (http://www.kiso.co.jp/html/jgs/pdfs/pdf_files/202)

[39] Toutin T (1995), "Generating DEM from stereo-images with a photogrammetric approach: Examples with VIR and SAR data," EARSeL Advances in Remote Sensing, vol. 4, no. 2, pp. 110–117.

[40] Toutin T (2002), "Three-Dimensional Topographic Mapping With ASTER Stereo Data in Rugged Topography", IEEE Transactions on Geoscience and Remote Sensing, Vol. 40, no. 10.

noticeable from a two dimension map of the same data. **Punia M & Pandey D (2006)**[41] used SRTM 3 data of Alwar district of Rajasthan in order to generate landscape model, which later underlines the importance 3D landscape for visualizing future design implications, land use change and visual exploration.

The technological advancement has led to a broader range of diverse cartographic products that can be made faster and less expensive, and the interaction with visual displays in nearly real-time. This has moved the importance from static to dynamic map use **(Taylor, 1994)**[42].

2.3 Combating Strategies

The impact of Aeolian processes on landforms as well as on the populace and social front is quite evident in the world. In all over the world people living in arid and semi-arid region face some common problems. This includes wind erosion, lack of water, land degradation and most important is "Desertification". The cause of desertification is either due to the anthropogenic factors or due to climate. Both factors are concurrently affecting desertification in different part of the world. The menace regarding expansion of sand dunes has been subject of various studies, such studies including the multi-temporal analysis. Multi-temporal analyses include land use land cover changes which provide appropriate information regarding the change in the morphology and distribution pattern.

An international effort for combating desertification is done in 17th June 1994 by the united nation resolution known as *United Nations Convention to Combat Desertification* **(UNCCD)**. It came into forced on 26th December 1996, where 193 countries are become the part of convention. This convention was drafted in response to the request made by the UN Conference on *Environment and Development* in Rio de Janeiro, 1992. A main operational body of the UNCCD is the *National Action Programmes* **(NAP)**. The NAP uses a participatory approach, through which local communities also involve in order to create useful steps and measures to be taken to

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[41] Ibid. pp.400

[42] Taylor, D. R. F. (1994), Cartographic visualization and spatial data handling. In: Advances in GIS Research, eds. T.C. Waugh and R.G. Healey, London: Taylor and Francis, Vol.1, pp. 16 - 28.

combat desertification. Various countries like Africa, Mongolia, China and India are working on the combating strategies for desertification and the sustainability of livelihood in such arid and semi-arid regions. Such effort is done by African countries, through their joint venture to form a 12,000 sq.km "*great green wall*" extending from Senegal to Djibouti with the participation of local communities. In this regards people's participation is vital for reclaiming lands from desertification. While, china is speeding up, its massive tree-planting project (*great green wall*) to combat climate change and desertification[43]. In India, programme for combating strategies includes in two levels. The first one has done through *Social Sector & Community Development Programmes* in which (Social Sector Programmes, Local Community Development Programme, Income Generating Schemes for Poverty Eradication, Credit Assistance for Rural and Agro-Based Activities and Capacity Building and Strengthening the Roles of Various Stakeholders in the Degraded Regions of the Country have been included), second one has focused on the Conservation of Land Resources and Eco-restoration of Degraded Lands. Under this Monitoring mechanism of desertification also included **MoEF (2001)**[44].

For the planning for the reclamation of the desert and semi-desert regions, there is a need for the proper study of meteorological elements which provide the trend and patterns of rainfall, evaporation and humidity for understanding the climatic variability in the region[45]. The continuous expansion of desertification and related problems has effect the locals in a large scale. The changes in the vegetal cover in the form of natural forest and grazing land has been noticeably signifying the increasing rate of soil erosion causing exposure of bedrocks on the hill margins of the Indian desert. Desertification and salinization of soil are also significant outcomes affecting

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[43] Basheer K.P.M (2012), "Desertification is nearly as critical as climate change", The Hindu, Vol.135, No.145, dated 18th June, 2012, pp.13

[44] National action programme to combat desertification, in the context of United Nations Convention to Combat Desertification (UNCCD): volume I, status of desertification, Ministry of Environment and Forests, Government of India, pp.62-136

[45] Pramanik, S.K (1952), Hydrology of the Rajasthan Desert- Rainfall, Humidity, and Evaporation, proceedings of the symposium on '*The Rajputana Desert*', National Institute of Sciences of India, New Delhi, pp.182-197

the society **Dhabriya (1988)**[46]. The major factor behind the sand dune mobilisation is the Wind erosion, which lead to the further degradation of soil in the Thar Desert. To tackle this menace in western Rajasthan, various efforts has been taken in order to stabilise the sand dunes mobilisation process. Since, 1950s Central Arid Zone Research Institute (CAZRI) has been working for the solution of sand dunes stabilisation. CAZRI has developed various technologies such as shelterbelt plantation, management of crop, pasture & range land areas, sand dunes stabilisation, enhanced agro-forestry systems and so on. To control the wind erosion, chemical and Machine-driven techniques are not economical reasonable in Rajasthan since farmers from this area are largely poor. Taking all aspects into care CAZRI has developed vegetative methods for sand dune stabilization and Shelterbelt plantation **(Kaul, 1985)**[47].

Another important strategy for combatting desertification is to make a continuous monitoring of desertification. Remote sensing technology has so far proven the one of the most capable method to monitor desertification. United nation convention to combat Desertification (UNCCD) Thematic Programme Network 1 (TPN-1) plan on 'Desertification Monitoring and Assessment', is one of the six thematic programme areas identified as part of Asian regional action programme. The chief assignment under TPN-1 was to make a desertification status map at national and regional levels, which could be link to the desertification status map of the world. India has sign the UNCCD TPN-1 plan in 1994 for making a desertification status map. The desertification/ land degradation status mapping was prepared on 1: 500,000 scale for the entire country using Indian Remote Sensing Satellite (IRS)-Resource sat AWiFS data **Ajai et al. (2009)**[48].

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[46] Dhabriya, S.S (1988): "Desert spread and desertification: An analysis of the identified Aravalli gaps on the desert fringe", Environmentalist, Jaipur.

[47] Kaul, R N (1985), Afforestation of dune areas: In Sand Dune Stabilization, Shelterbelts and Afforestation in Dry Zones, FAO Conservation Guide10. FAO, Rome, pp. 75-85

[48] Ajai, A. S. Arya, P. S. Dhinwa, S. K. Pathan and K. Ganesh Raj (2009): Desertification/land degradation status mapping of India. Current Science Vol. 97, No. 10, pp. 1077 – 1081

Chapter 3

Aeolian Landforms and Processes

3.1 Aeolian Environment

The word '*Aeolian*' is driven from German word '*Aeolus*', the Greek god of the winds. Its processes define as "those which involved wind action, that is, erosion, transport, or deposition arising from movement of air over the earth's surface" **Pye and Tsoar (2009)**[1]. 'Richard John Nelson' was the first who used the word "Æolian" in 1853, he describe this word as a geological process in his paper entitled "On the geology of Bahamas, and on the coral formation generally[2]. In Aeolian Environment '*wind*' is an important geomorphic agent which is responsible for erosional and depositional landforms. Such landforms appear in a variety of environments such as cold and hot desert, coastal zone and poor land use practice. These environments are characterised by some common structures such as sparsely vegetation cover, strong winds and a supply of fine sediments particles. Hence, beaches, glacial outwash plains, deserts, dry lakes, loess plains are usually regard with the Aeolian features. The Aeolian processes in variety of environment are varying significantly. In the cold climate region or '*Cold Desert*' Aeolian processes are ineffective because of ice cover. "The frost and melting glacial ice produce large qualities of unconsolidated sediments favourable for the wind transport. It has believes that wind has secondary role that increase in the later part of the per-glacial cycle"[3]. But Aeolian processes are very active in '*Desert*' area's because such area is characterised by the minimal vegetation cover, high wind speed, high temperature, loose, friable geomaterials in the form of silt and sand, high uneven annual rainfall. Such condition Provide a base for Aeolian processes for the mobilization and formation of sand dunes and further accelerated the erosional processes through

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1 Pye and Tsoar (2009): Aeolian Sands and Sands Dunes, Springer.

2 As cited in Stout, J.E, Andrew, W and Gill, T. E (2009): Publication trends in Aeolian research: An analysis of the Bibliography of Aeolian Research, Geomorphology Vol. 105, pp. 8

3 As mentioned " Seppala M, (2004), *Wind as a Geomorphic agent in cold climate*, Cambridge University Press, Cambridge, pp.2"

loosen material, which later picked up by the blowing winds and deposits it as a depositional landforms.

Aeolian environment is found in Arid and Semi Arid regions, areas undergoing Desertification and Land Degradation, Peri-glacial and recently deglaciated areas, shorelines, river banks. Climatic variability has influenced the environments, which changed through time, and continue to do so. What once was a glacial or fluvial environment may be an Aeolian environment in the present or *vice versa.* In arid and semi-arid environment apart from Aeolian processes, Fluvial processes also act through a partial extend. In these areas occasional rainstorm become important agents of erosional and transportation. The arid and semi arid environment cover up the 40 per cent of global surface **Deichmann and Eklundh (1991)**[4]. '*United Nations Environment Programme*' **(UNEP, 1992)**[5] has categorized arid regions by the ratio of mean annual rainfall to mean annual potential evapotranspiration or Aridity Index into three classes, these includes *Semi-arid (0.2 - 0.5)*, *Arid (0.5 - 0.20)* and *Hyper Arid (< 0.05).*

[4] Deichmann, U., Eklundh, L., (1991). Global Digital Datasets for Land Degradation Studies: A GIS Approach, GRID Case Study Series 4.

[5] UNEP, (1992), "World Atlas of Desertification", Edward Arnold, London, UK

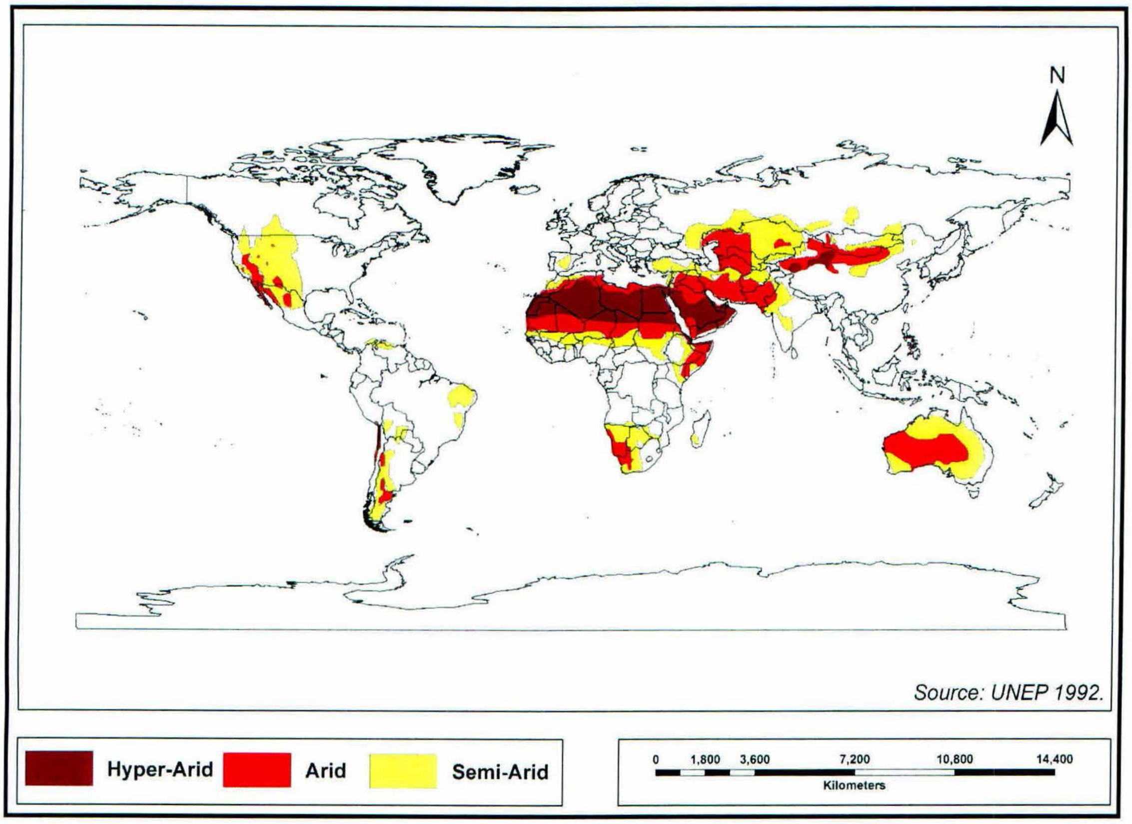

Fig. 3.1: Arid Regions of the World

Most Desert (including Arid and Semi-arid regions) occur between 10° and 35° latitude. There are variety of desert-producing factors such as descending drying air currents, rain shadows, distance from oceanic moisture sources or effect of continality, and cold ocean currents are influential, sometimes individually, more often in combination, as primary forces producing arid lands. The largest parts of the Deserts in entire world are formed by different conditions such as:

- Topographic obstacles, which hindered and locked the moisture laden winds. Hence, such region developed into a rain shadow areas. Such examples are found in Gobi Desert in Asia.

- The existence of prolonged anticyclone such examples are observed North Africa.

- In the western coast of land mass cold currents also impacting the desert like conditions. Such examples are found in Peru, Namib Desert.

The present study is focused on the arid and semi arid region of the '*Great Indian Desert*' and its depositional environment and deals with the Aeolian processes and its related landforms.

3.2 Aeolian Processes

In Aeolian Environment, Aeolian processes comprise the composite interaction between the wind and surface of the earth. It involves with three forms *Erosion, transportation* and *Deposition (Sedimentation)* of particles by the wind **Lancaster, N. (2009)[6], Pye & Tsoar (2009)[7].**

1. *Erosion* by wind involved two processes: *Abrasion* and *Deflation.* In *abrasion* surface materials are carried by the wind and expose the rock surface. In this process cutting tools are require such as mineral particles. While in *deflation* wind remove the loose materials from the ground and form a shallow depression. In such processes wind play a very crucial role in order to transport the sediments and sands particles, which further construct the erosional and depositional landforms.

2. *Transportation* process involves the movements of fine particles by the wind. Under this processes materials were transported by winds through the way of *Creep or traction, saltation* and *suspension.* In creep or traction mechanism the particles are move forward and kept in contact with ground surface. Materials in this mechanism are transported without bouncing and leaping. The material in saltation mechanism is larger size and they are transported through bouncing or rolling process. Whereas, in suspension mechanism the material are kept in air by the turbulent eddies. There is a relationship between fine materials and wind speed. The mode of transportation depends primarily upon the ratio between particle settling velocity and size of particles, wind share stress and turbulence intensity. As per **Lancaster, N. (2009)[8]** there is two types of

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[6] Lancaster, N. (2009): Aeolian features and processes, in Young, R., and Norby, L., Geological Monitoring: Boulder, Colorado, Geological Society of America, p. 1–25.

[7] *Ibid.*

[8] *Ibid.*

sediments transported by winds, the *long term suspension (< 20 microns)* and *short term suspension (20 – 70 microns)*. While, long term suspension (very mall particles) are kept upward by the turbulent eddies wind are transported greater than 10 kms. Whereas, short term suspension (large particles) are transported from 10 to 100 meters.

3. *Deposition (Sedimentation)* in Aeolian environment is conducted by the wind. Deposition are the product of erosion and transportation, which includes sand dunes, coastal dunes, deposits of loess, dune fields and other fine grain materials through which soil formation and Aeolian landforms produced. **Pye & Tsoar (2009)**[9] in Aeolian processes has used the word '*Sedimentation*'. According to him the sedimentation processes can also be divided into those which involve individual grains and those which involve stabilization of bed forms. In individual grain deposition involves the accumulation of particles through continuous transportation of wind action. Individual grains spread widely due minuteness. Stabilisation of bedforms are generally accumulations of windblown sand, which have a level or gently undulating surface without significant development of dune topography.

Apart from Aeolian processes, Fluvial processes also very much effective in desert region. Frequent rainfall cause a flash flooding in the certain semi-arid and arid region enhance the erosion work of Aeolian landforms, thus the interaction of Aeolian-fluvial also responsible for shaping landforms. **Kar A. et al (2001)**[10] has mentioned such geomorphological processes in the lower reaches of the River Luni (Thar Desert), which is largely climate driven. These processes represent the depositional environment where '*fluvially reworked Aeolian*' evidences has observed. **Moharana and Kar (2010)**[11] used quantitative study on fluvial processes

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[9] *Ibid.*

[10] Kar A., Singhvi A.K, Rajaguru S.N, Juyal N, Thomos J.V, Banerjee D, Dhir, R.P (2001), Reconstruction of the late Quaternary environment of the lower Luni plains, Thar Desert, India, Journal of Quaternary Science, 16 (1), pp. 61-68.

[11] Moharana P.C and Kar A (2010), Quantitative Measurement of Arid Fluvial Processes: Results from an Upland Catchment in Thar Desert, Journal Geological Society of India, Vol. 76, pp. 86.

in Thar Desert of Rajasthan. According to their observation s during two effective rainfall events in the desert, low rainfall of desert occasionally leads to the significant runoffs that can influence channel morphology and sediment movement. Thus, they have found that the spatial relationship between discharge and erosion and deposition is significantly positive.

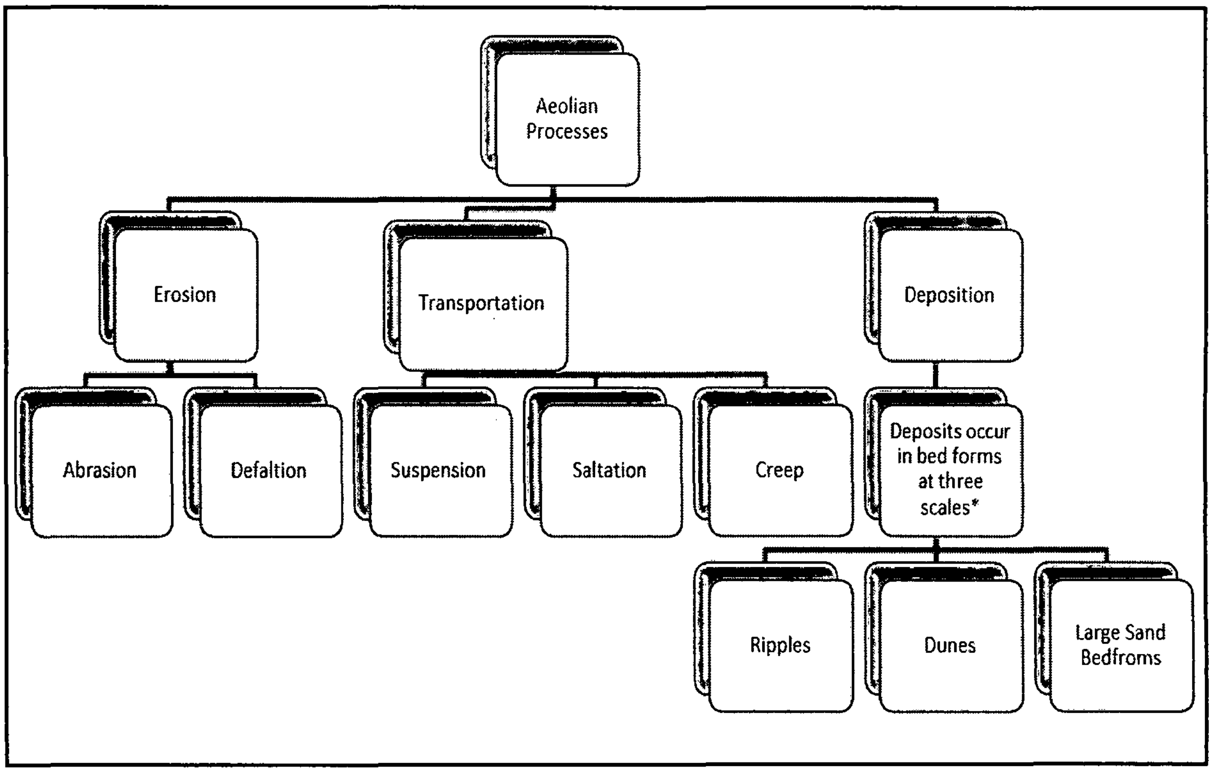

Fig. 3.2: Aeolian Processes and Landforms

3.3 Aeolian Landforms

Deserts are such area where Aeolian activities are prominently active. Such prominent activities including erosion, transportation and deposition are responsible for the construction of various landforms in Desert region. Aeolian landforms are the products of wind action. Through wind action, two types of Aeolian landforms (erosional and deposition) appear. Erosional landforms are generated by the continuous action of wind; under which velocity of wind and available erosional tools (sands, pebbles and coarser materials) are play a major role in order to determine the characteristic of landforms. The important forms of erosional

* Wilson, I. G (1973)

landforms in Aeolian environments are: Ventifacts, Yardangs, Blowout or deflation hollow, Lag deposits or Desert pavement.

- ***Ventifacts:*** "Ventifacts are aerodynamically shaped rocks up to meters in size that have been cut, and sometimes polished, by the abrasive action of wind" **Walker (1986)**[12]. Such erosional landforms are created due to the abrasion by suspended grain and pebble on the rock surface. The abrade rock becomes grooved and pitted by the abrasive action of wind, which causes facets towards the windward side. Such facets rocks, pebbles and cobbles are generally consider called *Ventifacts*. A pebble having one sharp edge forming the intersection between the two facets known in Germany as an "*Einkanter*", one with two edges, a "*Zweikanter*", and with three edges, a "*Dreikanter*" **Glennie K.W (1970)**[13].

- ***Yardangs:*** Yardangs are the overhanging rock ridges streamlined by winds action, which is separated by the parallel grooves, depressions. They are formed through the dry out of the sediments which was previously as a swamp deposits under humid conditions. This dry sediment later is eroded by wind or fluvial action and such continuous process of erosion leads to the high ridges and mesas, which is separated by the narrow corridors. These corridors are further toward the base of sediments. Abrasion widens the corridors gap and cause ridge into a cones, pyramid, and whalebacks shape.

There are two forms of Yardangs, which are distinguished on the bases of size classes. These two forms are *Mega-Yardangs* and *Yardangs*. Mega-Yardangs are over 100 meters long and up to 1000 meters wide, these are found in china, Egypt and North America deserts as well. While, Yardangs are 80 meters tall and formed with the fine clay horizontally bedded, silty clays and limey gypsum-bearing sands **Huggett R.J (2011)**[14].

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[12] Walker (1986): "Eolian landforms" in Nicholas M. Short, Sr. and Robert W. Blair, Jr. (ed.) Geomorphology from Space (NASA publication)

[13] Glennie K.W (1970) Desert Sedimentary Environments, Elsevier, Amsterdam.

[14] Huggett R.J (2011), Fundamental of Geomorphology- Third Edition, Routledge publication, Oxon

- ***Blowout or deflation hollow:*** Blowout or deflation hollow is a depression which is formed by the wind erosion. Wind erosion in such landforms remove the particles from the ground and form a deep hollow or depression on the surface. Such landforms are known as deflation hollow, deflation basin or Blowout. They are mostly found in the weak and unconsolidated sediments region and areas of low depth of ground water table. Their size varies from few meters deep to few meters across. **Glennie (1970)**[15] confers in his book about the size of blowout in Libya, which is a circular 2 to 3 km in diameter and 60 to 70 meters deep.

- ***Lag Deposits:*** Majority of Aeolian deflation zones are comprise with lag depositions. In deflation landforms, the particles (sand and slits) are sorted and let down the level of ground surface. Such process leave the concentrated layer of rocks and sand, which make a thin layers of gravel and fine materials which is known as *Lag Deposits* **Huggett R.J (2011)**[16]. After, wind blow out of a sand from the surface these lag deposits resist the further wind erosion. The surface covered up by the lag deposits are known as *desert or stone pavements.*

The depositional work of Aeolian processes, sand dunes are the most significant depositional landforms because of its shifting in nature. Sand Dunes are the most common features in Aeolian environment. It is formed by the wind processes, which mounds the loose sand particles and deposit it obstructed areas. The wind energy and direction direct the progress, extend, shape and growth of a sand dunes. The overall form of a dune depends on the wind speed in the area, duration of sand-transporting winds, the direction of the winds and their variability. Dunes are classified on various bases, this includes structure, shape, morphology, orientation and slip faces etc. **McKee, E. D. (1979)**[17], **Walker (1986)**[18], **Breed and Grow**

[15] *Ibid.*

[16] Ibid.

[17] McKee, E. D. (1979): Introduction to a study of global sand seas, In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052

[18] *Ibid.*

(1979)[19] **and Pye & Tsoar (2009)**[20] are some works, who has try to simplify the intricate dynamics of sand dunes. Following classification of sand dunes are the combinations of aforementioned works, and used them to highlight the general pattern of the sand dunes in all over the world. Following are the some basic types of sand dunes: ***Barchan, parabolic, transverse, longitudinal*** and ***star shape dunes*** are some kinds of sand dunes. The details of these types of sand dunes will be discussed in the next chapter.

3.4 Aeolian Landforms and Processes in India

The activities of Aeolian landforms and processes are very prominent in the Thar Desert of India. It is one of the hot deserts in the world, which is located along the tropics spreading up to 30° North and South latitudes. According to **Dhir R.P and Singhvi A.K (2012)**[21] it is covering over 4000 sq. km in the north western part of the Indian subcontinent. It is situated in the Rajasthan state, which is extended from Pakistan in west to foothills of Aravalli ranges in the east. The vast extend of Aeolian bed forms in Thar desert is originated through the various combination of factors, which includes intensity and the period of wind, rainfall, supply of sedimentation, vegetation cover and land surface conditions. These factors are responsible for the construction and developing of landforms over the period of time. Thar Desert is dominated by Aeolian bedforms of different magnitudes, including the sand dunes. The thickness of Aeolian cover can range from 1m to 100 m **Singhvi A K and Kar A (2004)**[22].

[19] Breed, C. S. Fryberger, S.G. Andrews, S. McCauley F.L. Gebel, D. and Horstman, K. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052.

[20] Ibid.

[21] Dhir R.P and Singhvi A.K (2012), The Thar Desert and its antiquity, Current Science, Vol. 102, NO. 7, pp. 1001-1008

[22] Singhvi A K and Kar A (2004), The Aeolian sedimentation record of the Thar Desert, Proceeding of Indian Academic Science (Earth Planet Science), 113, No. 3, pp. 371-401

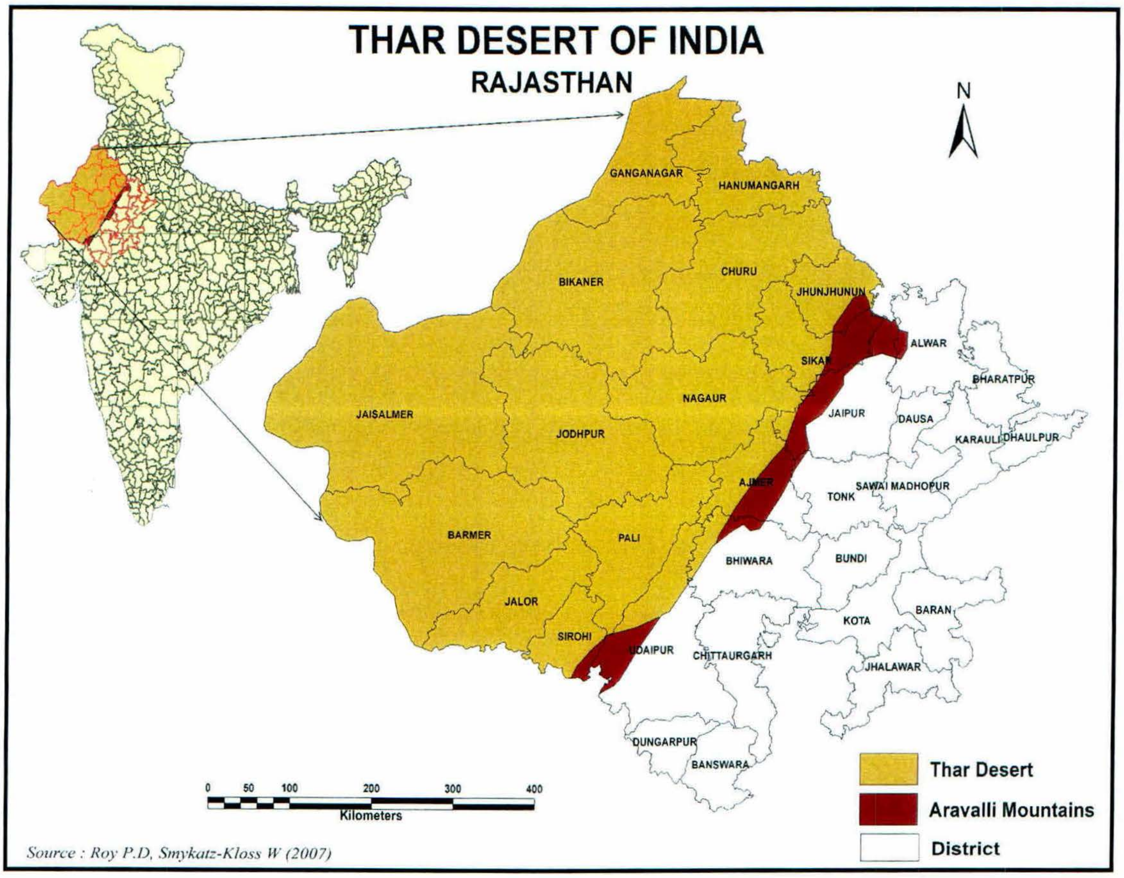

Fig. 3.3: Boundary of a Thar Desert of India[23]

The region is dominated by Aeolian bed forms of different magnitudes, including the sand dunes. According to **Singh (1981)**[24], there are two major and one minor zone of sand dunes in Rajasthan desert. These zones are unevenly distributed, which comprise with different types of dunes and its origin. These zones are:

ZONES	AREAS	REMARKS
I. Westernmost Zone Dunes	Jaisalmer, Ramgarh, Tanot, Pugal and Mahajan.	This Zones Organizes with high to very high dunes with reactivated crests & flanks.
II. Eastern Zone Dunes	Chohtan, Barmer, Pachpadra, Shergarh, west nagaur, Churu & Rajgar.	In this Zone dunes are medium to high and very high.
III. Small Dunes Zone	Sanchor, Jalor, Saila, Ddwana, Sikar and Jhunjhunu.	This zone is distributed in discontinuous patches which joins the two major zones near Rajgarh.

[23] Demarcation of Thar desert boundary drawn from 'Roy P.D, Smykatz-Kloss W (2008)'

[24] Singh S (1981), "Types and formation of sand dunes in the Rajasthan Desert" in the Sharma H.S (Ed.), Perspectives in Geomorphology - Vol.2, Concept Publishing company, New Delhi, pp.165-182

Aeolian bed form in the Thar Desert of Rajasthan is divided into arid and semi-arid environment. In western Rajasthan due to arid environment the sand dunes are completely fragile. Thus lack of vegetation, moisture made sand dunes mobile. These Aeolian processes are well active and continuous, which are responsible for the changing of sand dunes shape. While in the eastern portion of Rajasthan sand dunes are well stabilised and static. Study suggests Aeolian bed forms in this region are not clearly through Aeolian processes, but also through fluvial and lacustrine processes. In eastern Rajasthan around Aravalli Mountains major obstacle dunes are noticed which suggest that the periods of high runoff from the hills, especially as armours of sub-angular rock fragments spread over the Aeolian sand. While, the stratigraphy's of the non-crescentic high sand dunes with abundant vegetation suggest several episodes of dune building activities, separated by periods of landscape stability **Singhvi and Kar (2004)**[25]. The Thar Desert comprise with various landforms which is, sand sheet and sand dunes, inter-dunal trough, rocky and mounded hills, palaeochannels, salt lakes or playas. The rocky landscape occurs north of Jaisalmer, near Barmer, Jodhpur and Shergarh and shows pediment, tors, linear hills, cuestas, bornhardts and fault scarps, etc.

Before taking up the discussion of the Aeolian landforms and its processes in Thar Desert of India, it is vital to study the origins and the creation of the Great Indian Desert. The main reasons for the development of the Indian desert are:

- **a.** *Location of high Himalayas.* (including the ranges of Suleiman, kirthar and Tibetans Plateaus)
- **b.** *Presence of low pressures.*(mainly occurred over the India and Pakistan central part)
- **c.** *South-west Monsoon Currents*
- **d.** *Dry North-West upper air.*

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[25] Singhvi A K and Kar A (2004), The Aeolian sedimentation record of the Thar Desert, Proceeding of Indian Academic Science (Earth Planet Science), 113, No. 3, pp. 371-401

There is a huge debate regarding the origin of Thar Desert. The opinion about the age of Thar Desert varies between the various researchers. **Gupta (1975)**[26] projected the age of Thar Desert around 2,000-4,000 years old; according to him it evolved in the Pleistocene period. **Wadia (1960)**[27] mentioned the age of Thar Desert is 10,000 years old. The Thar Desert was shaped in the mid-Miocene period, later during that period the tertiary mountains covered this part from North, North West and from the West. This tertiary mountain system began the South West Monsoons. During glaciation in the Himalayas, some sequential alteration in the climate of this region appears. The vast distribution of sand in Thar Desert has also been a subject of arguments. **Wadia (1960)**[28] argued that the source through which sand dunes in Thar Desert is accumulated is from the Rann of Katch and Arabian Sea coasts. South west winds are responsible to transport sand from source area to target area. Contrary to it, **Singh (1977)**[29] argue is opposite of wadia argument, as singh mentioned in his work that the origin of sand in Thar region is indigenous. The spatial mineralogy differences propose its aboriginal argument. While, **Wasson, et al. (1983)**[30] has proposed that the sands in this region is locally originated from the current landforms by its processes.

For better understanding of Aeolian landforms and its processes, a case study of district Churu and Jhunjhunu of Rajasthan has been taken. Meanwhile, remote sensing and GIS technology also used for the analysis of the study area and identify the spatial pattern of Aeolian landforms and its pattern. Before going for analysis, field visit has been carried out in order to see the existing pattern of terrain and increase the understanding of the patterns of land cover in the study area. For

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[26] Gupta, R.K. (1975), "Origin and geomorphic evolution of the Thar Desert", In: R.K. Gupta and I. Prakash (eds) *Environmental analysis of Thar Desert.* English Book Depot, Dehra Dun. Pp. 22–37.

[27] Wadia, D. N (1960), the post-glacial desiccation of Central India. Monograph of National Institute of Sciences of India, p. 1.

[28] *Ibid.*

[29] Singh, S. (1977): Geomorphological Investigation of the Rajasthan Desert, Central Arid Research institute, Jodhpur, Monograph No. 7

[30] Wasson, R. J., Rajaguru, S. N., Misra, V. N., Agarwal, D. P., Dhir, R. P., Singhvi, A. K. and Rao, K. K. (1983), Geomorpohology, Late Quaternary stratigraphy and palaeoclimatology of Thar dune field, Annals of Geomorphology, Supplement Vol. 45, pp.117–151.

evaluation of Aeolian landforms of Churu and Jhunjhunu, few places has been visited which includes, Jhunjhunu tehsil and Churu tehsil.

3.5 Field Observations of Aeolian Landforms and Landcover

Intensive field work has been carried out to know the present situation of the Aeolian landforms and to take out the ground control points (GCPs) for the Digital Elevation Model. In the second case Z values have been generated through GCPs and visual evaluation of sand dunes have been carried out. But for better understanding about its shape pattern and landcover, field observation demanded. The following sites vital details have been used to known about the nature of terrain.

Site 1 (Niradhanu Village and its nearby areas)

The mean elevation height of Niradhanu village is 244 meters. There is a sand dune in its south west and west direction. Dune which is situated in its southwest direction is afforested and stabilised properly. As per the information which was gathered while interfacing with local people, the forest cover on dune was almost 30 years old. While the spices of the forest over sand dune was considered as an '*Acacia tortilis*'. This species has been used as a Surface vegetation technology for effective control of sand drift and sand dune stabilization. Tracking in this area distinctly experienced that the surface is very undulating in nature and it also show the evidence of Aeolian processes of erosion and deposition. Moving away from sand dunes which is mentioned in Fig. 2.4 show the agricultural practices around it.

Geographical Information System (GIS) is very suitable tool for understanding and visualising the study area. In Fig. 1, the three dimensional view provides the information of Niradhanu Village and its surrounding topography, such view provides the virtual environment of an area; which can help to understand the shape, pattern of a sand dunes in a three dimensional prospect. Fig: 2.5 illustrate the map of a Niradhanu Village and it contained the information of various layer such as village boundary, sand dunes and road. This map show the different sides of the sand dunes surveyed on the field and various numbers in it represent the location of a photographs in the field.

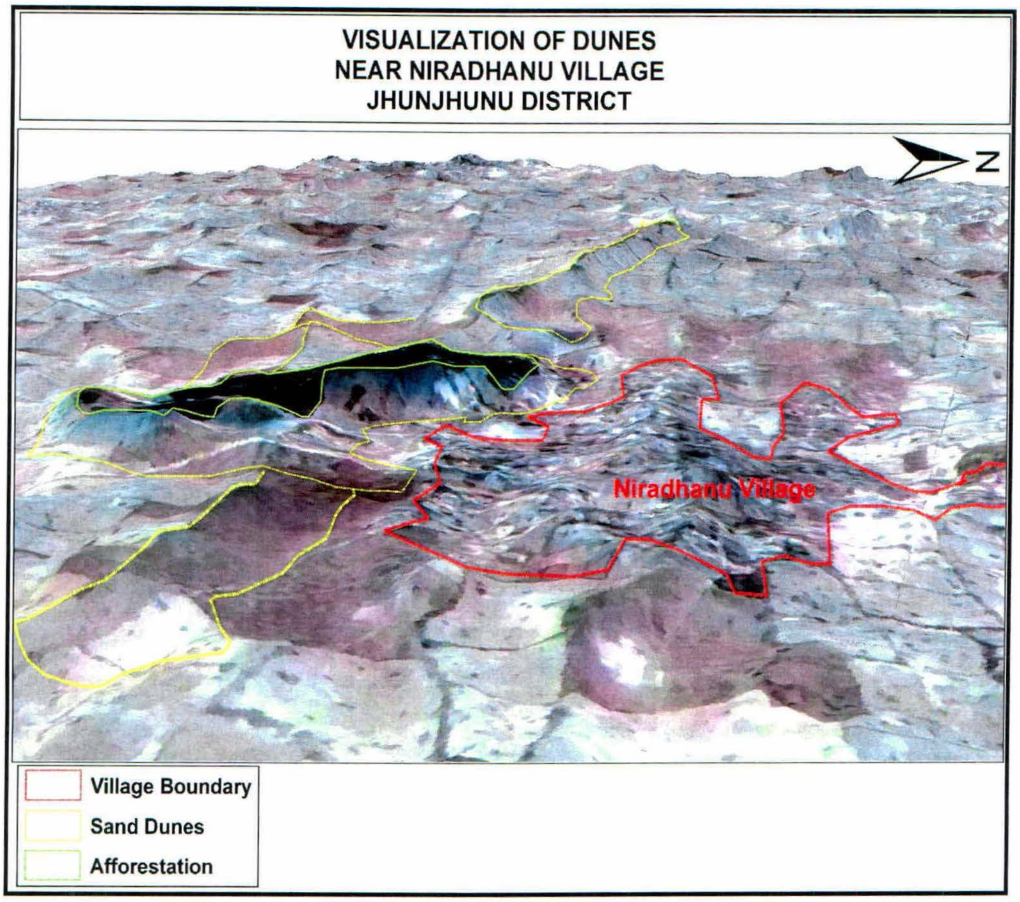

Fig. 3.4: 3D Visualisation of Sand Dunes near Niradhanu village.

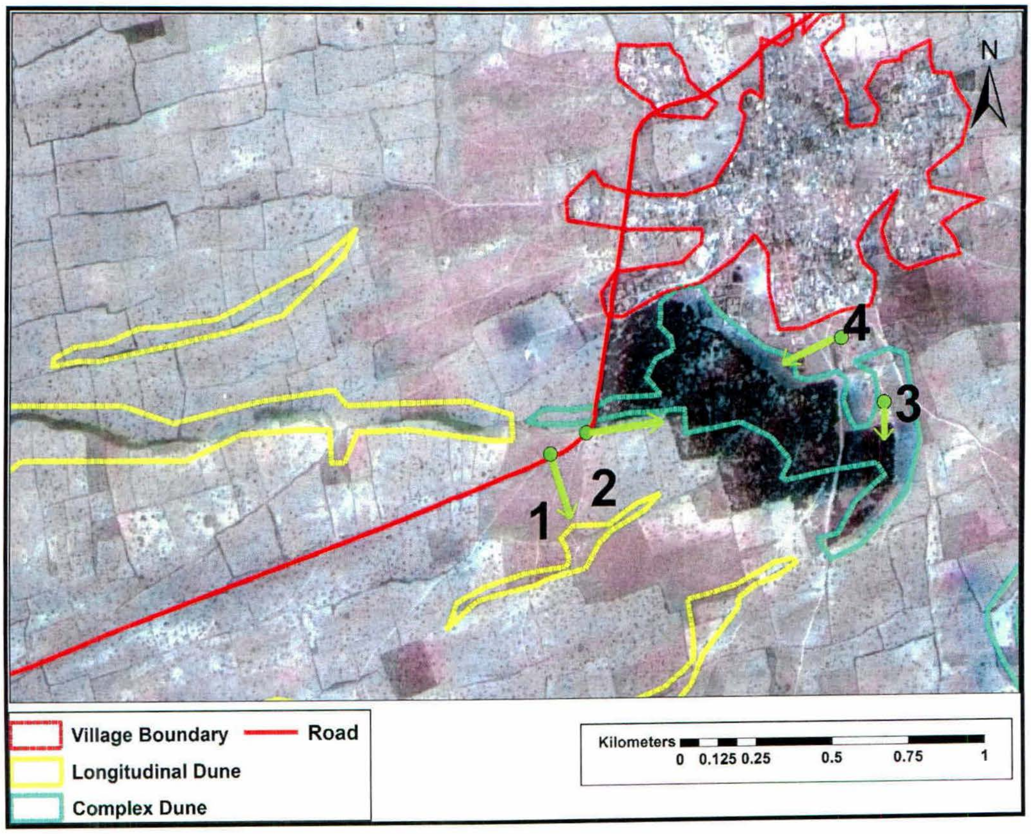

Fig. 3.5: Different sides of the sand dunes surveyed on the field near Niradhanu village in Jhunjhunu District

Fig. 3.6: Different View of Sand Dunes near Niradhanu Village, Jhunjhunu District. (1) Longitudinal Dune in the South West Side of Village (2) Complex Dune in the Southern side of Village (3) Crest of a Complex Dune (4) Slope of a Complex Dune along with Afforestation.

It has been observed that the soil is very loose near the sand dunes in Niradhanu village. The vehicle movement in unmetalled track has also responsible for such conditions. In the afforestation side the soil is very flimsy and there is a demarcation between such soil condition and the scrub land. Fig. 2.7 photographs provide some short of information regarding the soil condition in Nirdhanu village and its nearby sand dunes.

Fig. 3.7: Soil conditions in Niradhanu Village and its nearby Sand Dune

- ***Site 2*** **(<u>Afforested area near Malsisar</u>)**

The mean elevation height of this afforested area is 238 meters. This area is affected by gully erosion so; in order to tackle this menace afforestation plan has been implemented. Gully erosion in this area shows the evidence of Aeolian-fluvial interaction. This area is also covered up with scrubs and animal grazing also noticed during field observation. While on the field, this site is surrounded by the elevated slopes indicating the probability of sand dunes, later information gathered from CartoDEM data prove the existence of sand dunes. In the demarcation process of sand dune (which will be elaborated in next chapter) reveal that the Malsisar town is situated on a sand dune. It has been clearly visible and simply carves out the shape of sand dunes in GIS. This site has a lower height as compare to its surrounding which has caused this area into a depression.

In Fig. 2.8 show the three dimensional view of a location. After processing sample data of the study area, it has been observed that the depth of an afforested place is low. In this area the outskirts are elevated from its margins and it clearly represent the existence of dunes around its fringe. While towards the central part of afforested spot is relatively lower in height and gully erosion is prominent.

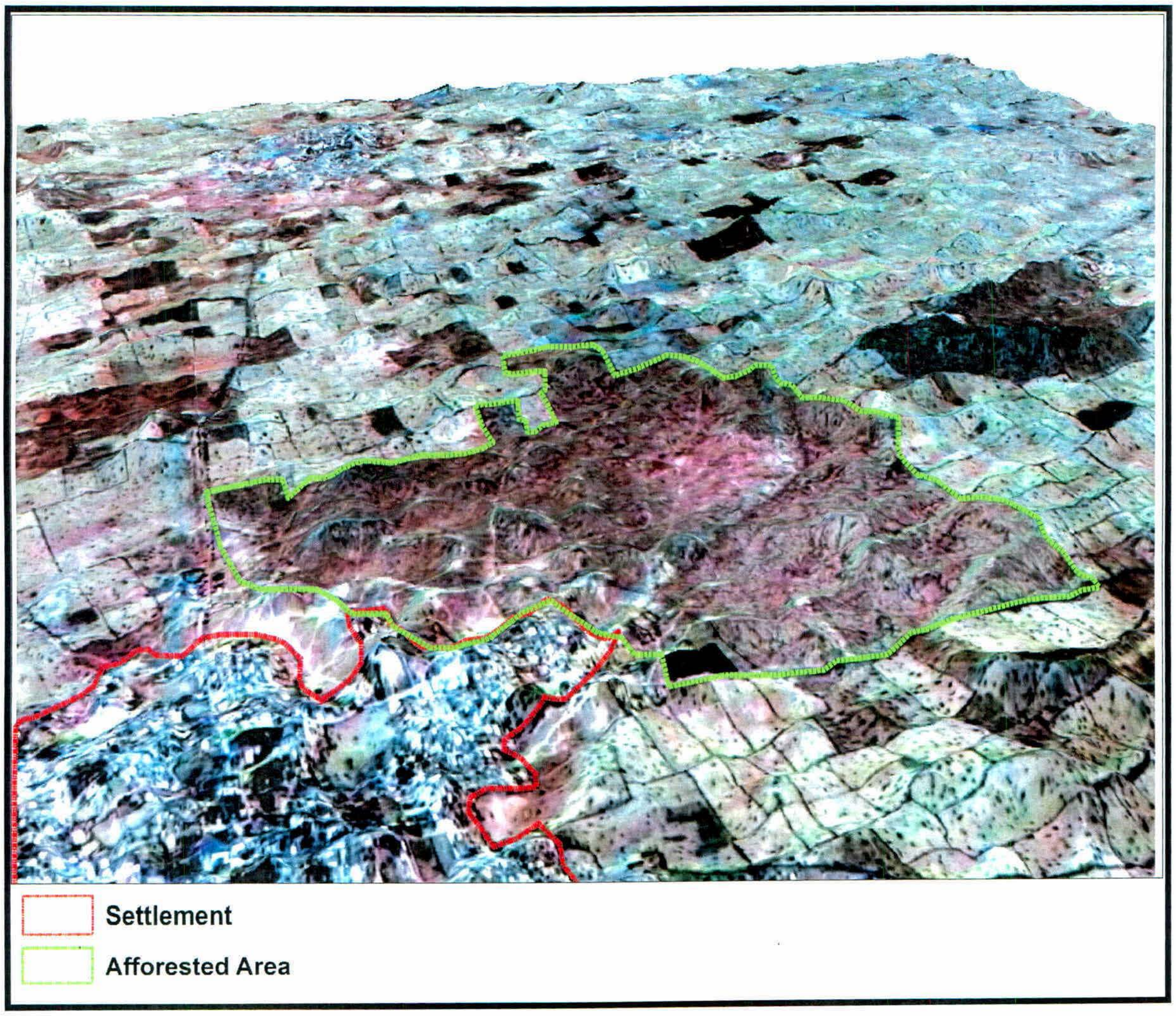

Fig. 3.8: 3D Visualisation of Afforestation site near Malsisar, Jhunjhunu District.

Following map in Fig. depict the spatial extent of the afforested site along with sand dune settlement extend. Afforested site covered up with a small and large size of dunes. Due to elevated slope along its margin gully erosion is very prominent. Numbers in it represent the location of photographs in the field.

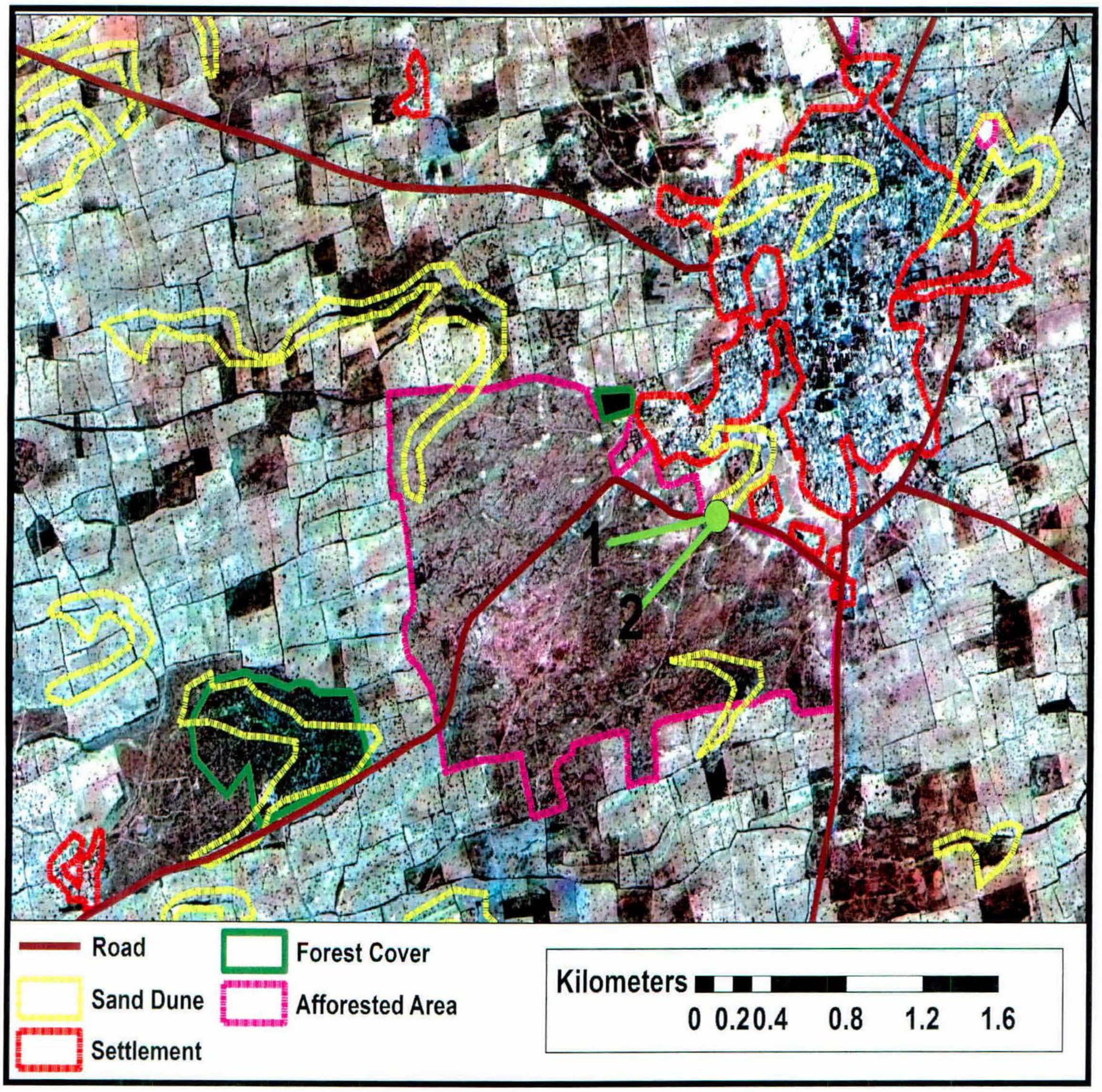

Fig. 3.9: Different sides of the Afforested Area observed on the field near Malsisar, in Jhunjhunu District

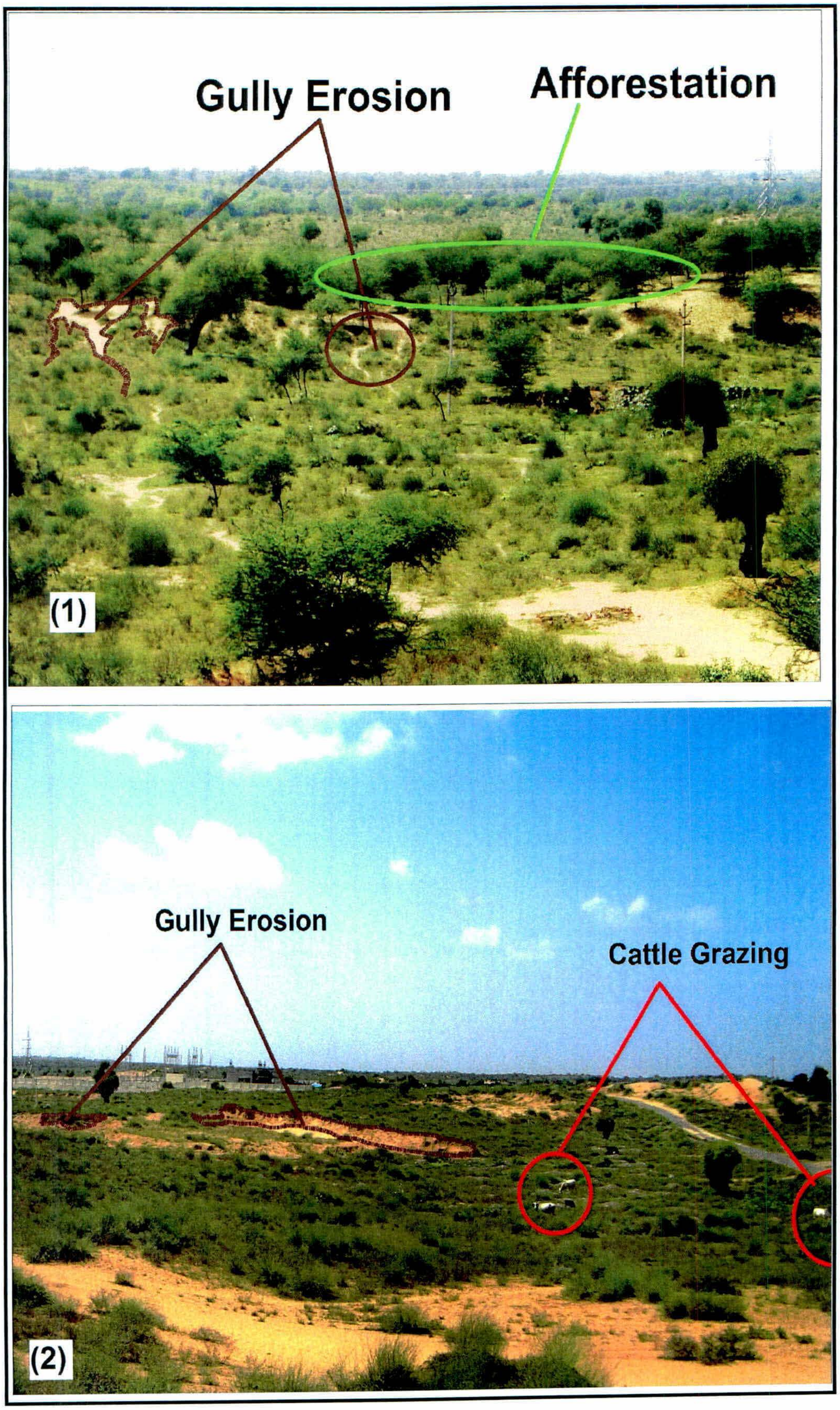

Fig. 3.10: Afforestation Site near Malsisar, Jhunjhunu District.

(1) Afforestation along Gully Erosion (2) Cattle Grazing near Gully Erosion

- *Site 3* (Sand Dune on the way to Lohsana Bada)

While on the way to Lohsana Bada for collecting GCPs through D-GPS, a prominent Dune spotted. The height of a dune is 231 meters and agriculture practices on dune also observe. Performing 3D visualisation in Arcscene illustrate that the sand dune type was in a very complex form. On the crest or top of dune, it has been found that the linear bushes were planted along the crest of a dune. These bushes are not only demarcating the agriculture fields but it also helps to stop soil erosion in such areas, this method known as '*Shelterbelt*'. On the slope and bottom of dunes few scattered trees also planted and the species of tree was considered as an 'Acacia *tortilis'*. Following are the three dimensional photographic image which show the slope in yellow line, whereas green line represent the vegetation on crest. The red line towards the right hand side in the graphic signifies the road, which is on the way to Loahsana Bada.

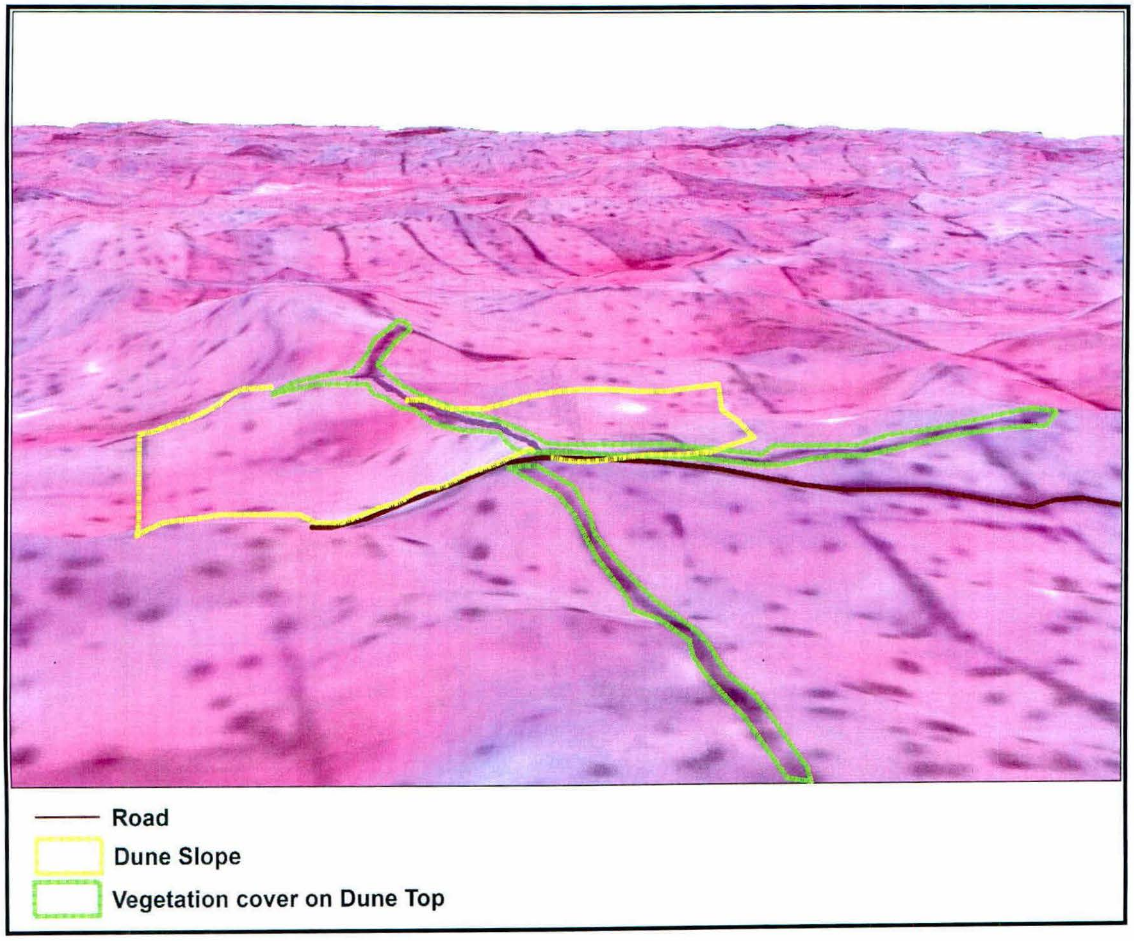

Fig. 3.11: 3D Visualisation of a Sand Dune near Lohsana Bada Village, Jhunjhunu District.

In this area the dunes are distributed in huge gap. Thus that there is an inter-sandunal spaces in the study area. On the filed it has been observed that the dunes are mostly under agricultural areas. While proper management of soil conservation practice make people to exercise agriculture on a sand dune. They had stabilised the sand dunes through various soil binding techniques, including the Shelterbelt technology.

In Fig. 2.12 the numbers in the map are showing the sites from where field photographs are taken.

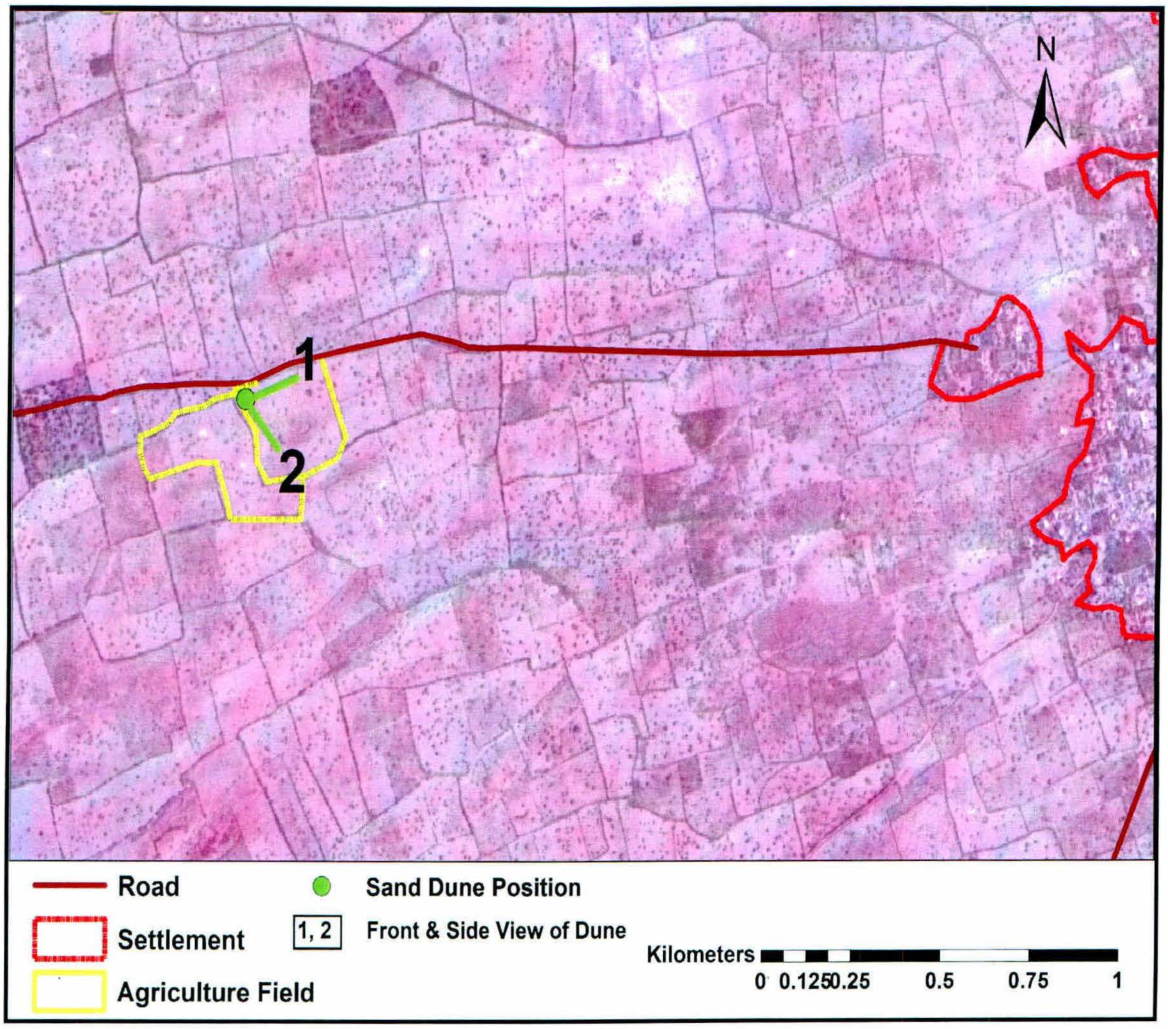

Fig. 3.12: Different sides of the Sand Dune observed near Lohsana Bada Village, in Jhunjhunu District

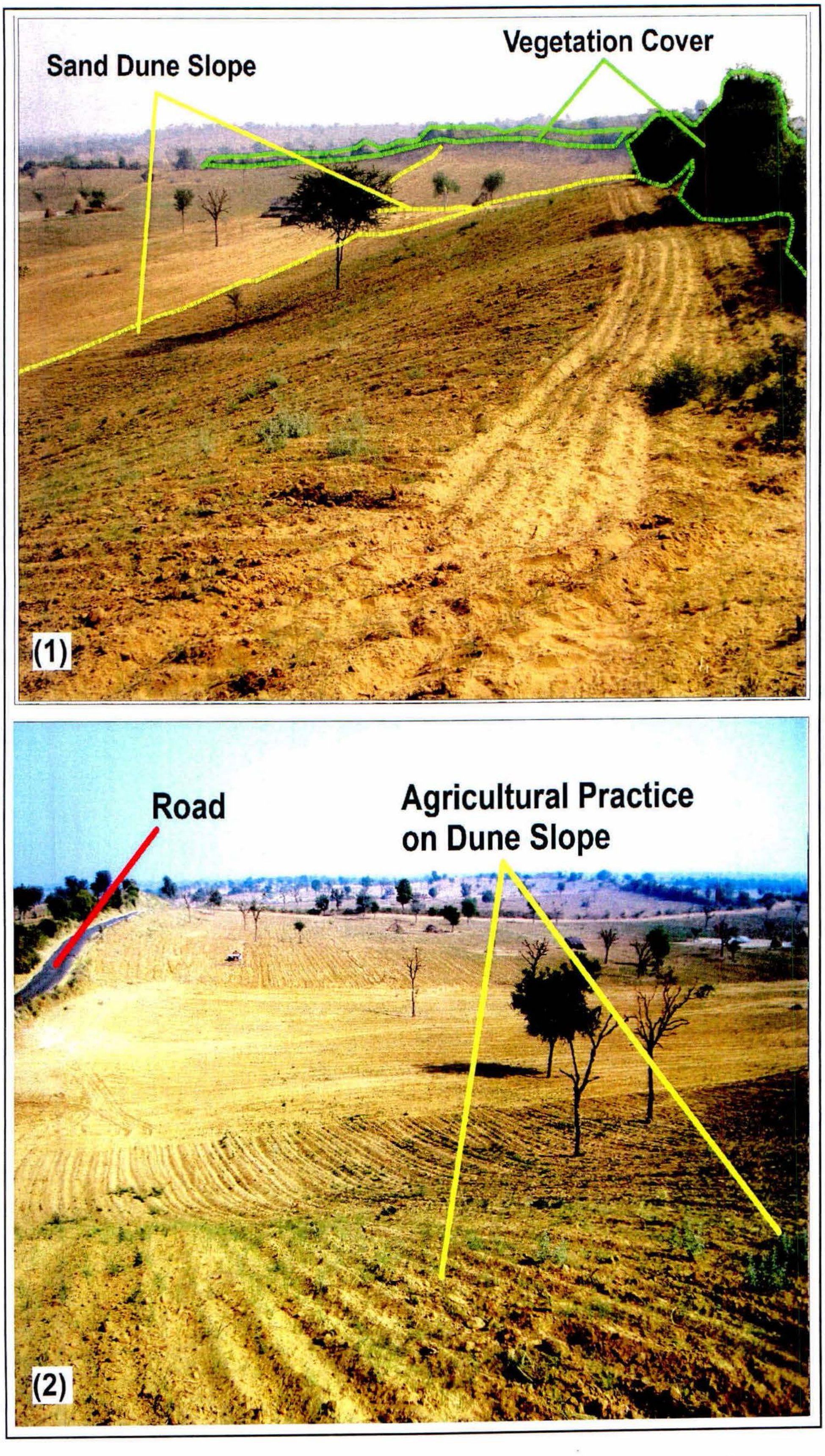

Fig 3.13: Dune Site near Lohsana Bada, Jhunjhunu District.

(1) Shelterbelt technique on Dune Crest (2) Agricultural practice on Dune Slope

3.6 Summary of Findings

1. Aeolian landforms and processes are mostly concentrated in desert regions of the world, and these desert conditions are the outcomes of variety of desert-producing factors such as descending drying air currents, rain shadows, distance from oceanic moisture sources or effect of continality, and cold ocean currents are influential, sometimes individually, more often in combination, as primary forces producing arid lands. But apart from desertic region, Aeolian landforms and processes also appear in a variety of environments such as in cold desert, coastal zone and poor land use practice. These environments are characterised by some common structures such as sparsely vegetation cover, strong winds and a supply of fine sediments particles. Hence, beaches, glacial outwash plains, deserts, dry lakes, loess plains are usually regard with the Aeolian features.

2. In India, Aeolian landforms and processes are prominent in the Thar Desert of India. It took round millions of years to shape the present form of Thar Desert. The Aeolian bed form in the Thar Desert of Rajasthan is divided into arid and semi-arid environment. In western Rajasthan due to arid environment the sand dunes are completely fragile. Thus lack of vegetation, moisture made sand dunes mobile. These Aeolian processes are well active and continuous, which are responsible for the changing of sand dunes shape. While in the eastern portion of Rajasthan sand dunes are well stabilised and static. The Thar Desert comprise with various landforms which is, sand sheet and sand dunes, inter-dunal trough, rocky and mounded hills, palaeochannels, salt lakes or playas.

3. In order to understanding of Aeolian landforms and its processes, a case study from district Churu and Jhunjhunu of Rajasthan has been taken. Remote sensing and GIS technology is used to analyse the spatial pattern of Aeolian landforms and its pattern. During filed observation it has been noticed that the sand dunes in the study sites are mostly under agricultural areas. While proper management of soil conservation practice make people to exercise agriculture on a sand dune. They had stabilised the sand dunes through various soil binding techniques, including the Shelterbelt technology. The land use practice

on them varies area wise but in general majority of sand dunes are observed under agricultural fields. Remote sensing and GIS technology prove very useful tool for the analysing the spatial pattern of Aeolian landforms.

Chapter 4

Types of Sand Dunes and Its Driving Variables

4.1 Classification of Sand Dunes

A Sand Dune is like a mound, which is build up by the wind action in different environments such as coastal, agricultural fields, arid and semi-arid region. In hot arid region more than 64 per cent of area is covered by the drifting or stabilised sand dunes, in some cases the heightisreachesup to 100 meters[1]. There is a need to study the sand dunes morphology, distribution and pattern. Various prominent factors such as, over grazing, deterioration of vegetation, agricultural practice on dunes and salinity are responsible for the mobility of fixed dunes. Whereas, along with this the parallel factors viz. windis also shaping the dunes and their position and orientation. During dry period the strength of wind is intense and easily erodes the loose particles and transports it into other new location. Such continuous processes are creating various new dunes and shift the dunes. This has raised the question on the desert spread or desertification in the Thar Desert of Rajasthan.

The distribution of different types of sand dunes signifies the geomorphology of the study area[2]. Severalefforts have been made by various researchers like**McKee, E. D. (1979)[3], Walker (1986)[4], Breed and Grow (1979)[5] and Pye&Tsoar (2009)[6]**to

[1]Tiwari C.J, Sharma A.K, Narain P, Singh R (2007), Restorative Forestry and Agroforestry in Hot Arid Region of India: A Review, Journal of Tropical Forestry, Vol.23 (I & II)

[2]Kumar M, Goossens E, Goossens R (1993), Assessment of Sand Dune Change Detection in Rjasthan (Thar) Desert, India, International Journal of Remote Sensing, Vol. 14, NO.9, pp. 1689-1703.

[3]McKee, E. D. (1979): Introduction to a study of global sand seas, In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052

[4]Walker (1986): "Eolian landforms" in Nicholas M. Short, Sr. and Robert W. Blair, Jr. (ed.) Geomorphology from Space (NASA publication)

[5]Breed, C. S. Fryberger, S.G. Andrews, S. McCauley F.L. Gebel, D. and Horstman, K. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052.

quantify sand dunes on the basis of structure, shape, morphology, orientation and slip faces etc..Role of remote sensing has provided a synoptic view for the monitoring and evaluation of sand dunes. In this direction **McKee (1979)**[7]had classified the dunes which are derived from the Landsat (ERTS), whereas, **Breedand Grow (1979)**[8]has classified the basic type of sand dune as linear, crescentic, dome, star, or parabolic. He has used Landsat images and aerial photographs in order to categorize dunes according to their shapes in plan view and slipfaces.

In Rajasthan,**Singh (1981)**[9]'identifiedand classified the sand dunes on the basis of their shape and morphology. There are six types of and dunes, which are major obstacle, minor obstacle, parabolic, longitudinal, transverse and barchan dunes. The factors responsible for the development and formation of dunes are wind. Wind act in diverse way and shape the dunes on the basis of their velocity and duration. The other factors affecting the formation of dunes are source of sand supply, biophysical barrier, existing land use practices and so on. In further this direction **Kumar M et al (1993)**[10]has identified different types of sand dunes and their spread in the extreme arid, arid and semi-arid region of Rajasthan Desert between the 100 and 400mm isohyet. Different types of dunes, viz. parabolic, linear, transverse, barchan and sand sheet has been identified and demarcated on Landsat imagery. According to his work, the parabolic dunes are the most dominant in the Rajasthan Desert followed by sand sheet, linear, barchan and transverse dunes.

In the present study CartoDEM data provide a significant platform to study the sand dune structure and distribution. The different types of sand dunes have been demarcated on the basis of shape, size, plan view and three dimensional views. This study is divided into two parts, the first one represent the macro view of the district Churu and Jhunjhunu sand dunes type, wherein micro level analysis specific type of sand dunes are demarcated individually and each types three dimensional view with

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[6]Pye and Tsoar (2009): Aeolian Sands and Sands Dunes, Springer.

[7]*Ibid.*

[8]*Ibid.*

[9]Singh S (1981), "Types and formation of sand dunes in the Rajasthan Desert" in the Sharma H.S (Ed.), Perspectives in Geomorphology - Vol.2, Concept Publishing company, New Delhi, pp.165-182

[10]*Ibid.*

cross-section profile has been generated. Before going to deal with the analysis of sand dune patterns and its driving variables of the study area; types of dunes from the study area need to be discussed. In the next section six types of dunes, Parabolic, Barchans, Longitudinal, Transverse and Deformed dunes areidentified from the study area. These types were than elaborated separately with the field samples in order to simplify the understanding with the explanation ofits related work and characteristics.

4.2 Types of Sand Dunes

According to **Singh (1981)**[11], there are two major and one minor zone of sand dunes in Rajasthan desert. The first major zone occurs in the western region of Rajasthan with dune height high to very high dunes (several kms long) with reactivated crests & flanks. The second major zone lies in eastern zone with dunes height from medium to high and very high.In minor zone dunes are scattered is patches they are mostly situated in the semi-arid part of Rajasthan which joins the two major zones near Rajgarh.

In District Churu and Jhunjhunu six types of sand dunes are observed in the CartoDEM data. In the macro level analysis the classification is based on the shape and size. The demarcation of dunes on macro level has been done in a generalized manner.For the micro level analysis six sample areashave been taken from Jhunjhunu and Rajgarh tehsils which represent the Jhunjhunu and Churu districts respectively. In these areas field visit has been done in order to observe the existing pattern of dunes. Each dune type was demarcated individually, while in each sample areas the different types of dunes are vary from three to five types.

There are six types of Sand Dunes which are observed in the study region these type are:

1. ***Parabolic Dune:*** Parabolic dune can be either U-shaped or V-shaped mound with concave crescent shape and elongated arms. Such types of dunes are shaped in the long arid period by the Aeolian processes of erosion and deposition. These dunes were active at the time of their formation but later it was stabilised during humid phase. Unidirectional winds remove the sand through erosion processes

[11]Singh (1981), *Op. Cit. pp.182*

and thus shaped feature in an either U-shaped or V-shaped or parabolas with elongated flanks upto several kilometres. Later the eroded sand wasredeposited in the leeward side of a parabolic dune. Thus the parabolic dune appears through such continuous processes. Parabolic dunes are sometimes called U-shaped, blowout, or hairpin dunes and are well known in coastal deserts. Such dunes are developed in the sand sheet area, in Rajasthan the elongated flanks of parabolic dunes are fixed or obstructed by the moisture and vegetation cover. Parabolic dunes are developed from the blowouts in a vegetated sand surface. When more than one parabolic dune combined with each other than compound parabolic dunes are produced, which are well stabilised and hold the vegetation cover properly. Such dunes occur in a region of approximately 200 mm average rainfall and are mostly vegetated.

In terms of area, parabolic dunes cover more space as compare to other types of dunes in Rajasthan desert. According to **Singh (1981)[12], Kumar M et al (1993)[13], Mainguet (1984)[14]**Parabolic dunes are widespread in Rajasthan.In the Thar Desert, compound parabolic dunes which have a rake-like form cover an area of about 100,000km2[15]. The mean length of single rake like form of parabolic dune is 2.6 km, whereas its width is 2.4km, such rake like forms having an average of seven arms[16].

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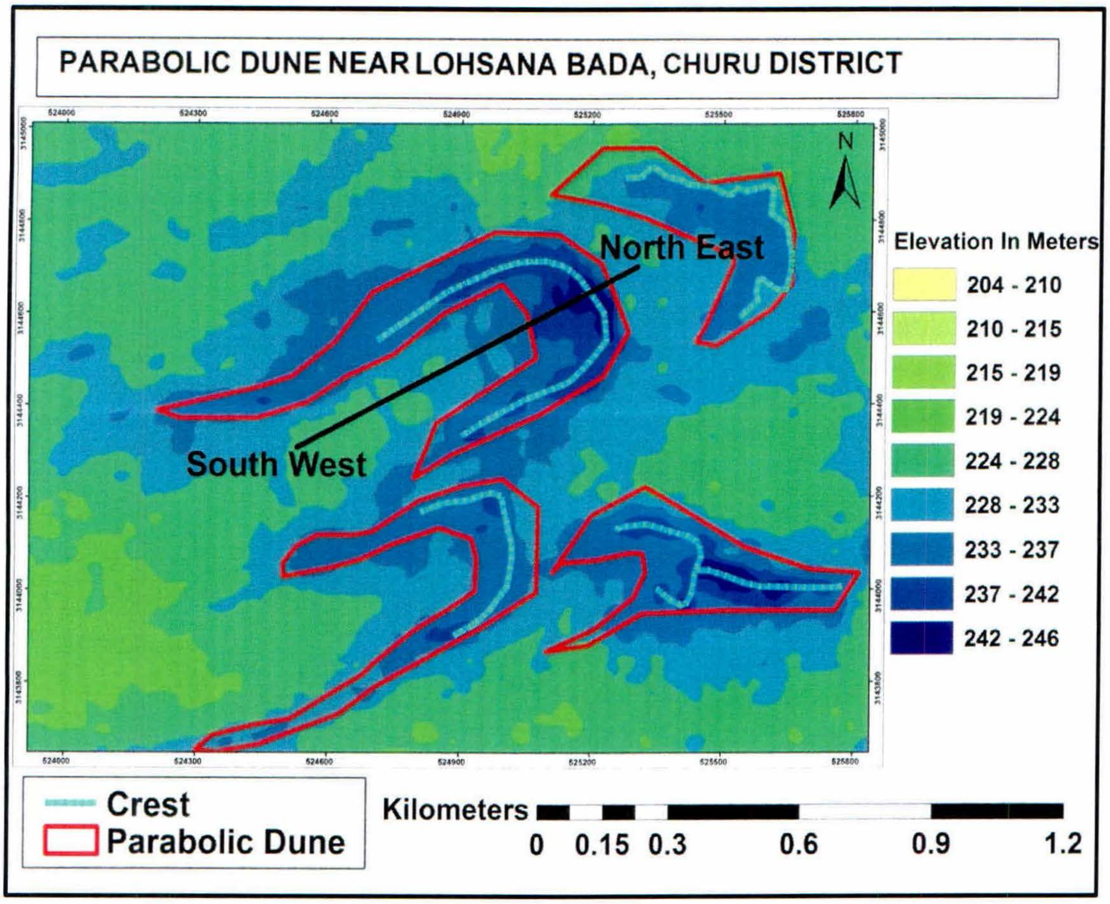
[12]*Ibid.*

[13]*Ibid.*

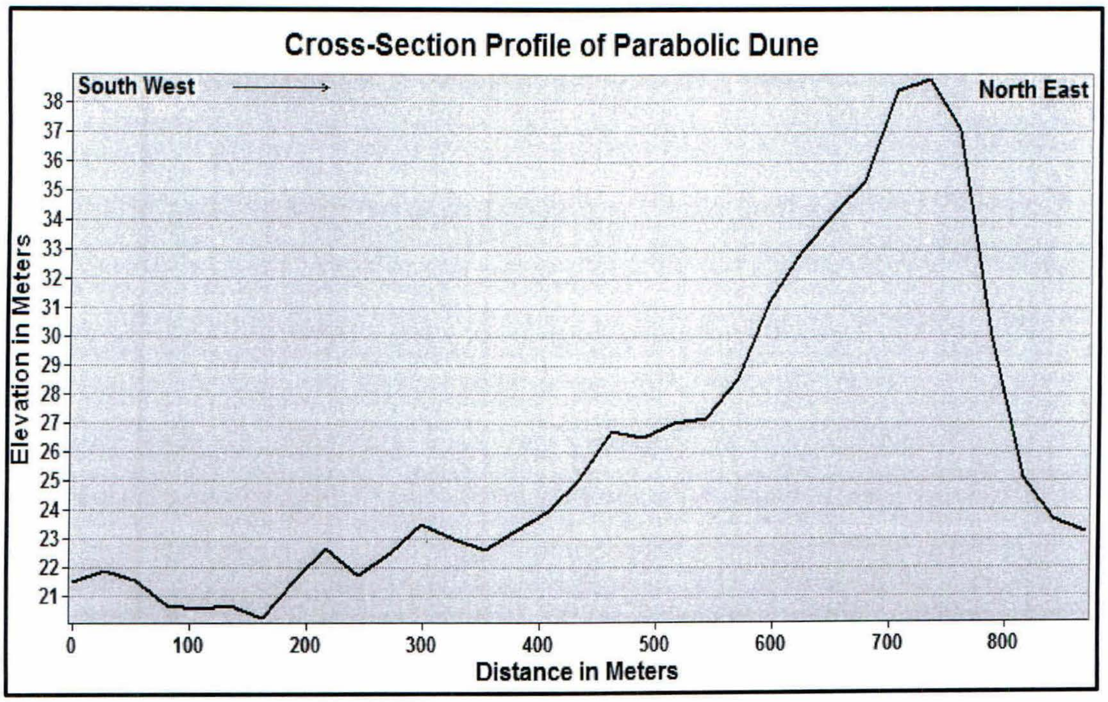
[14]Mainguet M. (1984), A Classification of Dunes based on Aeolian dynamics and the sand budget. In Deserts and Arid lands (ed.) by El-Baz, The hagueMartinusNjjhoff Publishers, pp. 31-58

[15]Verstappen H.T (1966), Landforms, water and land use west of the Indus plain, Nature and Resources, 2, pp.6-8

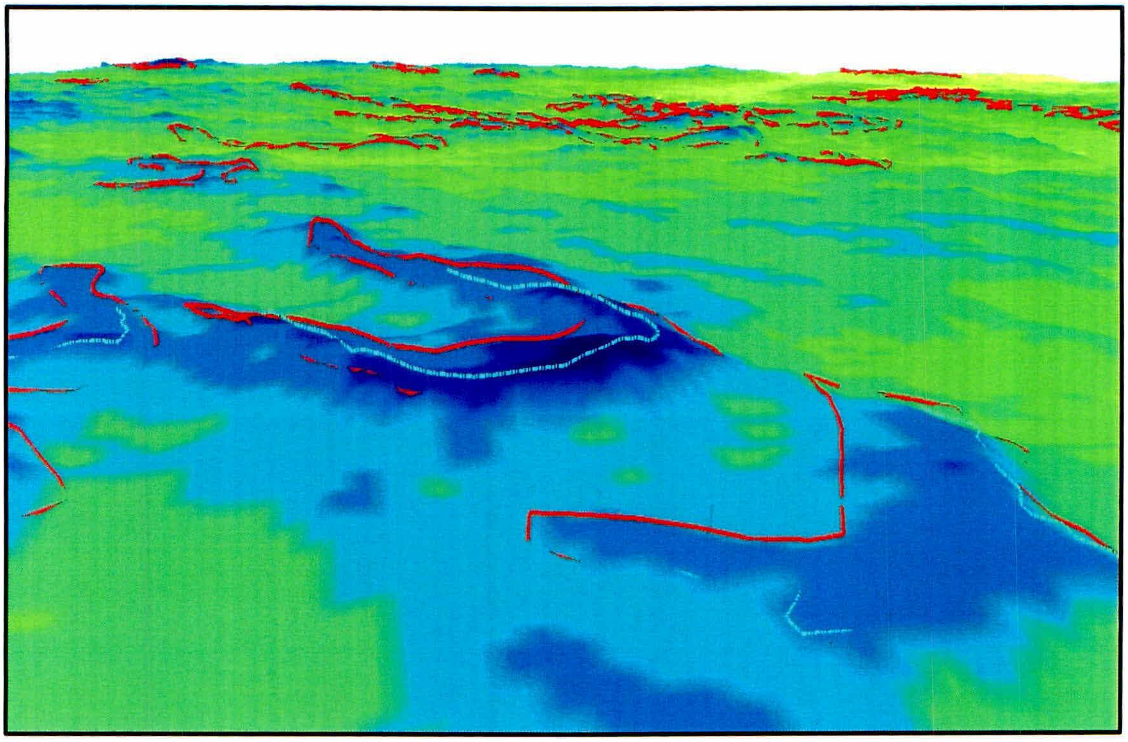
[16]Breed & Grow et al. (1979)*Op. Cit.*


PARABOLIC DUNE NEAR LOHSANA BADA, CHURU DISTRICT
North East
South West
N
Elevation In Meters
204 - 210
210 - 215
215 - 219
219 - 224
224 - 228
228 - 233
233 - 237
237 - 242
242 - 246
Crest
Parabolic Dune
Kilometers
0 0.15 0.3 0.6 0.9 1.2

(a)


Cross-Section Profile of Parabolic Dune
South West
North East
Elevation in Meters
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
0 100 200 300 400 500 600 700 800
Distance in Meters

(b)



(c)

Fig. 4.1: Example of a Parabolic Dune in the sample area of LohsanaBada Village, Churu District.(a) Acquired shape of a Parabolic Dune (b) Directional Cross-Sectional Profile of a Parabolic Dune (c) Three Dimensional View of a Parabolic Dune with Crest line.

2. ***Barchan Dune:*** Barchan dunes are crescent shaped, whichmigrate along the main wind direction and developperpendicular to the wind. Such dunes are form when there is inadequate sand available and the area between dunes is normally flat. When the sand supply is excessive than these dunes combine together and form transverse dunes. The movement of small barchan dunes very quick as compare to larger barchan or mega barchan, which movement is very slow speed. As mentioned in **Mainguet (1984)**[17]workthebarchan dunes move as an aggregated form. Sand particles are moved by the wind in saltation, thus causing advancing motion in the entire dune.

Usually, Barchan is formed by the unidirectional wind but its shape totally depends upon the condition of wind direction. In the case of one dominant direction than the barchan will shape like a crescent, whereas in case of

[17] *Ibid.*

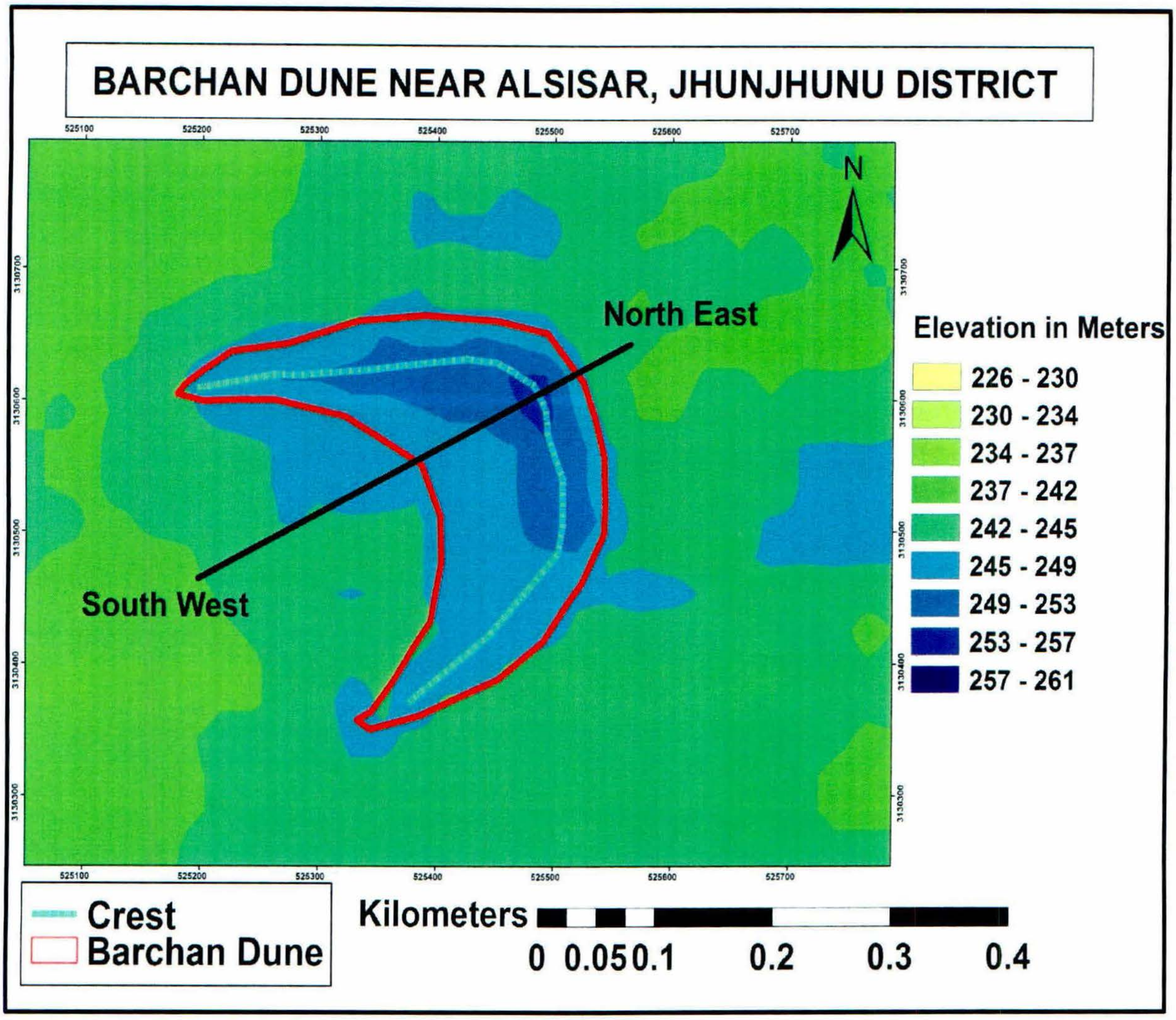
fluctuation in wind direction (due to season or local phenomena) than the dune will shape in linear form or even in star-shaped, depends upon the intensity and variation in the wind direction. Barchan are formed due to prevailing winds deposits in the lee of the crest. Due to continuous deposits on the lee of the crest form the steep face, while sand were removed from its downwind. Due to absence of any obstruction two drawn-out ridges on both sides were formed.In the direction of wind barchans can drift long distance without undergoing any change in shape and size[18].

According to **Singh (1981)[19],** most of the barchan are still being formed near the settlements. These dunes are developing due to recurrence of parabolic dunes in the Thar Desert[20]**.** The distribution of barchan dunes are scattered in the central, western and south-western parts of arid zone.

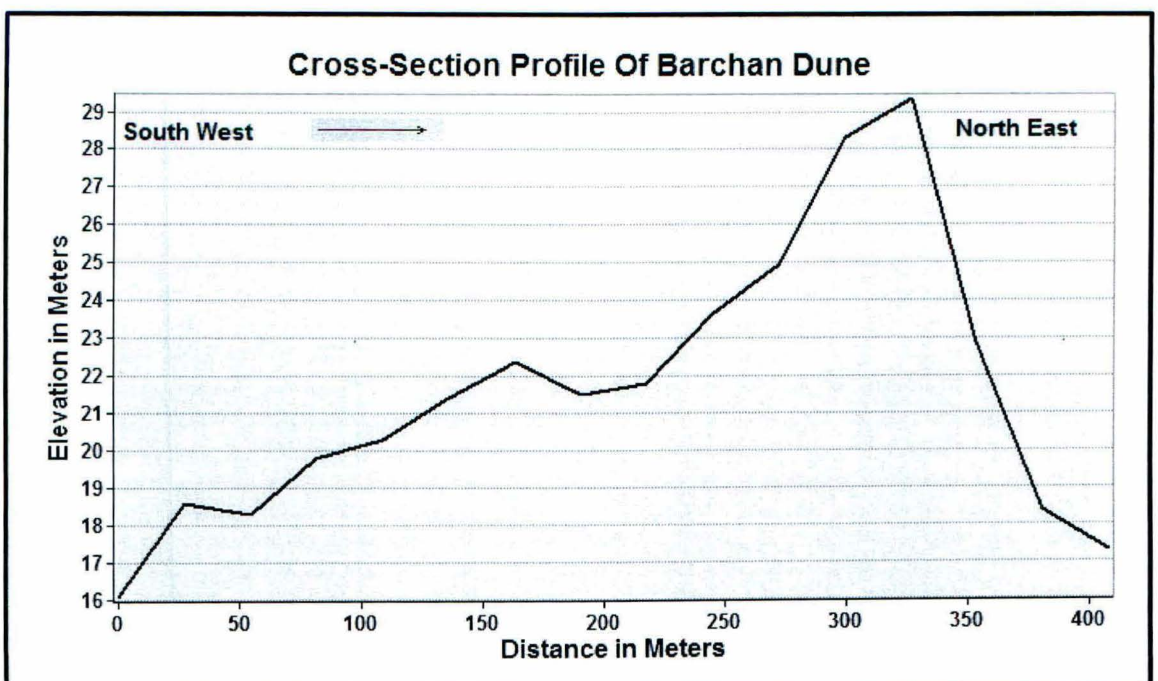
[18]Norris, R. M. (1966), Barchan dunes of Imperial Valley, California. J. Geol. 74, 292–306.

[19]Singh (1981), *Op. Cit.*

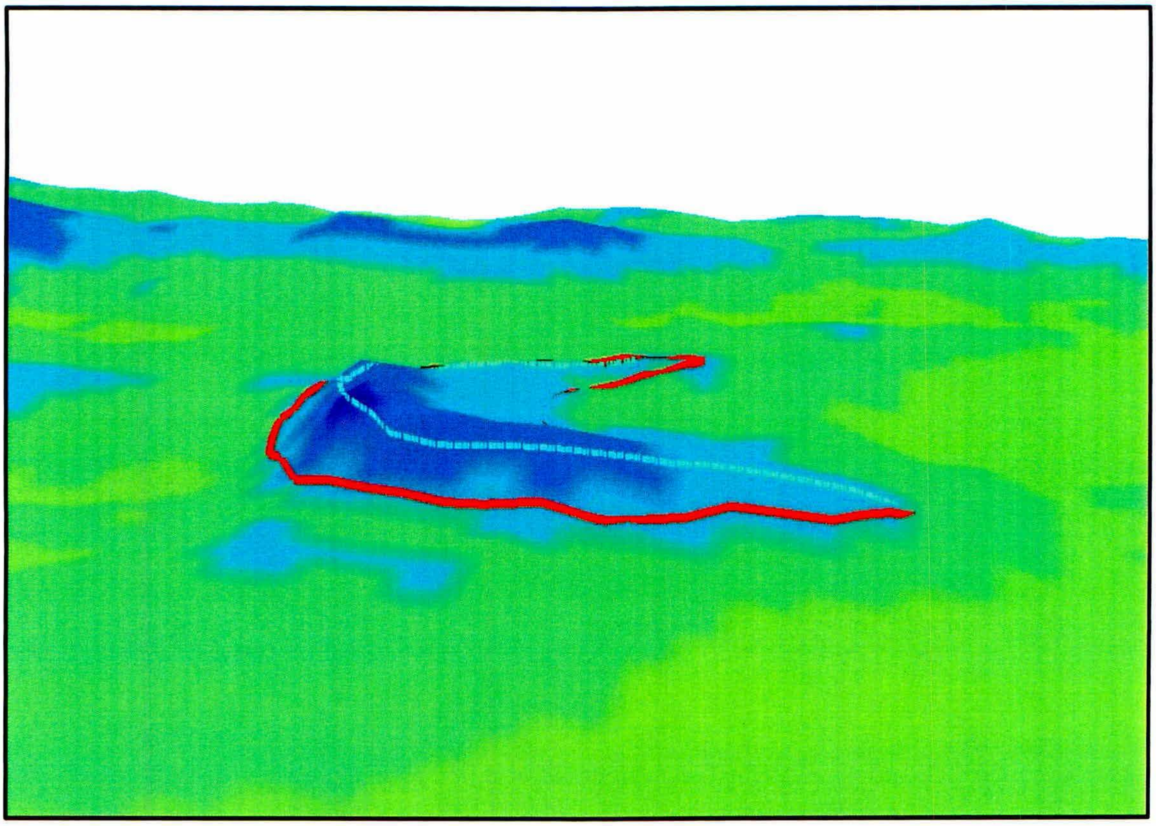
[20]*Ibid.*


BARCHAN DUNE NEAR ALSISAR, JHUNJHUNU DISTRICT
North East
South West
N
Elevation in Meters
226 - 230
230 - 234
234 - 237
237 - 242
242 - 245
245 - 249
249 - 253
253 - 257
257 - 261
Crest
Barchan Dune
Kilometers
0 0.05 0.1 0.2 0.3 0.4

(a)


Cross-Section Profile Of Barchan Dune
South West
North East
Elevation in Meters
Distance in Meters
16 17 18 19 20 21 22 23 24 25 26 27 28 29
0 50 100 150 200 250 300 350 400

(b)



(c)

Fig. 4.2: Example of a Barchan Dune in the sample area of Alsisartown. (a) Acquired shape of a Barchan Dune (b) Directional Cross-Sectional Profile of a Barchan Dune (c) Three Dimensional View of a Barchan Dune with Crest line.

3. ***Longitudinal Dune:***A longitudinal dune also known as 'Sief' dunes driven from Arabic language, this term is used in Africa and Saudi Arabia respectively.**Bagnold (1941)**[21] uses the term 'longitudinal' as synonymous with 'seif'.Longitudinal dunes are straight to irregularly sinuous and elongate in size; generally such types of dunes are long, narrow and parallel to wind direction. **Glennie (1970)**[22]describethe development of a '*sief*' dune is depend upon the velocity of wind. The wind speed determined the shape of a dunes and spacing between them.

[21]Bagnold, R.A. (1941),"The physics of blown sand and desert dunes". London: Methuen, pp.265

[22]Glennie K.W (1970) Desert Sedimentary Environments, Elsevier, Amsterdam.

The formation of longitudinal dunes is a subject of debate. There are various concepts proposed by the different scholars regarding the formation of a longitudinal or Sief dune. **Bagnold (1941)**[23]explains the formation of a seifs dunes were evolving from barchans, which was an extension of barchans one horn in a bidirectional wind regime.**Tsoar (1984)**[24]had advocate and modified the model of Bagnold in which he has stress on the role of both strong and gentle wind in the formation of longitudinal dune.But the advocacy of this explanation was not generally accepted. On the other side the concept of its formation was linked up with the parabolic dune which appears to be the modification of transverse sand ridge through the erosion by the strong wind. As per the opinion the transverse dunes merged with arms of parabolic dunes by the Aeolian processes, this leads to the formation of parallel sand ridges which was later further raised in the length by Aeolian deposition.The longitudinal dunes are not a result of barchan dunes but they are the result of parabolic dunes. The shifts of arid phase to humid phase in early Holocene period are responsible for the stabilisation of these dunes.**Mckee (1979)**,**Verstappen (1968)**,has also acknowledged the origin of longitudinal dunes from the barchan types.

The occurrence of longitudinal dune in Rajasthan has been observed by the **Singh (1981)**, **Breed et al. (1979)**, **Saxena and Singh (1976)**[25] and **Kumar M et al. (1993)**.They reported the distribution in the districts of Bikaner, Jodhpur, jaisalmer and west of Nagaurin small groups.

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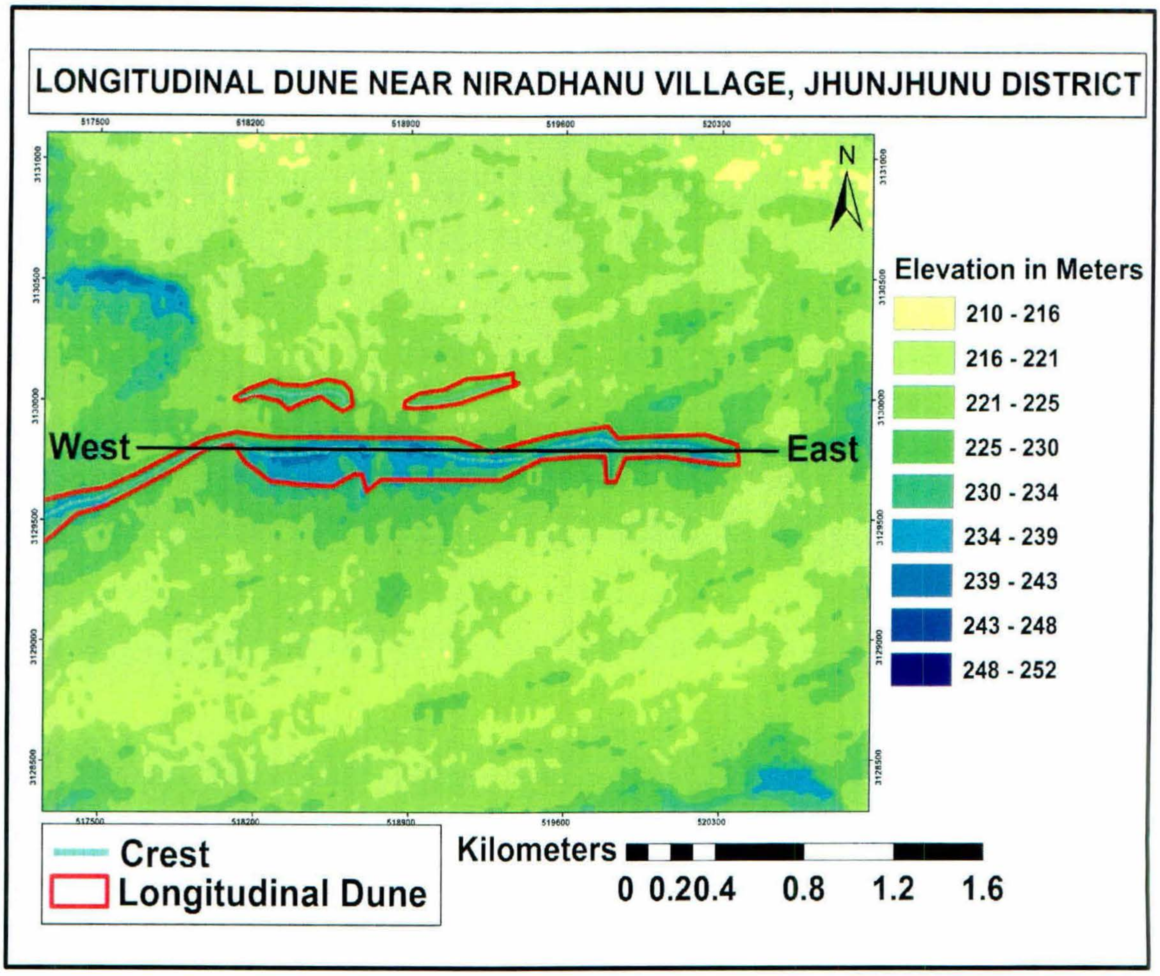
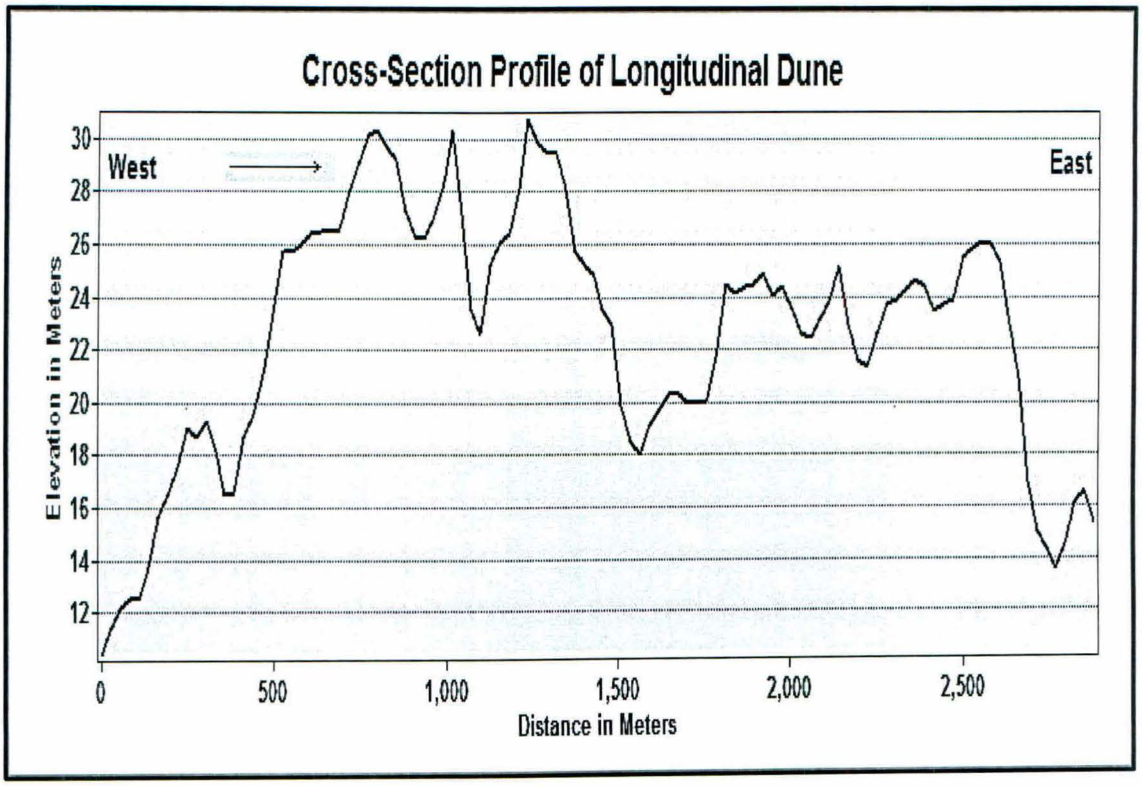
[23]*Ibid.*

[24]Tsoar (1984) *Op. Cit.*

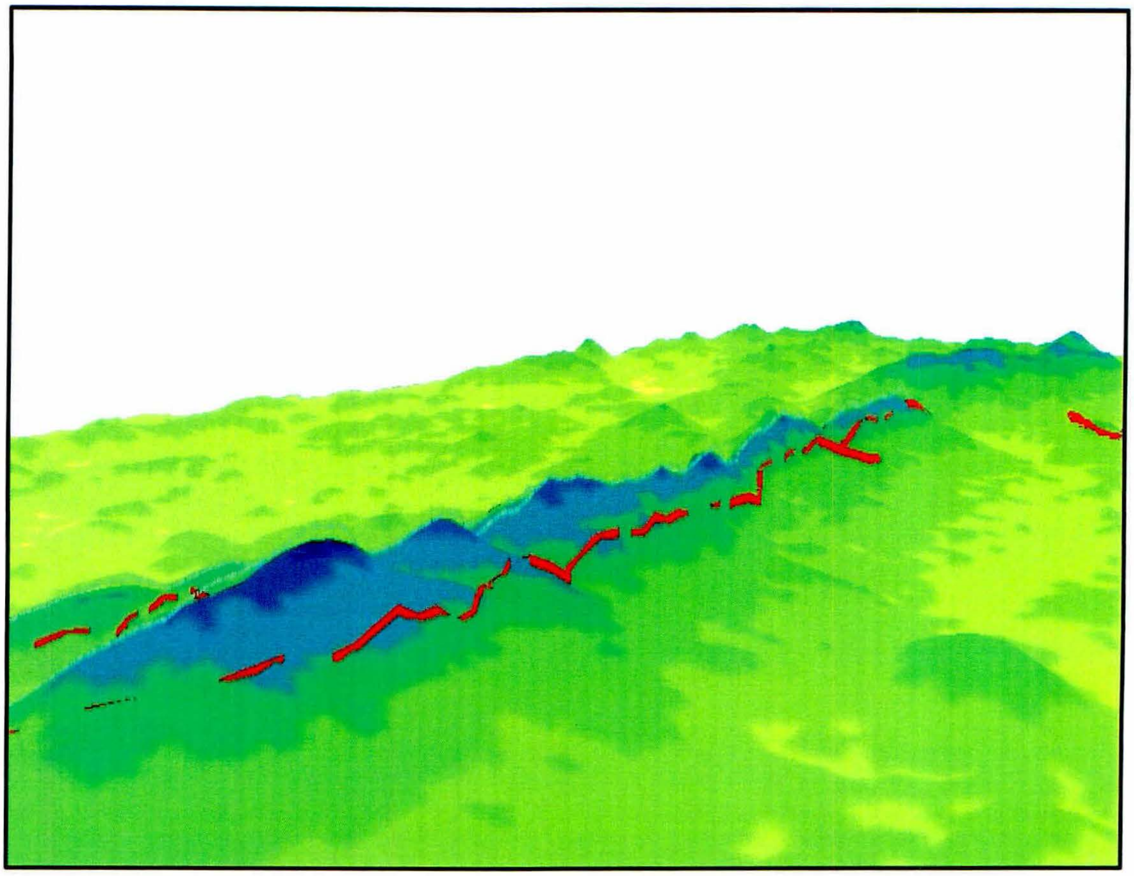
[25]Saxsena S.K, Singh S (1976), Observation on the sand dunes and vegetation of Bikaner district in western Rajasthan, Annals of Arid Zone, 15, pp.313-322.


LONGITUDINAL DUNE NEAR NIRADHANU VILLAGE, JHUNJHUNU DISTRICT
N
West
East
Elevation in Meters
210 - 216
216 - 221
221 - 225
225 - 230
230 - 234
234 - 239
239 - 243
243 - 248
248 - 252
Crest
Longitudinal Dune
Kilometers
0 0.20.4 0.8 1.2 1.6

(a)


Cross-Section Profile of Longitudinal Dune
West
East
Elevation in Meters
30
28
26
24
22
20
18
16
14
12
0
500
1,000
1,500
2,000
2,500
Distance in Meters

(b)



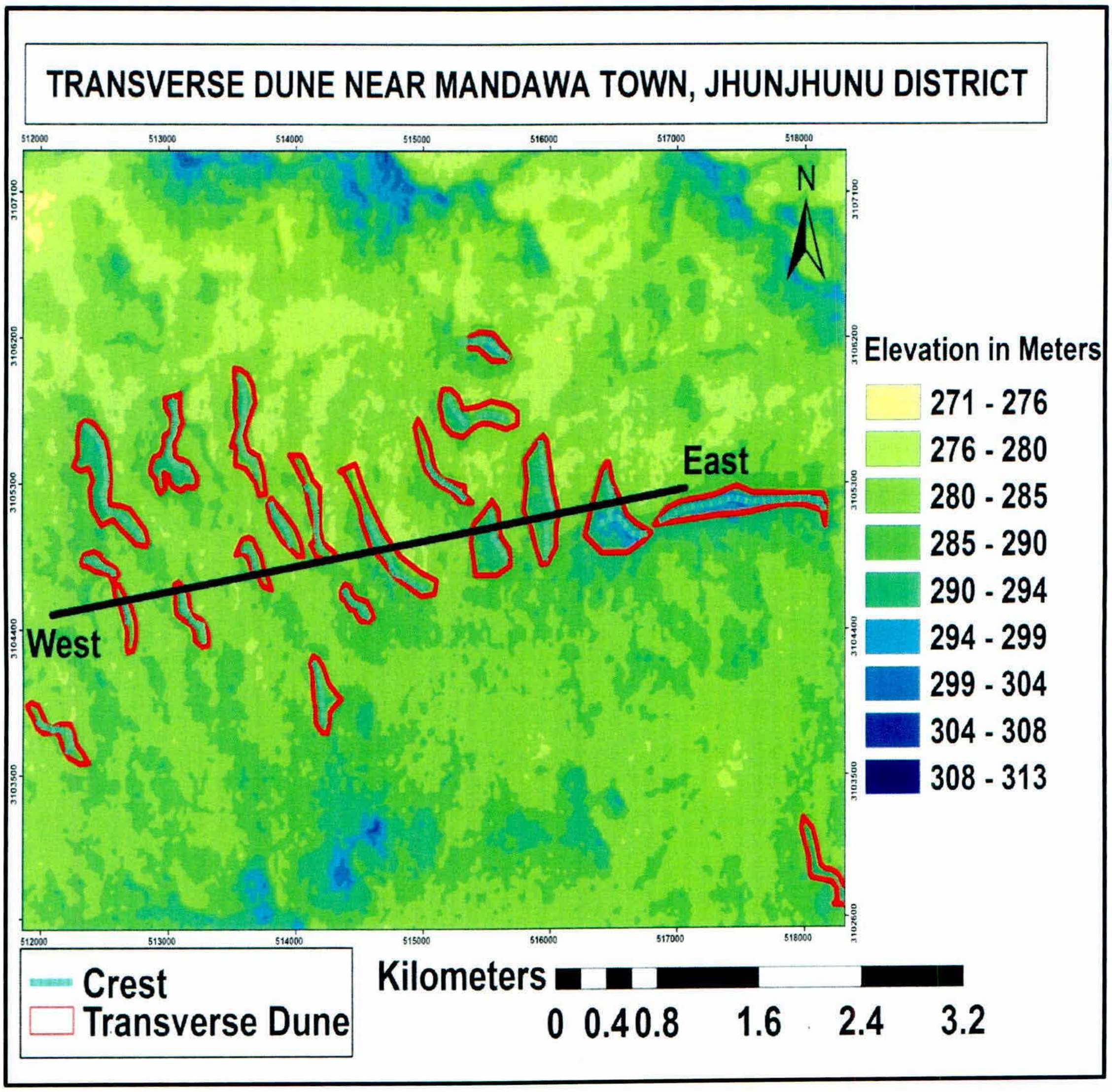
(c)

Fig. 4.3: Example of a Longitudinal Dune near the sample area of Niradhanu Village. (a) Acquired shape of a Longitudinal Dune (b) Directional Cross-Sectional Profile of a Longitudinal Dune (c) Three Dimensional View of a Longitudinal Dune with Crest line.

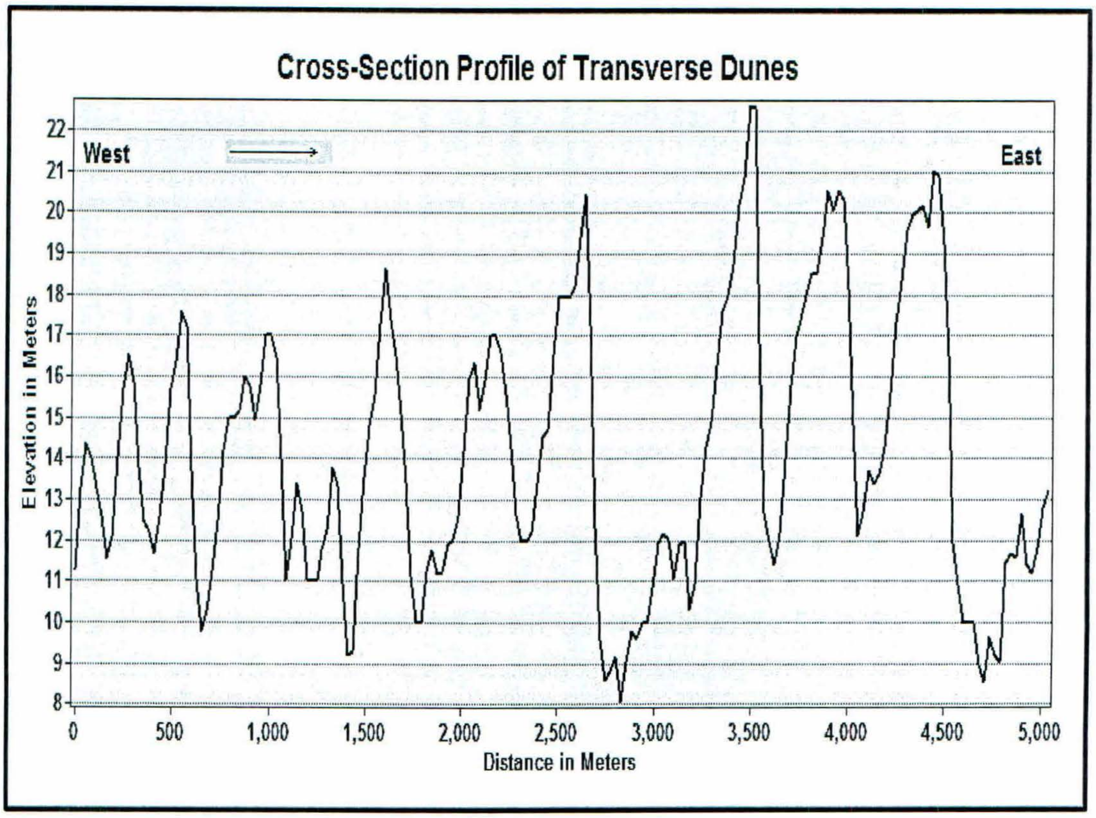
4. ***Transverse Dune:***Transverse dunes are shaped by the unidirectional wind and the high availability of sand. These dunes are in the range of crescentic dune ridges similar to Barchanoid or mega-Barchanoid ridges. These dunes are more irregular in pattern and also smaller in hierarchies, they are much straighter and slight curve of ridge segments is not apparent. These dunes types are migrate alongside which move toward the next dune ridge, instead of longitudinally down the long axis of the ridge.

The formation of these dunes is uncertaindoubtful**Mckee (1979)**describe the transverse dunes formed at right angles to the dominant wind direction. **Singh (1981)** mention that these dunes were originated due to prodigious sand cover on the ground, abundance sand supply, absence of vegetation and persistent and widespread wind action under arid climatic conditions. These factors created dunes shape in a wave like ridges separated by the trough like channel. According to him, "these dunes were stabilised during the humid phase which prevailed after the arid phase of pre-Holocene period".

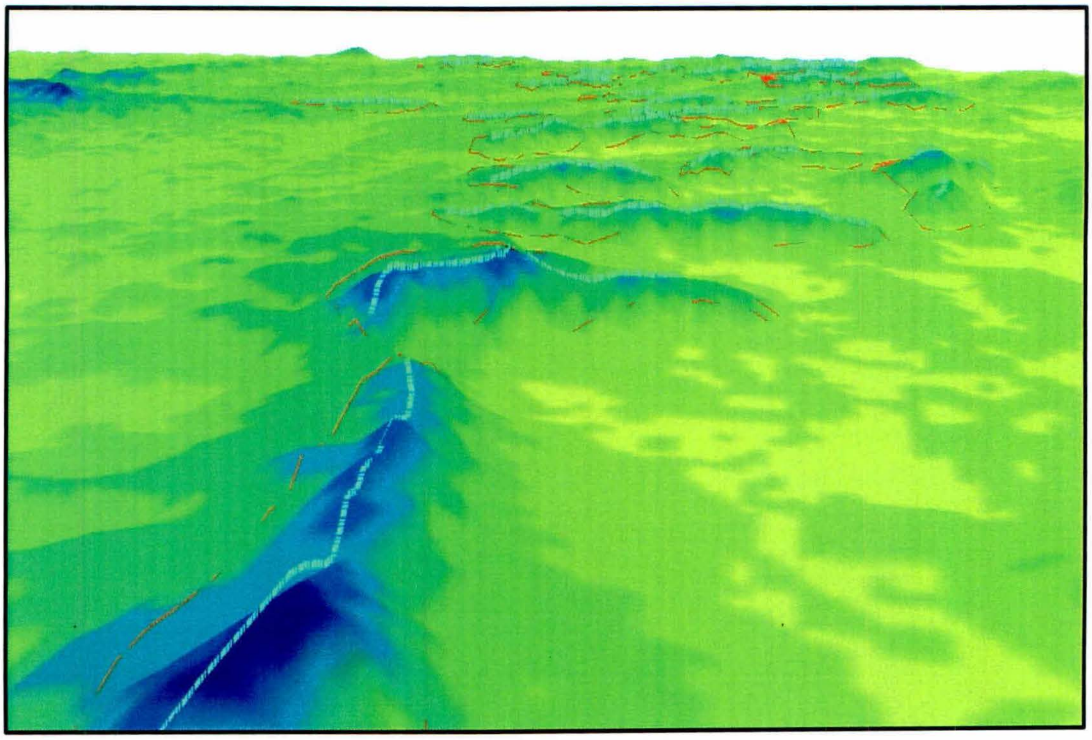
According to **Saxena and Singh (1976)**, **Kumar M et al. (1993)**, **Singh (1981)**transverse dunes types in the district of Bikaner and Jodhpur of Rajasthan



(a)



(b)



(c)

Fig. 4.4: Example of a Transverse Dune near the sample area of Mandawa Town. (a) DTM acquired shape of a Transverse Dune (b) Directional Cross-Sectional Profile of a Transverse Dune (c) Three Dimensional View of a Longitudinal Dune with Crest line.

5. ***Star-Shaped Dune:***Such Types of Dunes having radiating ridges from the high centre of the sand mound and are known as Star dunes. They are formed by the interaction of wind from various directions. The characteristic of these types are the pyramidal morphology, radiating sinuous arms and their large size[26].The star dunes are such types of sand dunes which have been studied least. This possibly reveals the facts that only around 8 per cent of all dunes are of this type[27]. The formation of star-shaped dunes has been associated with the physical barrier; the local topographical barrier has formed some intricacy in the local wind regime. This lead to the haphazard accretion of sand dunes and thus formed the star shaped dunes. **Breed et al. (1979)**[28] and **Wasson et al. (1983)**[29]have mentioned the formation of star dunes due to the topographical barrier.**Pyeet al. (2009)**[30]associate the link of star dune formation by the migration of transverse dunes into an area of multi directional winds flow.

The distribution ofStar-shaped dunes in Thar Desert of Rajasthan has been noted in **Kar (1996)**[31] and **Singhvi, A K et al. (2004)**[32]. Their distributions were found in the West and North West part of Rajasthan.

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[26]Lancaster N (1995), Geomorphology of Desert Dunes, Routledge publication, London

[27]Bullard J.E (2011), "Aeolian Environment", In Gregory K.J &Goudie A.S (Ed.) The Sage Handbook of geomorphology, Sage Publishers, London.

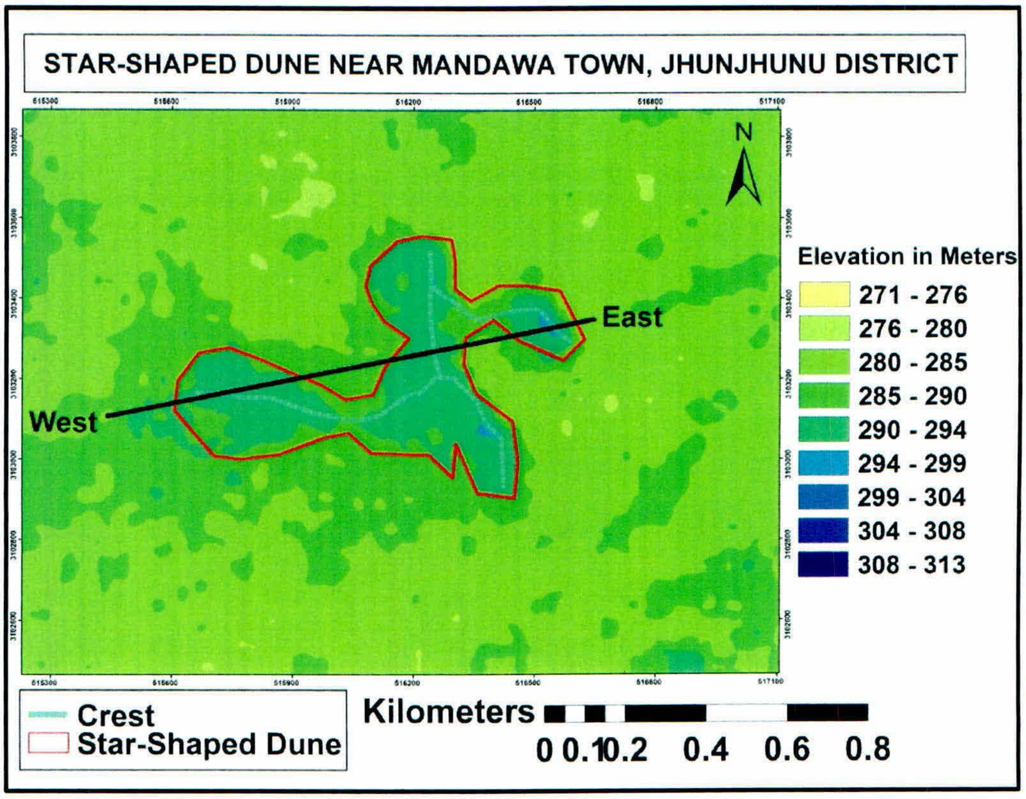
[28]Breed et al. (1979), *Op. Cit.*

[29]Wasson R. J., Hyde R. (1983), Factors determining desert dune type, Nature 304, 337–339.

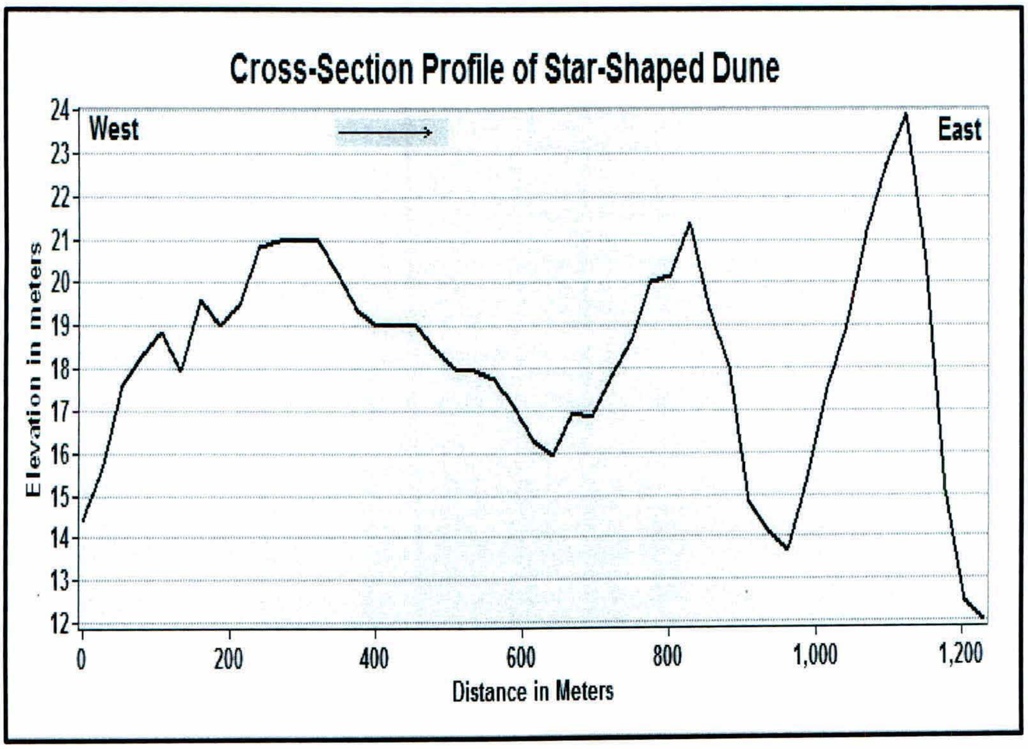
[30]Pye et al. (2009), *Op. Cit.*

[31]Kar A (1996), Morphology and evolution of sand dunes in the Thar desert as key to sand control measures, Indian Journal of Geomorphology 1(2), pp. 177-206

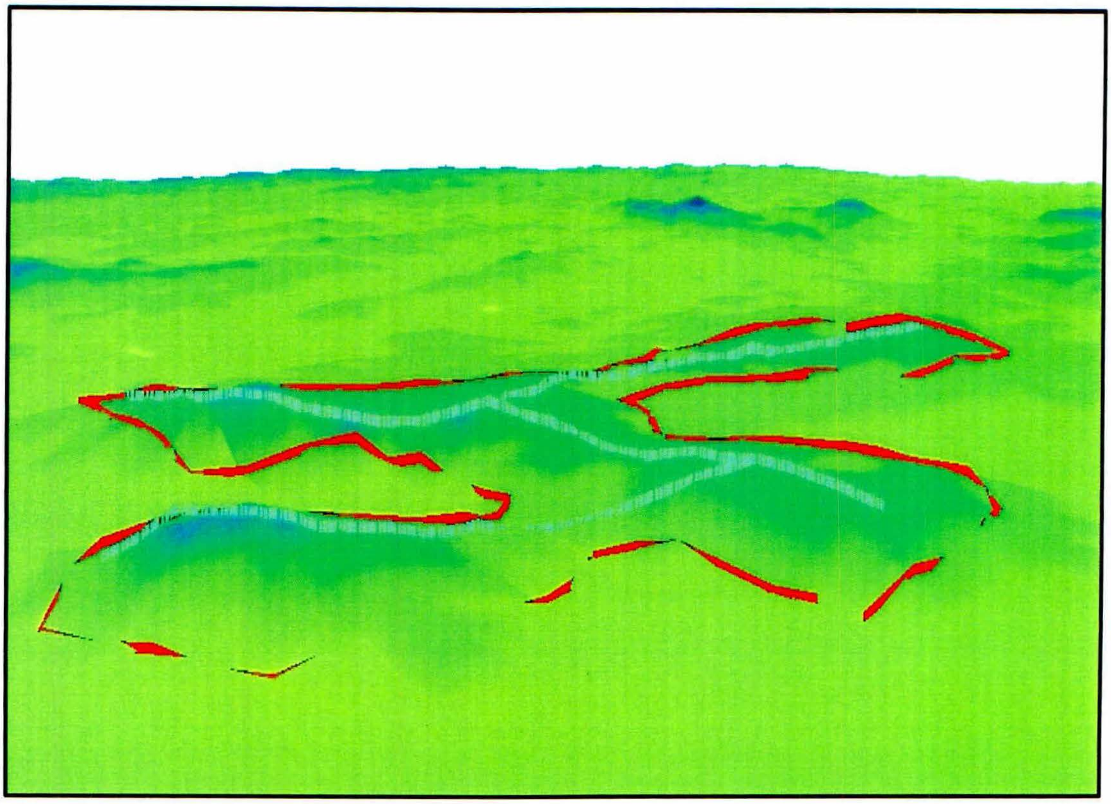
[32]Singhvi A K and Kar A (2004), The Aeolian sedimentation record of the Thar Desert, Proceeding of Indian Academic Science (Earth Planet Science), 113, No. 3, pp. 371-401


STAR-SHAPED DUNE NEAR MANDAWA TOWN, JHUNJHUNU DISTRICT
N
West
East
Elevation in Meters
271 - 276
276 - 280
280 - 285
285 - 290
290 - 294
294 - 299
299 - 304
304 - 308
308 - 313
Crest
Star-Shaped Dune
Kilometers
0 0.10.2 0.4 0.6 0.8

(a)


Cross-Section Profile of Star-Shaped Dune
West
East
Elevation in meters
24
23
22
21
20
19
18
17
16
15
14
13
12
0
200
400
600
800
1,000
1,200
Distance in Meters

(b)



(c)

Fig. 4.5: Example of a Star-Shaped Dune near the sample area of Mandawa Town. (a) DTM acquired shape of a Transverse Dune (b) Directional Cross-Sectional Profile of a Star Dune (c) Three Dimensional View of a Star Dune with Crest line.

6. ***Deformed Dune:***Such types of Dune category have been created on the basis of **Mckeeet al. (1979)**[33] based classification of sand dunes in which such types are considered as a *complex* and *compound* dunes. Compound dunes involve of two or more dunes of the same type which have conjoined or are superimposed. Complex dunes comprise of two or more different types of simple dunes which have combined or are superimposed. The need to merged complex and compound dunes class and formed the new one was that, there are some unique types of dunes in the study area which can't be categorized under them. Such types of dunes are distorted in shape, so these dunes are either in a transition phase of simple to compound or compound to complex types or they are in a process of making simple dunes. Yet, there is a need to study such dunes in further so that their intricacies can be judged. Such types of Dune are found in a micro analysis of six sample area. Perhaps these types has been categorised by some other

[33]Mckee et al. (1979), Op. Cit.

scholars. But visual based interpretation of satellite data and distorted shape of these dunes reveal the complexity in order to classify them.

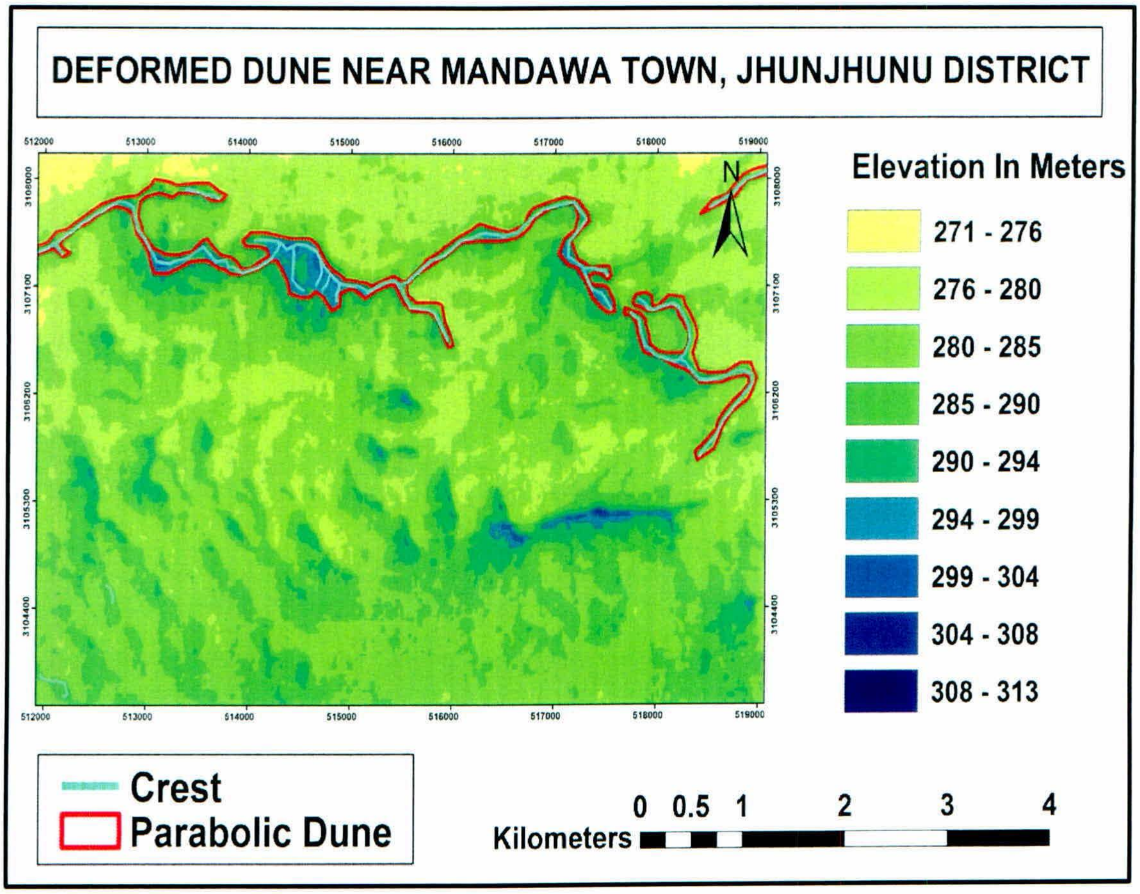
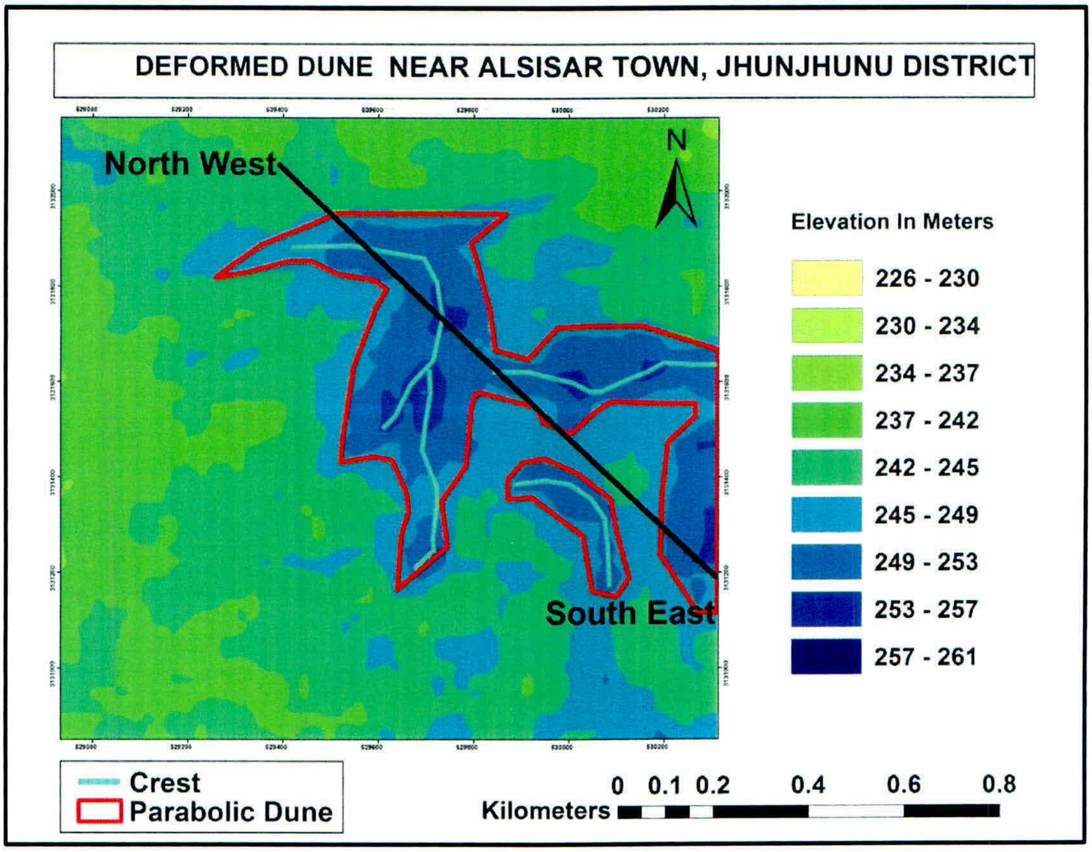
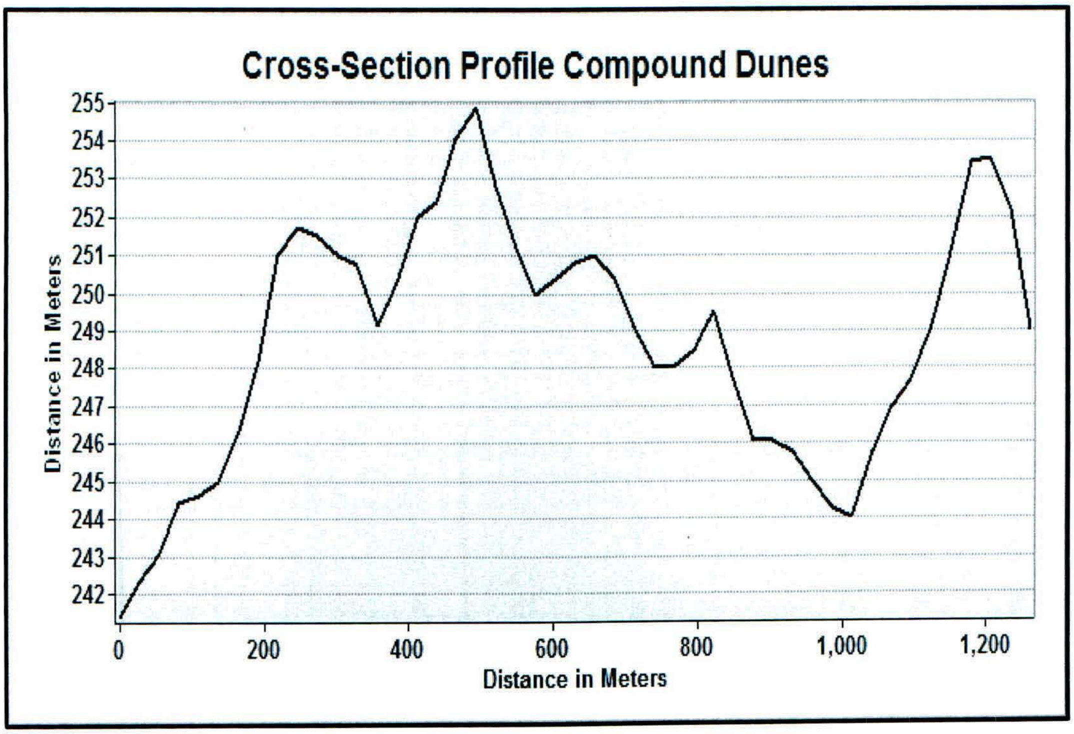


Fig. 4.6: A long and continuous form of dunes in the North of Mandawa Town, such dunes is a result of coalescence of various dunes together which termed as a deformed dune.



(a)



(b)

Fig. 4.7: Example of a Deformed Dune near the sample area of Mandawa Town. (a) DTM acquired shape of a Deformed Dune (b) Directional Cross-Sectional Profile of a Deformed.

4.3 Distribution of Sand dunes in the Study Area

In the satellite data various types of dunes were identified and curved out in the map. These types of dunes were mapped in macro and micro level studies. In Macro Level mapping the types of sand dunes were taken into a broad categories and in a very generalised manner, such dunes types are simple and easily observed in the all over the world. Whereas in micro level mapping these dunes were further analyse into a small scale in order to see their patterns and further categories on the basis of shape and its size.

4.3.1 Macro Level Mapping of Sand Dunes Types.

In this section the various dunes types were classifyand mapped for the entire district of Churu and Jhunjhunu. The classification of sand dunes in this section has been taken as simple types of dunes classification according to **Mckee (1979)** and **Singh (1981)**]. Previously various scholar **Breed et al. (1979),Mckee (1979),Livingstone et al.(2010),Singh (1981),Kumar et al. (1995)** used Landsat data in order to map the types of dunes. As the technological enhancement in space application, remote sensing and GIS evolved the mapping techniques also gets improved and enriched.

A map of dune types for District Churu and Jhunjhunu was constructed based on visual interpretation of CartoDEM dataset based on the pan and three dimensional views. It is very challenging to digitize the individual dunes in a broad scale and also distinguished the various types. Thus, a general pattern of dunes were identified and generalised for the macro level mapping. The boundary between different types of dunes is very precise and clearly distinguished in CartoDEM on the basis of height. But in some portions boundary between dune types is less clear but their forms and shape can be easily identifiable.The advantage of such mapping of dune types is that it provide platform to examine the dune morphology with other variables such as climate or vegetation, and to compare dune form classification with the available digital elevation models **Livingstone et al.(2010)**[34].

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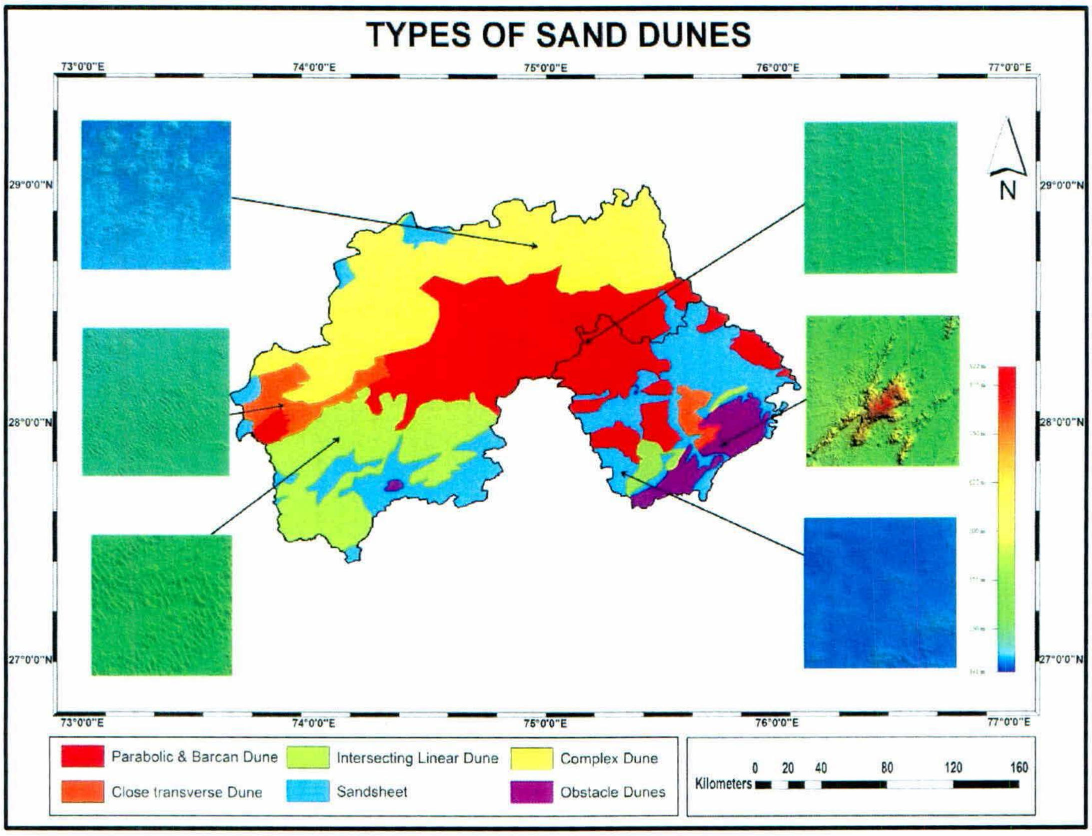
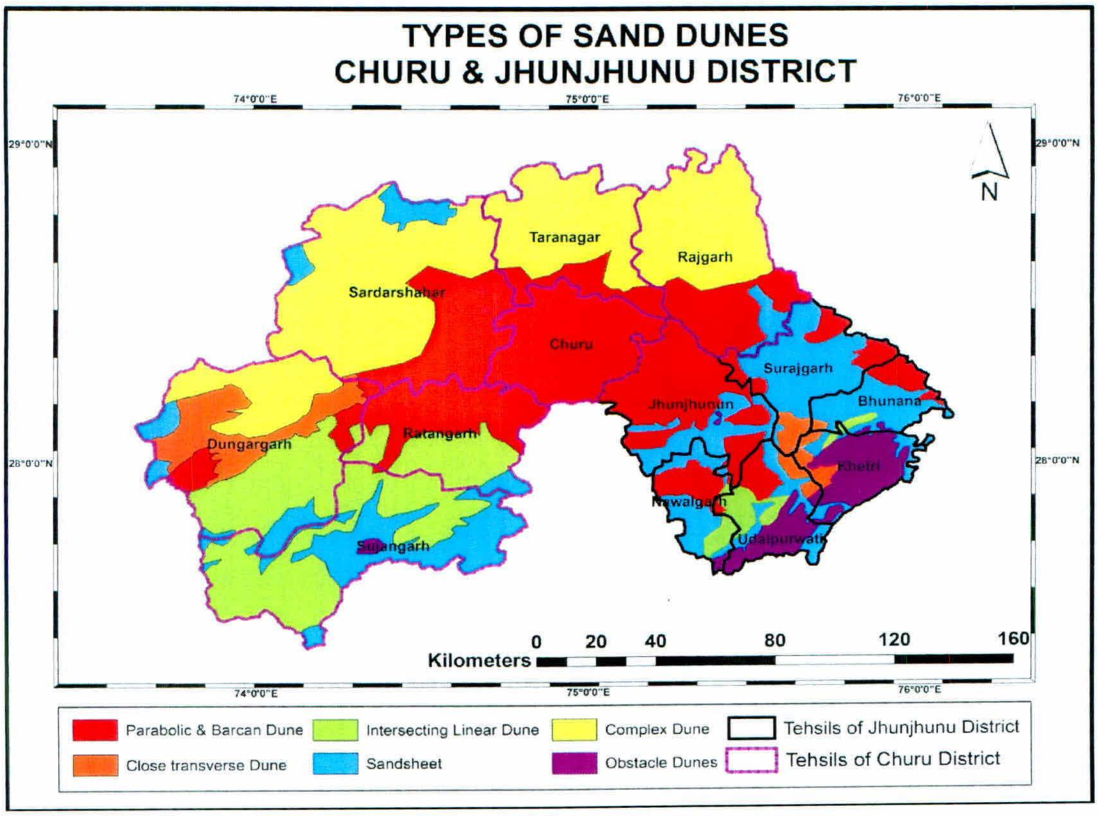
[34]Livingstone L, Bristow C, Bryant R.G, Bullard J, White K, Wiggs G.F.S., Baas A.C.W, Bateman M.D, Thomas D.S.G (2010), The Namib Sand Sea digital database of aeolian dunes and key forcing variables, Aeolian Research 2, pp. 93–104



(a)



(b)

Fig. 4.8: Types of Sand Dunes (a) Map of dune types in District of Churu & Jhunjhunu of Rajasthan, with example of CartoDEM Samples (b) Map of dune types with tehsils of District Churu and Jhunjhunu.

In the broad scale classification of sand dunes of district Churu and Jhunjhunu reveal that, there is specific dune type dominance than the other in terms of spatial coverage. As the classification was done in a general manner the analysis signify themajor dune type in a specific region.In further this direction micro level analysis also done for better understanding of the pattern and types of dunes.

In the Broad scale or Macro level mapping, six types of sand dunes were identified and classified as a *Parabolic & Barchan dunes, Close transverse dunes, intersecting linear dunes, obstacle dunes, complex dunes* and *sand sheet*. In the Central portion of district Churu and Jhunjhunu parabolic and barchans types of dunes are very common; they are extended in the eastern parts, whereinthe Northern region of thestudy area is covered up entirely by the complex dunes type followed by the portion of sand sheet. Sand sheet are vastly spread in the eastern and south western areas. In eastern region especially in district Jhunjhunu the vast spread of sand sheet is the result of some ephemeral rivers. 'The area in the south eastern part of Jhunjhunu is drained by Singhana River. Whereas the south and east of hill ranges in Khetri area is drained by Dohana River. All the rivers/nalas are ephemeral in nature and flows in response to heavy precipitation during monsoon'[35]. These ephemeral flowdeposited lot of fresh sediments into north-western portion of Jhunjhunu upto the rajgarh tehsil of district Churu. Thus in CartoDEM this vast spread of river deposits can be easily recognizable.

In the eastern portion a range of Aravalli hill is situated in the extreme south of district Jhunjhunu. This piece of hill portion is located in the udaipurwati tehsil and it is further extended up to east of khetri tehsil. The elevation of this district is between the 300 to 450 meters above from mean sea level. This act as an obstacle and formed sand dunes around hills, there are "major obstacle dunes around the hills vividly record the periods of high run-off from the hills, especially as armours of sub-angular rock fragments strewn over the Aeolian sand" **Singhvi et al. (2004)**[36]. The intersecting linear dunes were observed in the eastern part of district Churu. Majority of dunes were covered up by the agricultural practices as it has been observed in the Liss III data.

[35] (2008) Ground Water Brochure, Jhunjhunu District, Western region, Central Ground Water Board, Ministry of Water Resource, Government of India

[36]Singhvi A K and Kar A (2004), Op. Cit.

This broad scale mapping of dunes types show the general pattern of District Churu and Jhunjhunu. In further detail level of dunes type in the study area high resolution data Cartosat and CartoDEM has been used to show the micro level individual dunes type with its pattern and their distribution.

4.3.2 Micro Level Mapping of Sand Dunes Types.

For better visualisation of dunes types a micro level analysis assists to understand the sand dunes types, pattern and their distribution. To see the spatial coverage of sand dunes or Aeolian features in the micro level six samples area were taken from Cartosat image covering tehsil Rajgarh and Jhunjhunu and some portion of Churu and Sujangarh tehsil. These sample area taken from the boundary of district Churu and Jhunjhunu in order to see the sand dunes pattern in both districts minutely. These sample areas are:

1. Alsisar and Malsisar Town, Jhunjhunu District
2. LohsanaBada Village, Churu District
3. Mandawa Town, Jhunjhunu District
4. Niradhanu Village, Jhunjhunu District
5. Sankhu Fort, Churu District
6. NandKa Bas, Jhunjhunu District

The samples were taken on the basis of filed visit and a map of dunes type is produced. The sand dunes classification is done on the basis of shape, size and pan view and it was extracted from the CartoDEM data base. In this section the major portion is dealing with the only micro level Aeolian features mapping and its zonal topography, wherein further segment it will link up with its driving variable (especially wind). Following are the six sample area with details of dunes type.

Table 4.1: Spatial Coverage of different types of Sand Dunes

	Aslisar&Malsisar Town	*LohsanaBada Village*	*Mandawa Town*	*Niradhanu Village*	*Sankhu Fort Village*	*NandKa Bas Village*
Deflation	627221 **(0.9)**	424482 **(0.7)**	315096 **(0.4)**	141731 **(0.3)**	247485 **(0.3)**	303502 **(0.6)**
Parabolic Dune	3476164 **(5.1)**	235055 **(0.4)**	952498 **(1.1)**	1957936 **(3.6)**	2547941 **(3)**	1567190 **(2.9)**
Longitudinal Dune	173730**(0.3)**	472125 **(0.8)**	1585943 **(1.8)**	1192741 **(2.2)**	587095 **(0.7)**	1316424 **(2.4)**
Deformed Dune	1863116 **(2.8)**	1472121 **(2.4)**	2757466 **(3.1)**	2299434 **(4.2)**	3453709 **(4)**	1295242**(2.4)**
Barchan Dune	328034 **(0.5)**	-	654786 **(0.7)**	-	-	159496 **(0.3)**
Transverse Dune	-	-	1761442 **(2)**	-	-	-
Star-Shaped Dune	-	-	264518**(0.3)**	-	-	-
Total area Cover up by Sand Dune	5841045	2179302	7976657	5450112	6588746	4338353
% area cover by Sand Dune	**(8.6)**	**(3.5)**	**(9.0)**	**(9.9)**	**(7.7)**	**(8.0)**
Total area of Sample Boundary	67688311	61510427	88482928	54970852	85338415	54120375
Figure in Brackets are representing Percentage value, whereas rest figures are representing in square meters						

1. *Case Study 1 (Alsisar and Malsisar Town, Jhunjhunu District)*

In this sample study two major towns Alsisiar and Malsisaris situated, while the total area it covers is 68 sq. km and it havinga maximum height of 261 meters and minimum height of 226 meters. There are foursand dunes which were identified and mapped; this includes parabolic dune, barchan dunes, longitudinal dune, and deformed dunes.In total area of this case study only 8.6 per cent sand dunes are exist. Majority of dune types are situated in the agriculture fields. The shape of dunes denotes the pattern of wind direction towards the north east side. The detail of wind pattern will be studied in the next section of this chapter, but the preliminary study denotes the direction on the basis of dune shape and size.

It is also early to generalise the relationship between dune type and wind because this area is very much affected with anthropogenic activities and during field visit, it was also observed that the majority of dunes are situated on the agriculture land. These dunes were stabilised either by agricultural practices or by the afforestation. Such activities havechanged the dynamics of land cover and also the shape of dunes.

In this sample area the total sand dunes area is about6, 76, 88,311 sq. meters. In a percentage terms around 8.6 per cent area is cover up by sand dunes. Wherein term of dune types 5.1 per cent is covered up by parabolic dune and 2.8 per cent is cover up by deformed dunes which is followed 0.5 and 0.3 per cent by barchans and longitudinal dunes respectively.

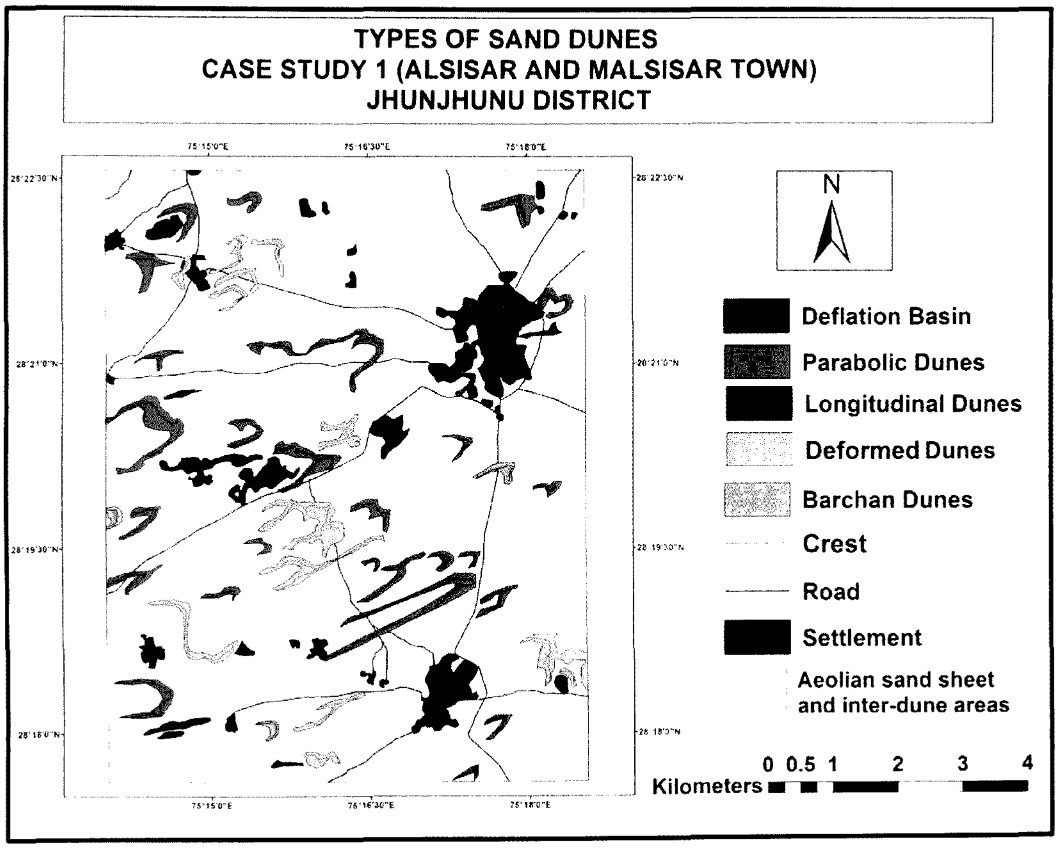


Fig. 4.9: Map of Dune types ofAslsisar and Malsisar Town including Crest line of a Dune and some Land Cover features.

2. *__Case Study 2 (LohsanaBada Village, Churu District)__*

In this sample area important settlements that exist is Lohsanabada village, which is situated in Churu district. The total area of this sample study is 62 sq. Kms with maximum and minimum elevation of 246 and 204 metres respectively. In this sample area there are four types of sand dunes observed, which are parabolic, longitudinal, barchan and deformed dunes. Deflation basin is also observed as

Aeolian erosional features.The total area cover by sand dunes is 61510427 metres square, which denotes only 3. 5 per cent of the total area of case study.

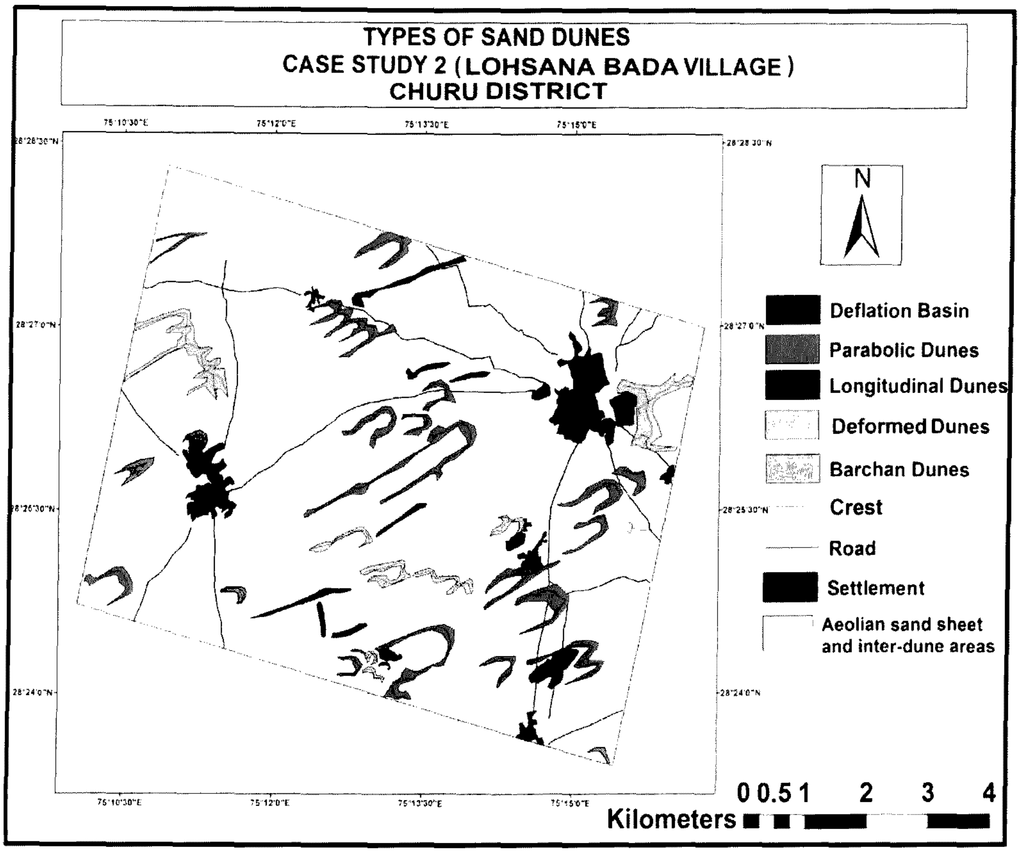


Fig. 4.10: Map of Dune types of LohsanaBada Village including Crest line of aDune and some Land Cover features.

In terms of spatial coverage of different sand dunes, the most common type of sand dune observed in this area is deformed dunes dune, which covers up about 2.4 per cent in the sample area of LohsanaBada. These types of dunes having a larger coverage of space and thus signifies a larger percentage. But if we visually observed the spatial distribution of sand dunes types than the parabolic dunes appear in a vast numbers. But in terms of spatial coverage parabolic dunes is only 0.8 per cent in the total sample area of lohsanabada. Longitudinal dune covers only 0.4 per cent of the area. Majority of dunes are situated on the agricultural fields, whereas in some settlements the dunes are situated on its margins.

3. ***Case Study 3 (Mandawa Town, Jhunjhunu District)***

In this case study Mandawa is a major town and settlement as well. The total area of this sample study is 88 sq. km with maximum and minimum elevation of 313 and 271 metres respectively. The reason for the maximum elevation of this sample as compare to other sample area is completely physiographic. The location of this sample area is located on the south of Jhunjhunu district, whereas the physiography of the district Churu and Jhunjhunu (in term of elevation)decrease drastically from south to north. In this sample area there are also different types of sand dunes observed. There are six types of sand dunes found in this area; this includes parabolic, barchan, longitudinal, deformed, transvers and star-shaped dunes. The total area cover by sand dunes is88,482,928 sq. m, which denotes only 9 per cent of the total area of case study.

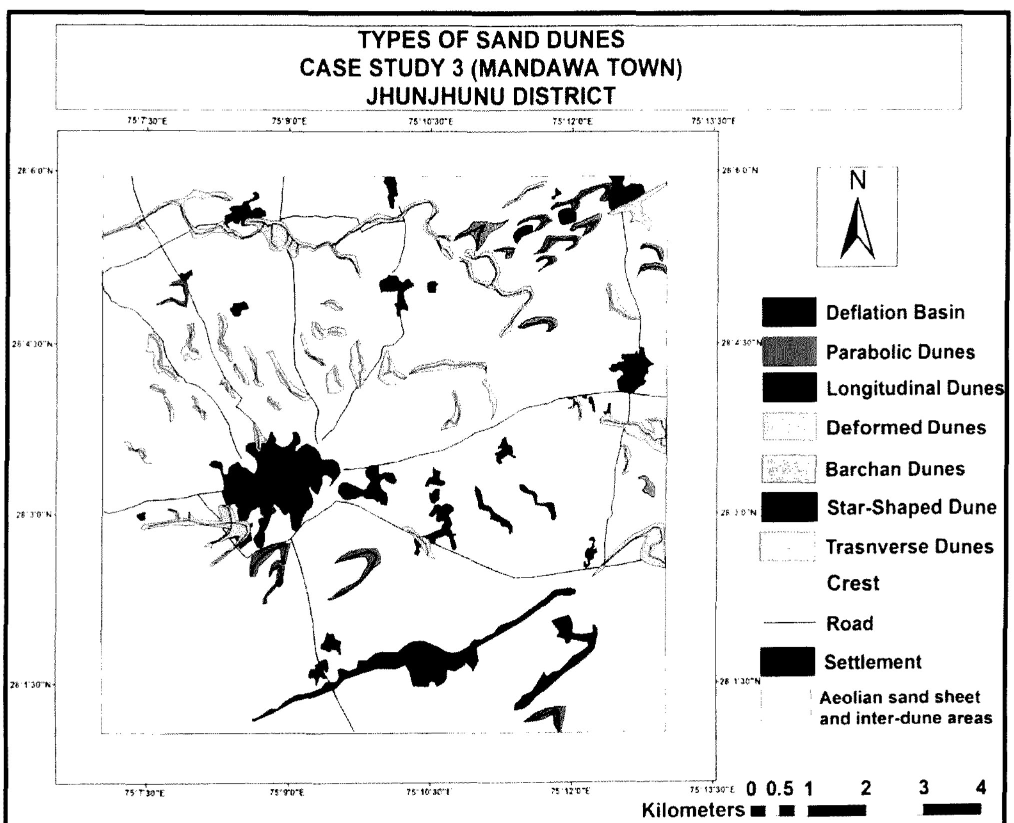


Fig. 4.11: Map of Dune types of Mandawa Town including Crest line of a Dune and some Land Cover features.

In terms of spatial coverage deformed dunes in this area covering maximum portion. It has 3.1 per cent of spatial coverage followed by transvers dunes 2 per cent, longitudinal dunes 1.8 per cent, parabolic dunes 1.1 per cent, barchan dunes 0.7 per cent and star-shape dunes 0.3 per cent respectively.

4. *Case Study 4 (Niradhanu Village, Jhunjhunu District)*

In this case study Niradhanu and Gangiyasar is an important village in this study area. The total geographical area of this sample section is 55 sq. km with maximum and minimum elevation of 277 and 234 metres respectively. In this case study Gangiyasar is the only village which is situated on the sand dunes and it also having a highest elevation 277 meters.Wherein, Niradhanu village is situated on the height of 255 meters which is comparatively low. In this area the variety of dunes are relatively low. There are only three types of sand dunes in this area; this includes parabolic, longitudinal and deformed dunes.

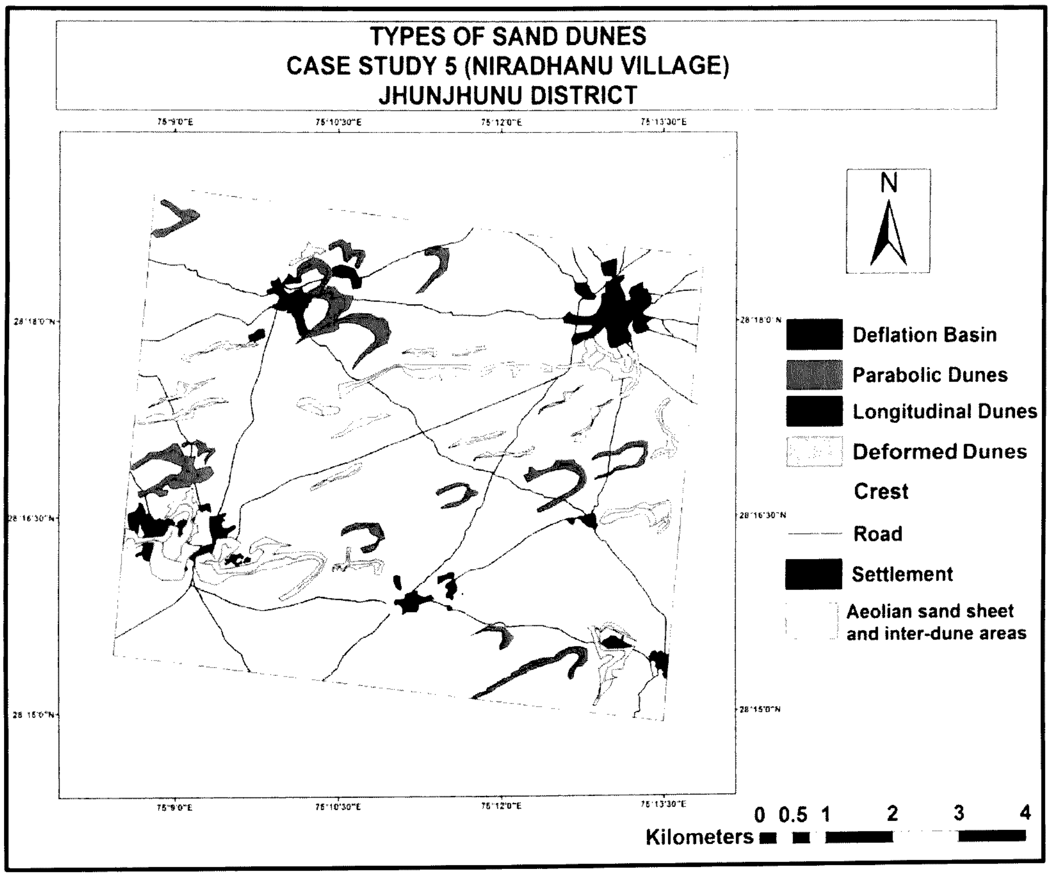


Fig. 4.12: Map of Dune types of Niradhanu Village including Crest line of a Dune and some Land Cover features.

The total area cover by sand dunes is5,450,112 sq. m, which denotes only 9.9 per cent of the total area of case study. In this sample area the deformed dunes cover around 4.2 per cent of geographical area of this case study, followed by the longitudinal and parabolic dunes cover 3.6 and 2.2 per cent individually.

5. *Case Study 5 (Sankhu Village, Churu District)*

In this case study Sankhu village is an important village of this case study. The total geographical area of this case study is 85 sq. kms and the maximum height of 252 meters and minimum height of 210 meters. There are three types of sand dunes which were identified and mapped; this includes parabolic dune, longitudinal dune, and deformed dunes.

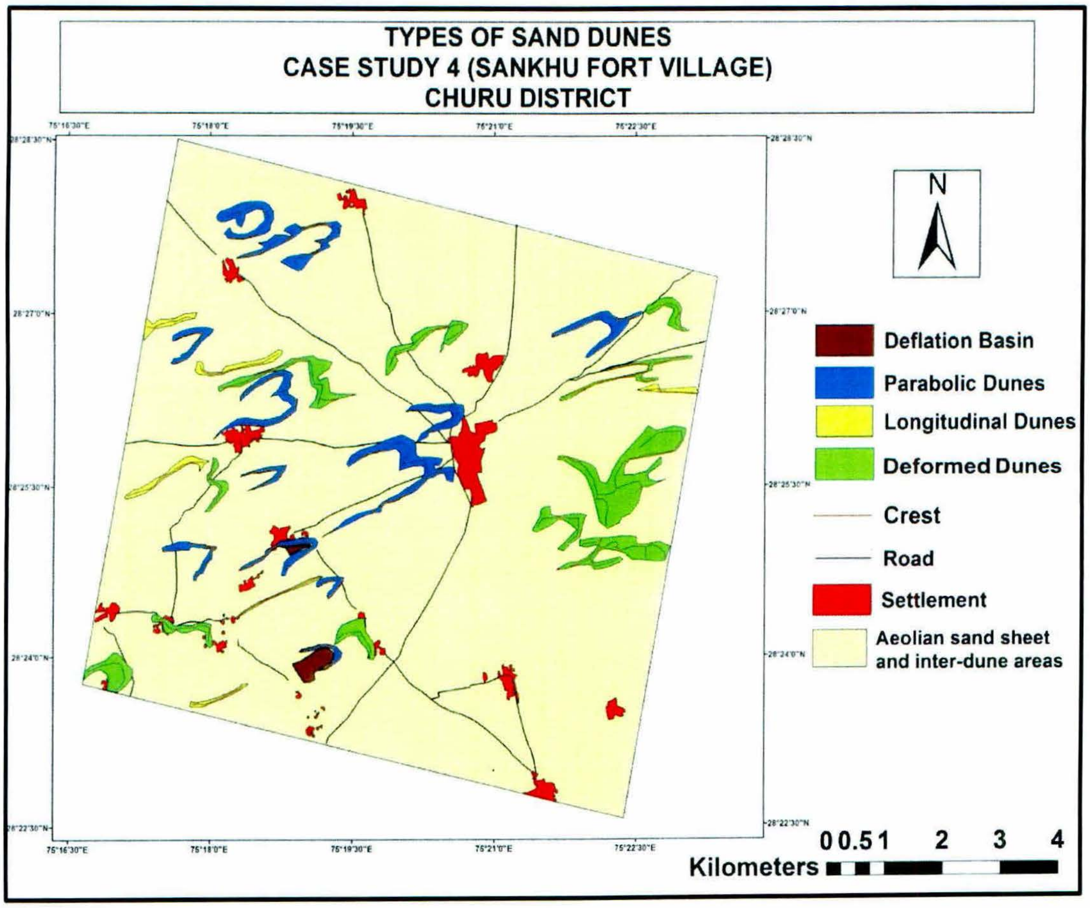


Fig. 4.13: Map of Dune types of Sankhu Fort village including Crest line of aDune and some Land Cover features.

The total area cover by sand dunes is6,588,746 sq. m, which denotes only 7.7 per cent of the total area of case study. In terms of spatial coverage of different sand dunes, the most common type of sand dune observed in this area is deformed dunes dune, which covers up about 4 per cent in the sample area of Sankhu Fort Village. After deformed dunes, parabolic have a second maximum 3 per cent followed by longitudinal dune with 0.7 per cent.

6. ***Case Study 6 (Nandka Bas Village, Jhunjhunu District)***

In this part of the case study NandKa Bas is an important village and the geographical extent of this sample area is 54 sq. km with maximum and minimum height of 256 and 221 meters respectively. The total area cover by sand dunes is4,338,353 sq. m which denotes only 8 per cent of the total area of case study. In this sample area there are four types of sand dunes observed, which are parabolic, longitudinal, barchan and deformed dunes.

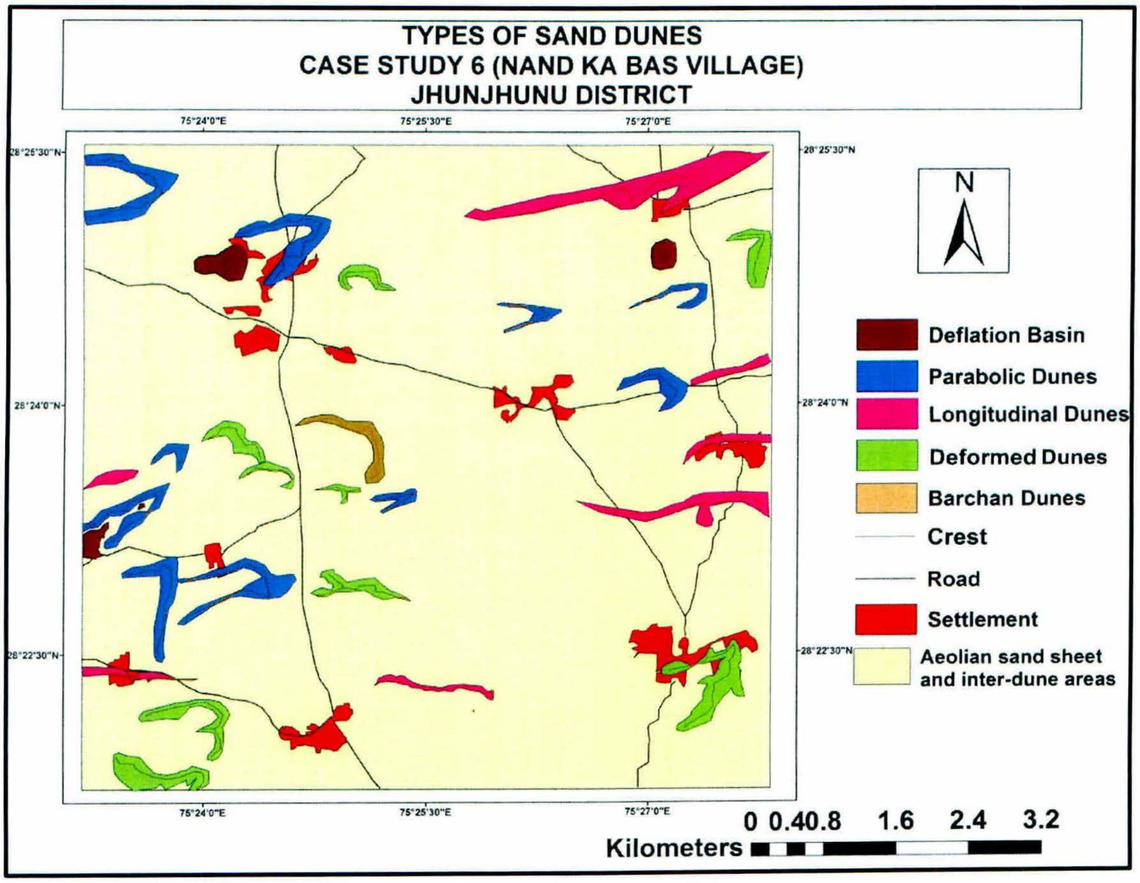


Fig. 4.14: Map of Dune types of Sankhu Fort village including Crest line of aDune and some Land Cover features.

In this sample area the parabolic dunes cover around 2.9 per cent of geographical area of this case study, followed by the longitudinal and deformed dunes cover 2.4 per cent individually.

4.4Driving Variables of Sand Dunes

The formation of the Thar Desert evolves through various climatic and tectonic fluctuations. And the source and formation of dune sand is still controversial. But the current patterns of sand dunes are still control or drive by the environmental variables.The Environmental variables (wind, rainfall, temperature) are constantly shaping Aeolian landforms, which lead them to such a current landforms structure. **Wilson (1973)**[37], **Frybergeret al. (1979)**[38], **Mainguet&Callot (1978)**[39], **Lancaster(2009)**[40], **Breed et al. (1979)**[41], **Singh (1981)**[42] are some works that had link the wind regime and other factors with the sand dunes morphology. In this section the wind, rainfall and temperature will tried to be associated with the structure and size of sand dunes of the study area. Whereas the seasonal and monthly wind direction, speed will be attempted to associated with the size and shape of sand dunes.

These climatic variables are very much responsible for the construction, modification and shifting of sand dunes. Rainfall and temperature are some of significant variables which had a great effect on the landscape. High temperature and low rainfall are such combination which had formed the various desertic conditions in all over the world, whereas the wind regimes are responsible for the erosional and depositional

[37]Wilson, I. G (1973), Ergs, Sedimentary Geology, 10(2), pp. 77-106.

[38]Fryberger, S.G. and Gary, D. (1979): "Regional Studies of Sand Seas, Using Landsat (ERTS) Imagery" In E. D. McKee (Ed.), A study of global sand seas, Professional Paper US Geological Survey No. 1052. Pp. 137-166

[39]Mainguet M. (1984), A Classification of Dunes based on Aeolian dynamics and the sand budget. In Deserts and Arid lands (ed.) by El-Baz, The hagueMartinusNjjhoff Publishers, pp. 31-58

[40]Lancaster, N. (2009): Aeolian features and processes, in Young, R., and Norby, L., Geological Monitoring: Boulder, Colorado, Geological Society of America, p. 1–25.

[41]Breed et al. (1979) Op. Cit.

[42]Singh (1981) Op. Cit.

processes.**Breed et al. (1979)**[43] also attempted to link the wind, precipitation with the types of sand dunes in the eight desertic regions of the world.

In the current study the data on last 55 years of rainfall, temperature data has been studied to understand the trend and pattern of climatic conditions in the study area. Whereas,last 9 years of wind data also taken to observe the direction and speed in the study region. In this section each individual variable will be studied separately and an attempt will be made to link it with the types of sand dunes in the study region.

4.4.1 Rainfall, Temperature and Wind

The Climatic condition is also very much responsible for carving the shape of landforms but their influence on sand dunes occurs in a very slow process. Rainfall and temperatures are some such environmental variables which affectthe condition of Aeolian environment and contributing affords to modify the Aeolian features. Following are the description of rainfall and temperature of study region, which provide a general view regarding the climatic conditions and their pattern will help to understand the dynamics of landforms.

- **Rainfall**

The study area is located in an arid and semi-arid region.To study the spatial coverage of rainfall,last 55 years data of Churu and Jhunjhunu station were taken. The trend of last 30 years mean annual rainfall of all station of district Churu and Jhunjhunu is mapped in the following isohyet map, which will provide an overview of rainfall pattern. The rainfall pattern decrease from east to west and thus it clearly show the division of arid and semi-arid region.

[43] *Ibid.*

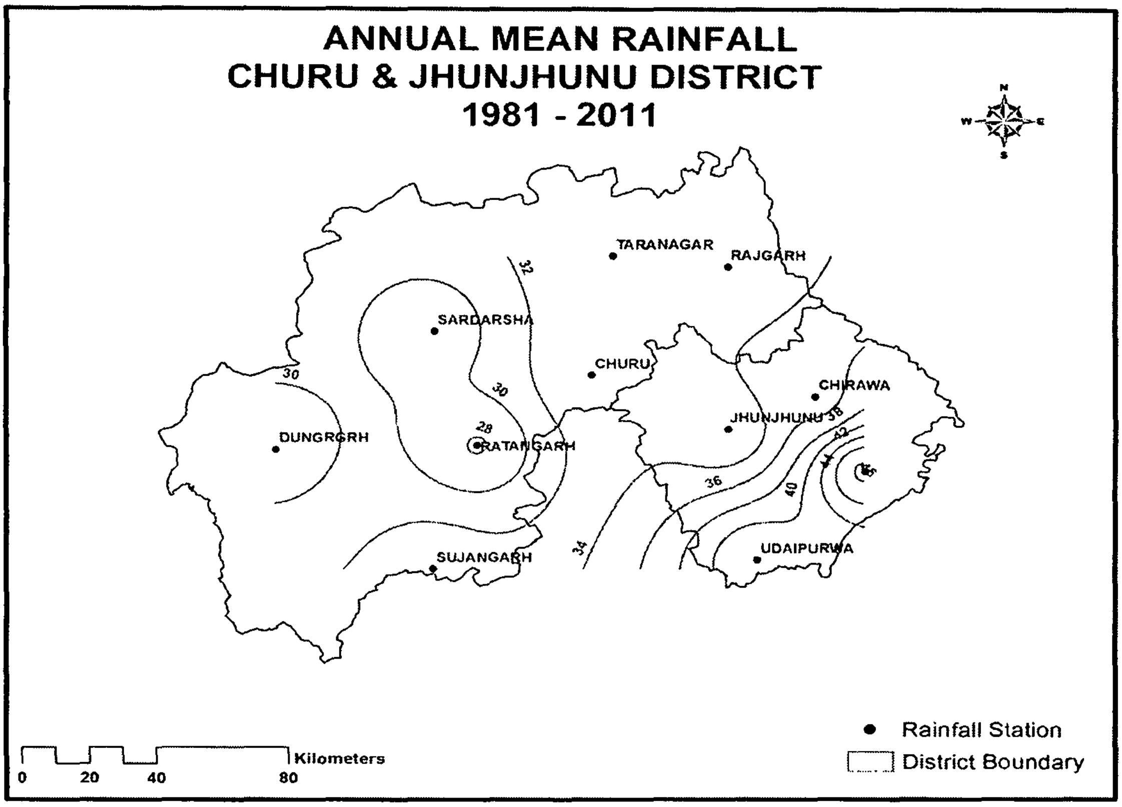


Fig. 4.15: An Isohyet Map of Annual Mean rainfall from 1981 to 2011, showing the distribution of rainfall in the region.

Rainfall in district Churu and Jhunjhunu is mostly governed by the south west monsoon period. The south west monsoon condition is poor and it brings rain in a very sporadic manner. But when the rainfall conditions were better than it will not onlyendow agriculture production, it also accelerates the erosion processes. The fluvial processes act less frequently and occasionalthan the Aeolian processes, but their impacts on landforms can be observed after that, especially after the high-intensity rainfall events for short period of time during the summer monsoon. The short period rainfall turn the Aeolian processes into fluvial processes for a while. Gully erosion, sediment redistribution are some such processes which is triggered by the arrival of monsoon rain.

According to **Kar (1992)**[44] the fluvial and Aeolian processes are still active in the Thar Desert of India. The present distribution of rainfall direct the fluvial processes in the

[44] Kar A (1992), Morphological Processes, Human influences and Land Degradation in the Indian Desert. In New Dimensions in Agricultural Geography: The ecology of agricultural system by Mohammad Noor (Ed.), Concept Publishers, New Delhi.

Indian Desert. According to him, the gradual change of climate made wetter east along the Aravalli and drier west along the Indo-Pakistan border. Thus it has made dominant fluvial erosion along the east and Aeolian processes along the western margin. Whereas the central part having both fluvial and Aeolian processes. **Gupta J.P (1979)**[45]also linked moisture or rainfall conditions with the stabilised and in unstablised sand dunes of Bikaner regions.

The 30 years mean annual rainfall of district Churu and Jhunjhunu are 31.2 and 39 mm respectively. The mean average rainfall and mean average rainy days during 1956 to 2010 of Churu and Pilani stations are shown in Table 4.3, both station individually representing the district Churu and Jhunjhunu. The rainfall statistics in numbersshows that the rainfall conditions are much better in the eastern margins of study area as compare to the western margins. The mean Annual rainfall and mean annual rainy days in both station is almost same but the monthly and seasonal fluctuation show the clear variation in the rainfall in both station.

Table 4.2: Seasonal variation of Rainfall (mm) of Churu and Pilani Station

	Churu	*Pilani*
Winters	19.0	8.7
Pre-Monsoon	13.4	13.7
Monsoon	76.8	88.5
Post-Monsoon	12.0	6.1

[45]Gupta J.P (1979), Some Observations on the periodic Variations of moisture in stabilised and unstablised sand dunes of the Indian Desert, Journal of Hydrology, 41, pp.153-156

Table 4.3: The Mean Monthly/Annual Rainfall and Mean Monthly/Annual Rainy Daysof Churu and Pilani Station from 1956 to 2010

	Churu		Pilani	
	Mean Annual Rainfall	*Mean Annual Rainy Days*	*Mean Annual Rainfall*	*Mean Annual Rainy Days*
Jan	28.4	1	7.8	1
Feb	9.5	1	9.7	1
Mar	9.0	1	9.4	1
Apr	6.4	1	5.9	1
May	24.9	2	25.7	2
Jun	40.6	3	53.3	3
Jul	121.4	7	131.5	7
Aug	96.0	5	118.6	6
Sep	49.0	3	50.4	3
Oct	14.7	1	10.9	1
Nov	14.1	0	3.4	0
Dec	7.1	0	4.0	0
Annual	35.1	2	35.9	2

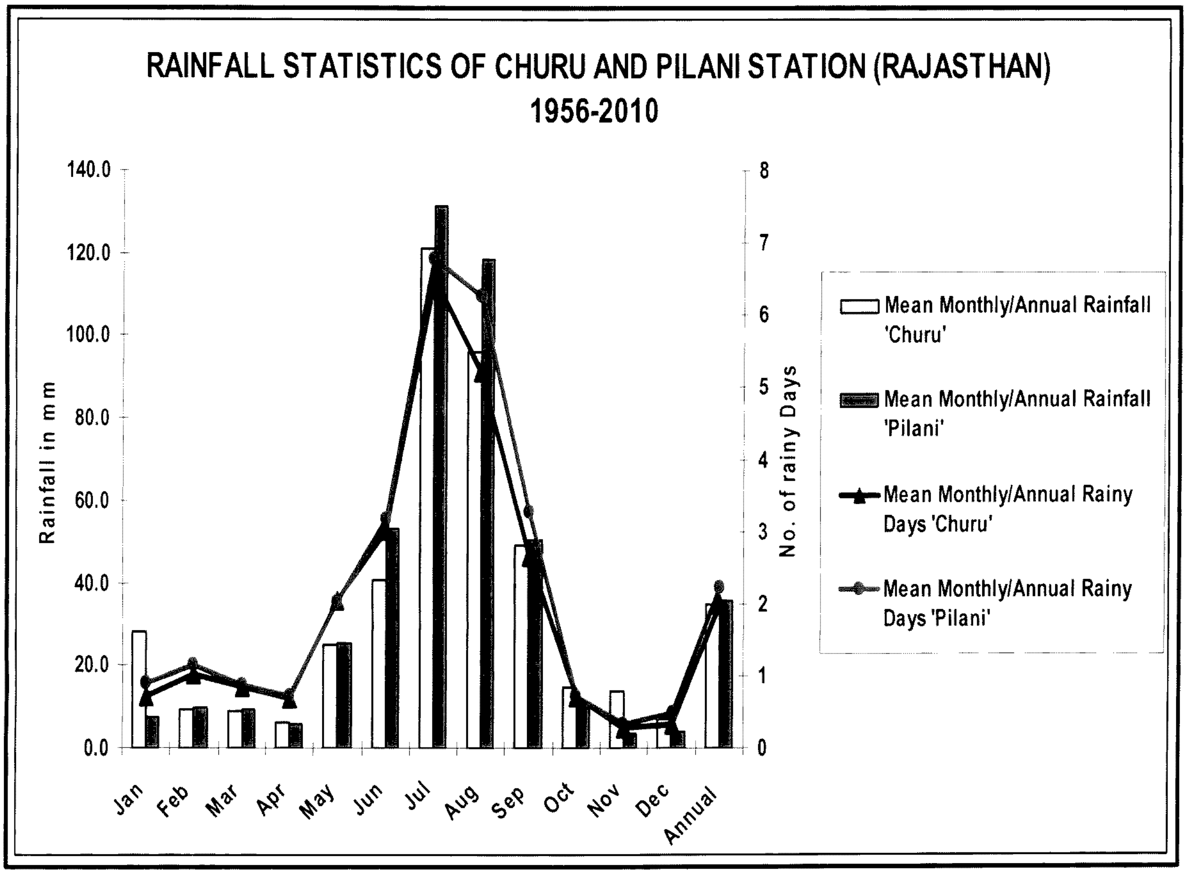


Fig. 4.16: The graphical representation of Mean Monthly/Annual Rainfall and Mean Monthly/Annual Rainy Daysof Churu andPilani Station.

- **Temperature**

The temperature condition of Churu and Jhunjhunu district also vary significantly. The seasonal pattern of temperature of last 55 years is shown in the following table.

Table 4.4: The seasonal Mean Highest and Lowest temperature of Churu and Pilani Station from 1956 to 2010

	Churu		Pilani	
Seasons	***Mean Highest Max. Temp (in Deg. C)***	***Mean Lowest Min. Temp (in Deg. C)***	***Mean Highest Max. Temp (in Deg. C)***	***Mean Lowest Min. Temp (in Deg. C)***
Winters	30.2	0.9	29.1	2.0
Pre-Monsoon	42.5	13.5	41.3	13.3
Monsoon	42.0	22.5	40.8	21.7
Post-Monsoon	34.5	6.3	33.6	7.2

As the afore-mentioned figure 4.16clearly show, the temperature condition of two different stations. The temperature of Churu is relatively high by 1 Deg. C in terms of highest maximum temperature. In Lowest minimum temperature shows the mix trend of fluctuation. These temperature trends affect the existing relief and hence provide favourable conditions for the development of landforms. The 1 Deg. C difference can make huge difference in terms of vegetation, water condition etc.

The same pattern can also beobserved in the mean monthly/annual temperature of Churu and Pilani Station from 1956 to 2010.In the mean monthly/annual monthly figure the two stations have relatively 1 degree difference, but if we go further away from the Churu station than the temperature condition will again increase. This trend has been verified by the Indian Metrological Department report on Climate of Rajasthan (1988) in which classified the climate of Churu district having a tropical desert, arid and hot conditions whereas Jhunjhunu is classified as having a tropical steppe, semi-arid and hot conditions.

Table 4.5: The Mean Monthly/Annual Temperature (Centigrade) of Churu and Pilani Station from 1956 to 2010

	Churu	Pilani
Jan	14.6	13.4
Feb	17.7	16.8
Mar	23.5	22.5
Apr	29.7	28.2
May	33.8	32.4
Jun	34.4	33.8
Jul	31.8	31.4
Aug	30.4	30.1
Sep	30.1	29.2
Oct	27.1	26.1
Nov	21.3	20.5
Dec	16.1	15.1
Annual	26.2	25.0

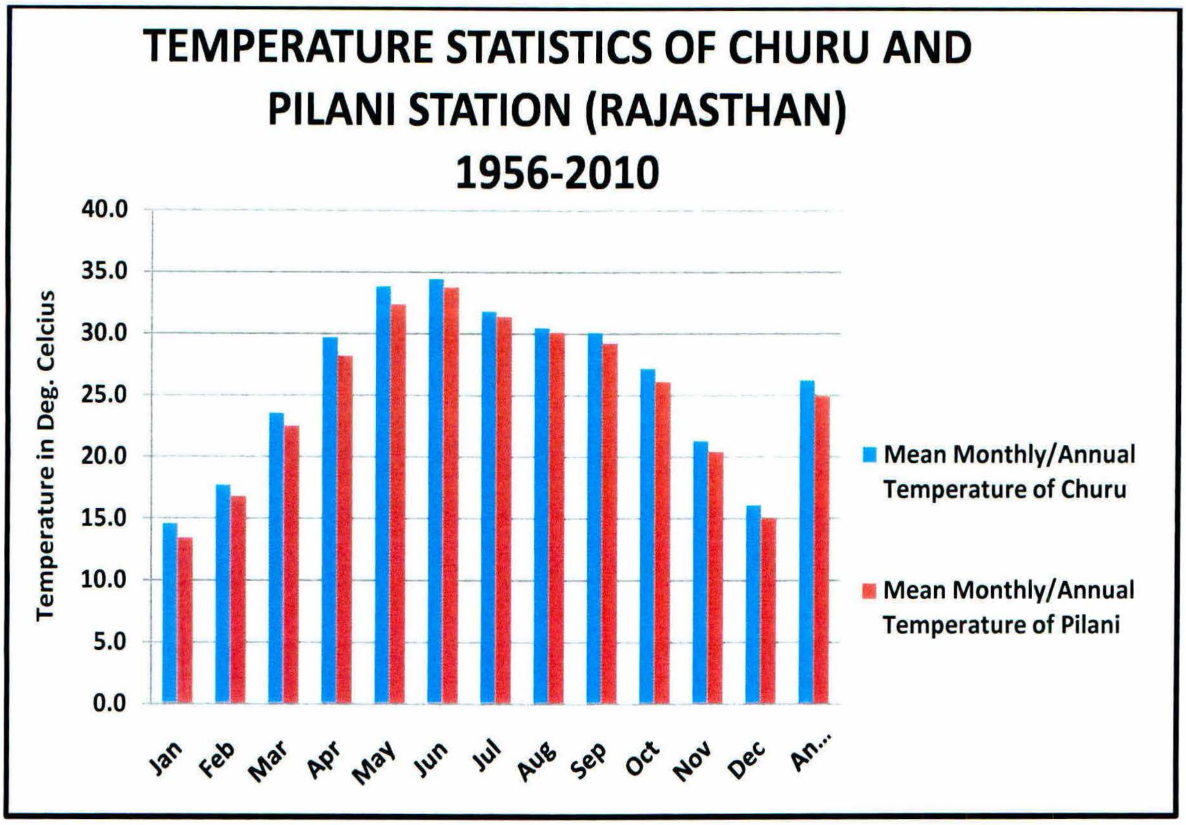


Fig. 4.17: The graphical representation of Mean Monthly/Annual Temperature (in Deg. C) of Churu andPilani Station from 1956 to 2010.

The relationship between temperature and sand dunes can be understood with the effect of temperature on the regional soil, moisture and vegetation condition. The temperature condition determined the availability of moisture and the condition of soil. Maximum temperature leads to the greater evaporation which dries the soil structure and hindered the vegetation for further growth. In addition, wind action play crucial role and erode the top layer of soil and start the Aeolian processes. **Tang C et al. (1999)**[46]also relate the temperature distribution in the sand dune is closelyrelated to the water content of an area in their experiment.Thus maximum temperatures for long duration lead to the greater moisture lose which will affect the sand dunes stability. Temperature is also an important variable for driving the sand dunes and controlling its morphology and size.

[46]Tang C, sindo S, Sakura Y, Machida I (1999), In situ experiments on water infiltration in sand dunes traced by temperature, Proceedings of IUGG 99 Symposium HS4, Birmingham.

- **Wind Speed and Direction**

Wind is the most significant and powerful medium of erosion and deposition in the Aeolian Environment. This variable is not only change the shape of a dune but it also distributes the sand dunes through transportation mechanism. **Frybergeret al. (1979)**[47], **Breed et al. (1979)**[48], **Singh (1981)**[49]are some works which have related the wind regime pattern with the sand dunes. According to **Sharma (1987)**[50]the wind speed and direction has an effect on the intensity of abrasion which form the dunes in Rajasthan Desert. The alignment of the dunes in Barmer, Bikaner, Churu and Jhunjhunu is related with the direction of the wind.

The distribution of daily wind intensities obtained from data recorded from 2000 to2009 at Churu and Pilani stations by Indian Meteorological Department, Pune. The available 9 year period wind data reveals that the direction of wind is blown from the south-south west (SSW) in all season and months with some variation. But the speed of the wind in between varies significantly. Following tables 4.6 show the mean monthly wind speed from 2000 to 2009 in (Km/hrs.)of both stations.

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[47]Fryberger et al. (1979), Op. Cit.

[48]Breed et al. (1979), Op. Cit.

[49]Singh (1981), Op. Cit.

[50]Sharma, H.S (1987): Tropical Geomorphology: A Morphogenetic Study of Rajasthan, Concept New Delhi.

Table 4.6: The Mean Monthly Wind Speed from 2000 to 2009

	Monthly Average of Wind Speed Pilani (km/hrs.)	Monthly Average of Wind Speed Churu (km/hrs.)
Jan	2.9	2.5
Feb	2.9	2.5
Mar	4.6	5.8
Apr	4.6	5.8
May	4.8	5.8
Jun	5.3	5.9
Jul	5.2	5.8
Aug	5.5	5.8
Sep	5.5	5.7
Oct	2.8	1.3
Nov	2.8	1.2
Dec	2.8	1.2

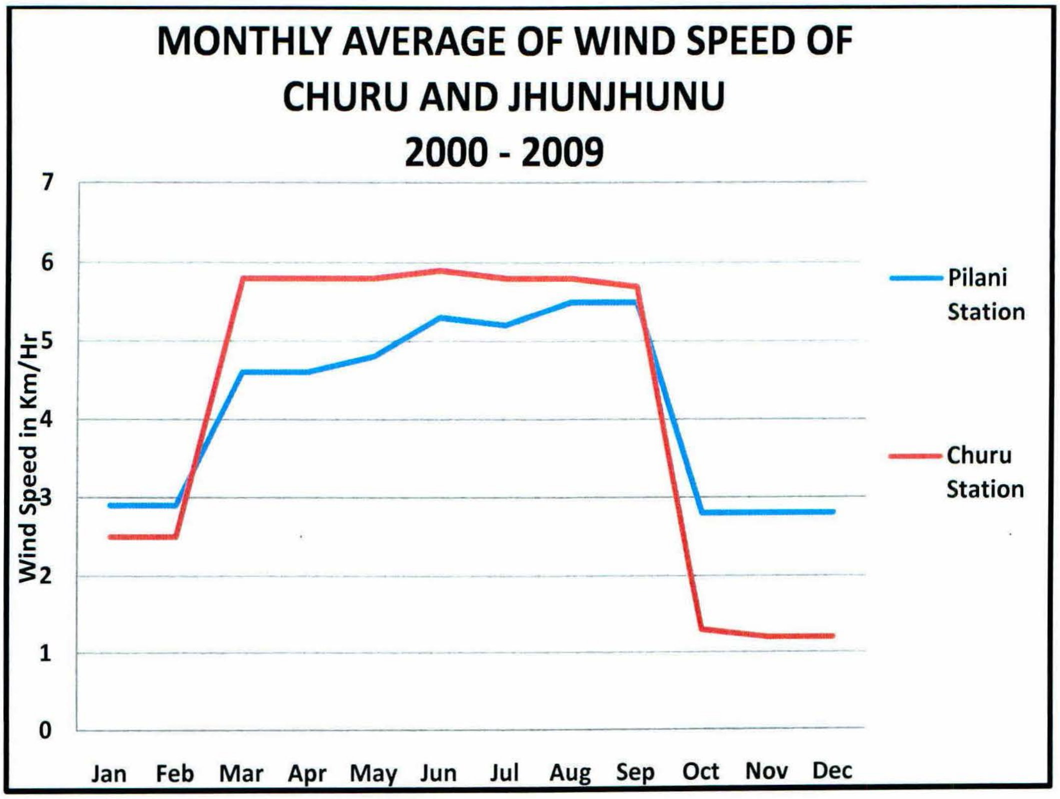


Fig. 4.18: Graph of mean monthly wind speed at two representative stations in Churu and Jhunjhunu District, Rajasthan

As observed from the table the mean monthly wind speed of Churu and Pilani station is clearly showing the variation. Whereas, graphical representation also indicate that the wind speed at Pilani station is comparatively low as compare to Churu station. The maximum wind speed of Churu station is started from March to October and it was at its lowest from November to December months. In Pilani station the conditions of wind speed is relatively low almost constantly distributed over the seasonal basis.

After plotting nine years data on 16 directional scales the mean seasonal pattern of wind direction of both stations is from the SSW. For seasonal analysis *winter season* were taken from January to February, *Pre-Monsoon season* were taken from March to April, *Monsoon season* is taken from June to September and *Post Monsoon season* were taken from October to December.The wind direction also shows a clearseasonal pattern, blowing from the South-south west for most of the year. Almost all the years in both stations wind comes from the same direction with different intensity. As per the mean seasonal wind speed, Churu station experience the maximum wind speed during monsoon season followed by the pre-monsoon period. Whereas the Pilani station also experiences the same trend but the wind speed is comparatively lower. Most Aeolian activityoccurs during the dry season from March to July month.

The most ideal conditions for Aeolian activities can be determined by the combineevents of frequent winds, rainfall, sand dune morphology, and vegetation cover. These optimumconditions signify the maximum number of hours during which such combine forcecan potentially occur in arid and semi-arid region. The percentage frequency tables for Seasonal analysis of wind direction are following:

Table 4.7: Percentage Frequency of Pilani station (Winter Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0	0	0	0	0	0
22.5 (NNE)	0	0	0	0	0	0
45 (NE)	0	0	0	0	0	0
67.5 (ENE)	0	0	0	0	0	0
90 (E)	0	0	0	0	0	0
112.5 (ESE)	0	0	0	0	0	0
135 (SE)	0	0	0	0	0	0
157.5 (SSE)	0	0	0	0	0	0
180 (S)	14.95	2.25	0.09	0.00	0.17	0
202.5 (SSW)	58.69	2.33	0.09	0.00	0.09	0
225 (SW)	19.27	1.04	0.00	0.00	0.00	0
247.5 (WSW)	0	0	0	0	0	0
270 (W)	0	0	0	0	0	0
292.5 (WNW)	0	0	0	0	0	0
315 (NW)	0	0	0	0	0	0
337.5 (NNW)	0	0	0	0	0	0

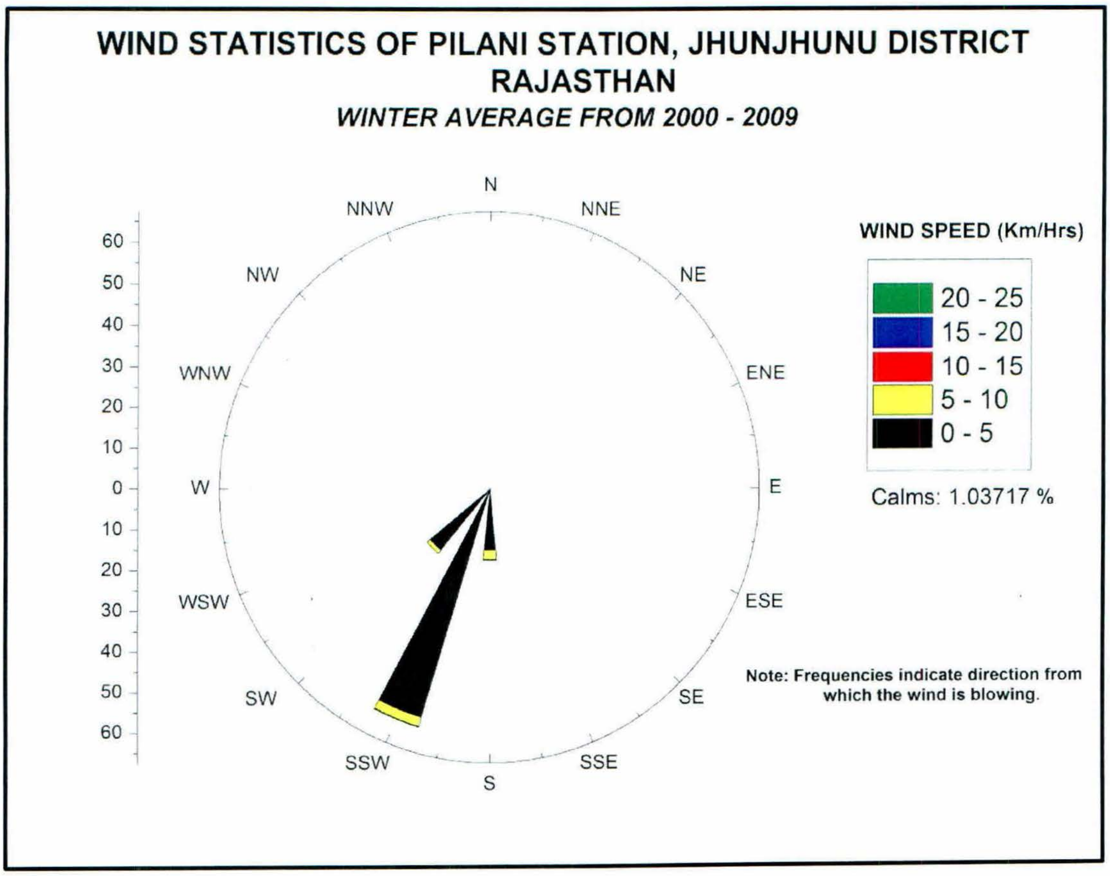


Fig. 4.19: Wind roses, showing wind speed, direction, and frequency of occurrence at Pilani Station during winters (2000-09).

Table 4.8: Percentage Frequency of Pilani station(Pre-Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	8.56	3.17	0.76	0.13	0.06	0.13
202.5 (SSW)	47.34	14.20	4.69	0.76	0.63	0.06
225 (SW)	14.39	3.87	0.38	0.06	0.06	0.13
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

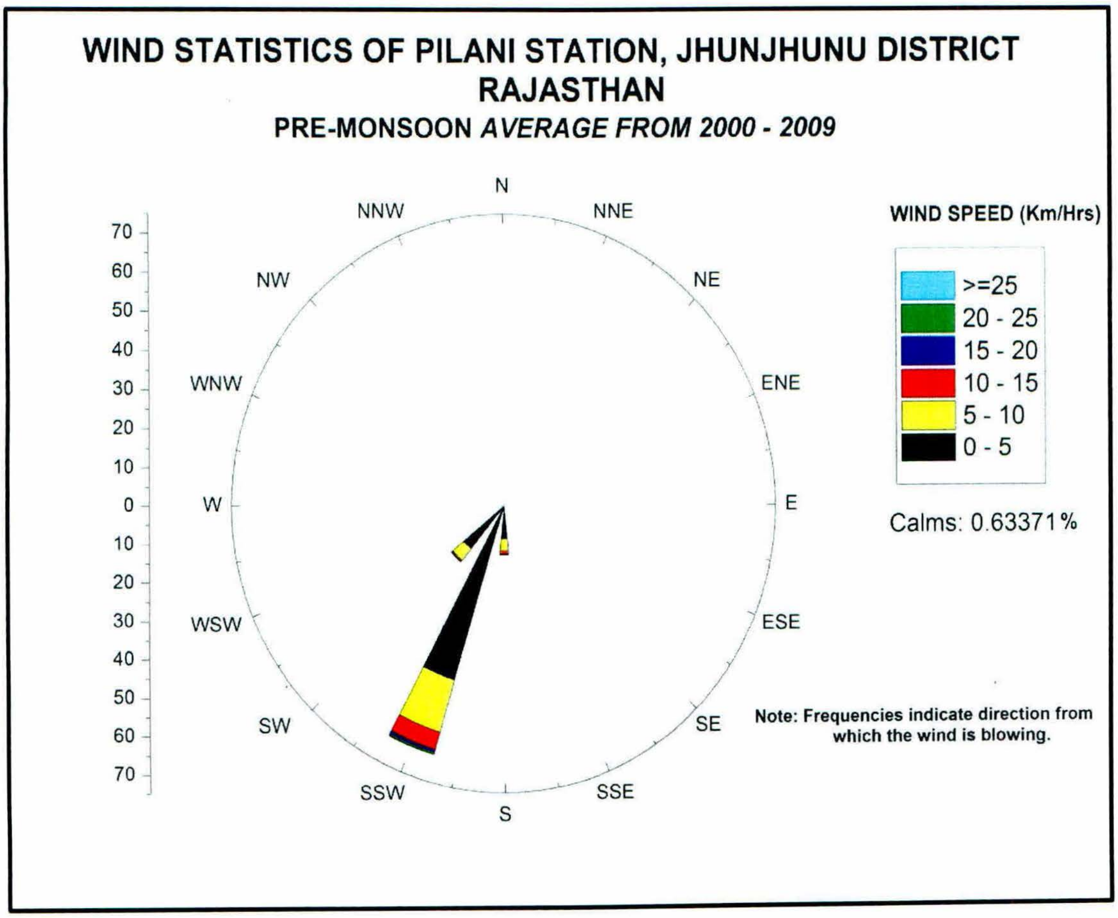


Fig 4.20: Wind roses, showing wind speed, direction, and frequency of occurrence at Pilani Station during Pre-Monsoon Season (2000-09).

Table 4.9: Percentage Frequency of <u>Pilani station</u>(Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	11.75	3.88	1.22	0.06	0.17	0.00
202.5 (SSW)	47.37	15.07	5.04	1.33	1.94	0.39
225 (SW)	9.14	1.83	0.44	0.17	0.11	0.00
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

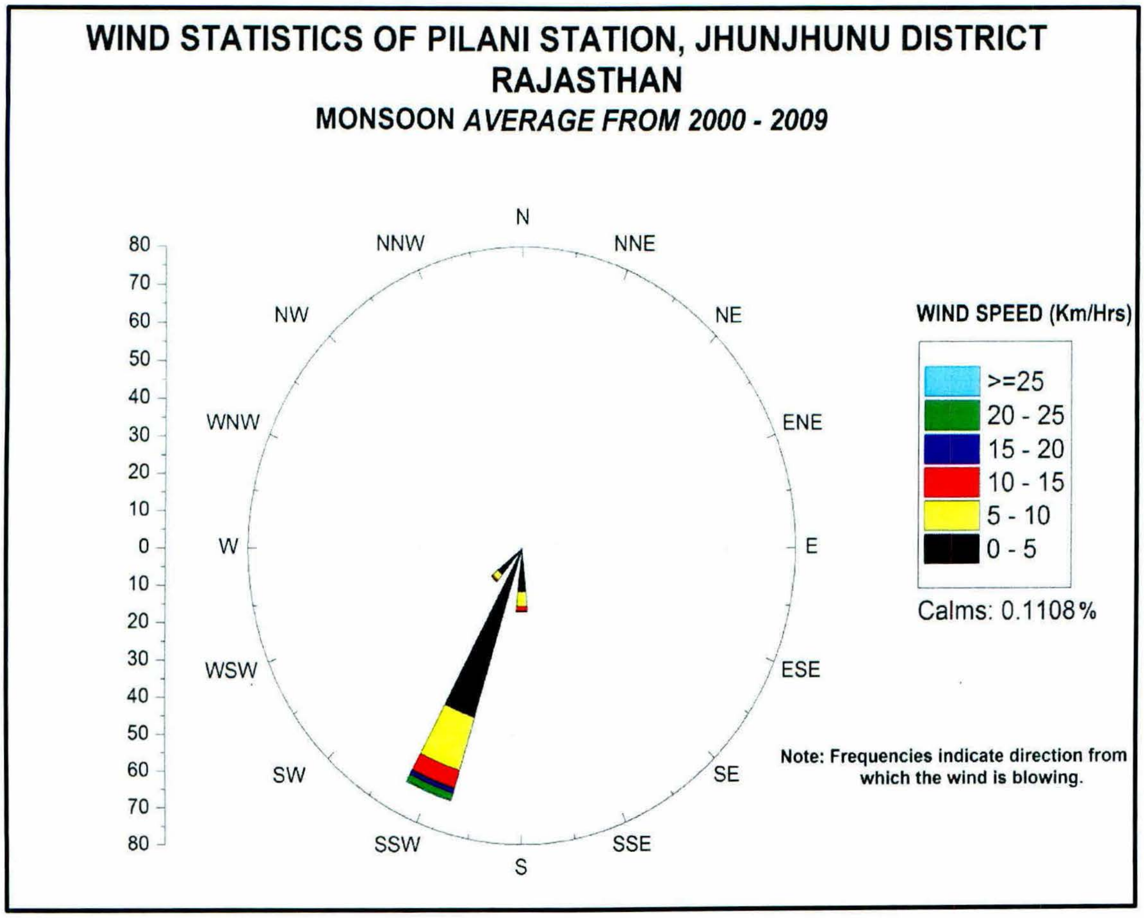


Fig. 4.21: Wind roses, showing wind speed, direction, and frequency of occurrence at Pilani Station during Monsoon Season (2000-09).

Table 4.10: Percentage Frequency of Pilani station(Post-Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	>=20 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00
180 (S)	8.96	0.45	0.15	0.07	0.00
202.5 (SSW)	63.85	1.19	0.07	0.00	0.00
225 (SW)	23.53	0.52	0.07	0.00	0.00
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00

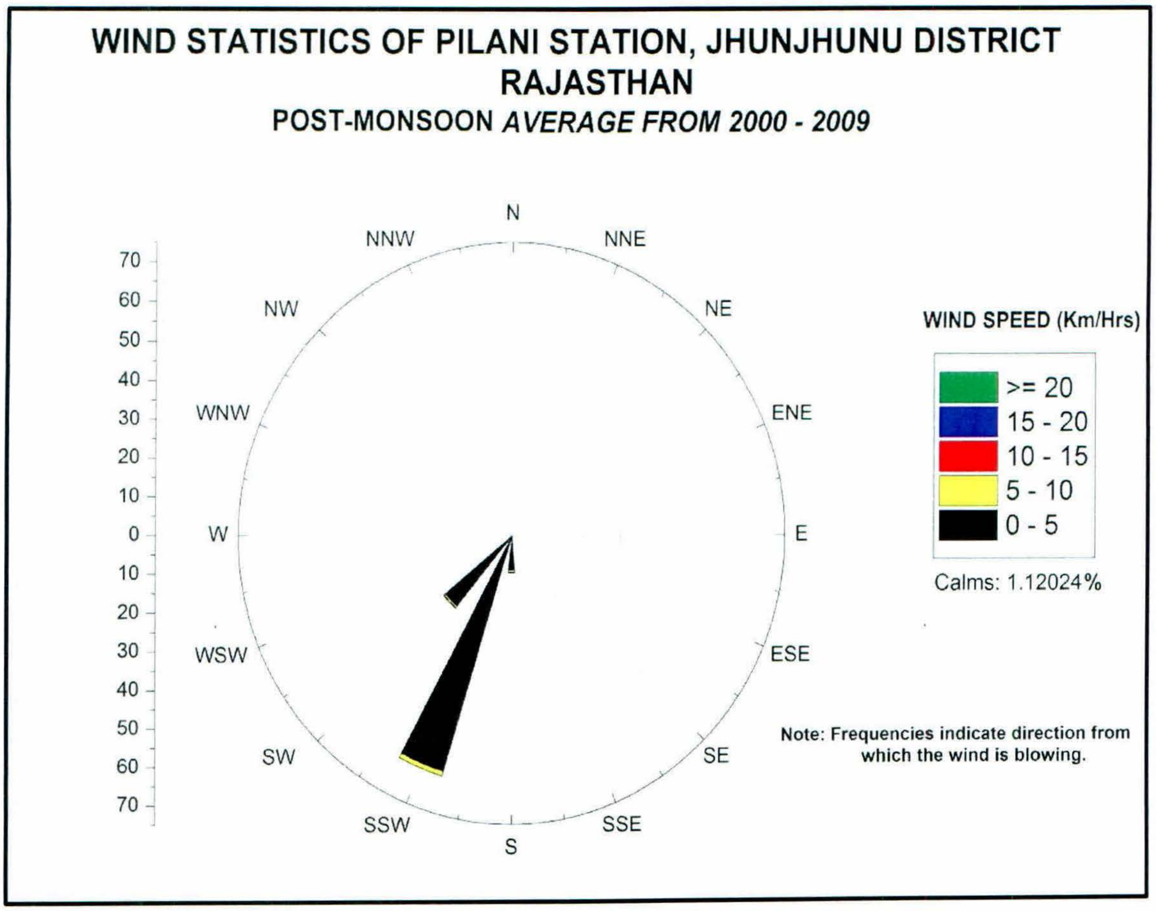


Fig. 4.22: Wind roses, showing wind speed, direction, and frequency of occurrence at Pilani Station during Post-Monsoon Season (2000-09).

Table 4.11: Percentage Frequency of Churu station (Winter Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	12.72	3.40	0.66	0.00	0.00	0.00
202.5 (SSW)	22.48	7.46	1.54	0.55	0.33	0.00
225 (SW)	7.89	1.54	0.33	0.00	0.00	0.00
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

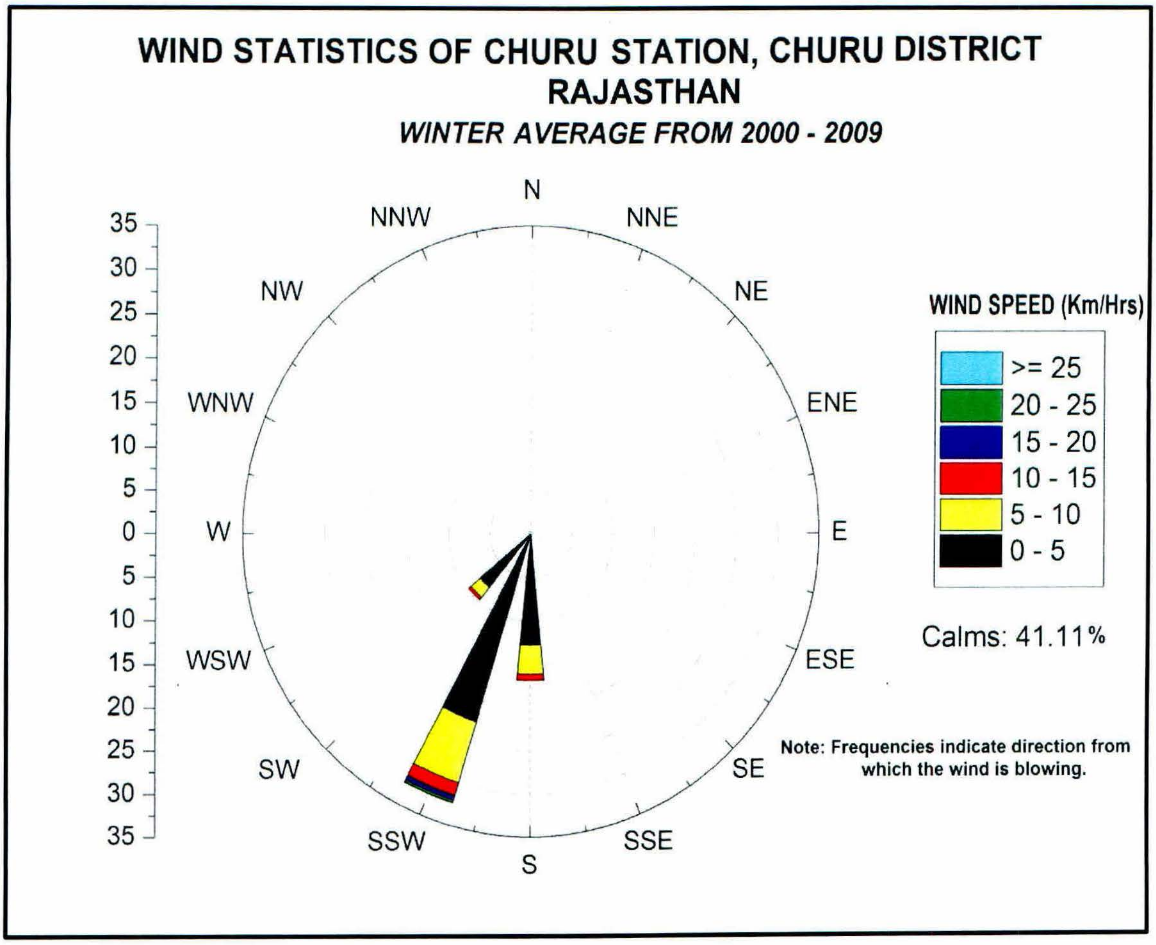


Fig. 4.23: Wind roses, showing wind speed, direction, and frequency of occurrence at Churu Station during Winter Season (2000-09).

Table 4.12: Percentage Frequency of **Churu station** (Pre-Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	6.98	2.99	1.52	0.12	0.12	0.00
202.5 (SSW)	30.30	19.99	10.73	2.93	2.05	0.66
225 (SW)	3.52	1.52	0.29	0.06	0.06	0.12
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

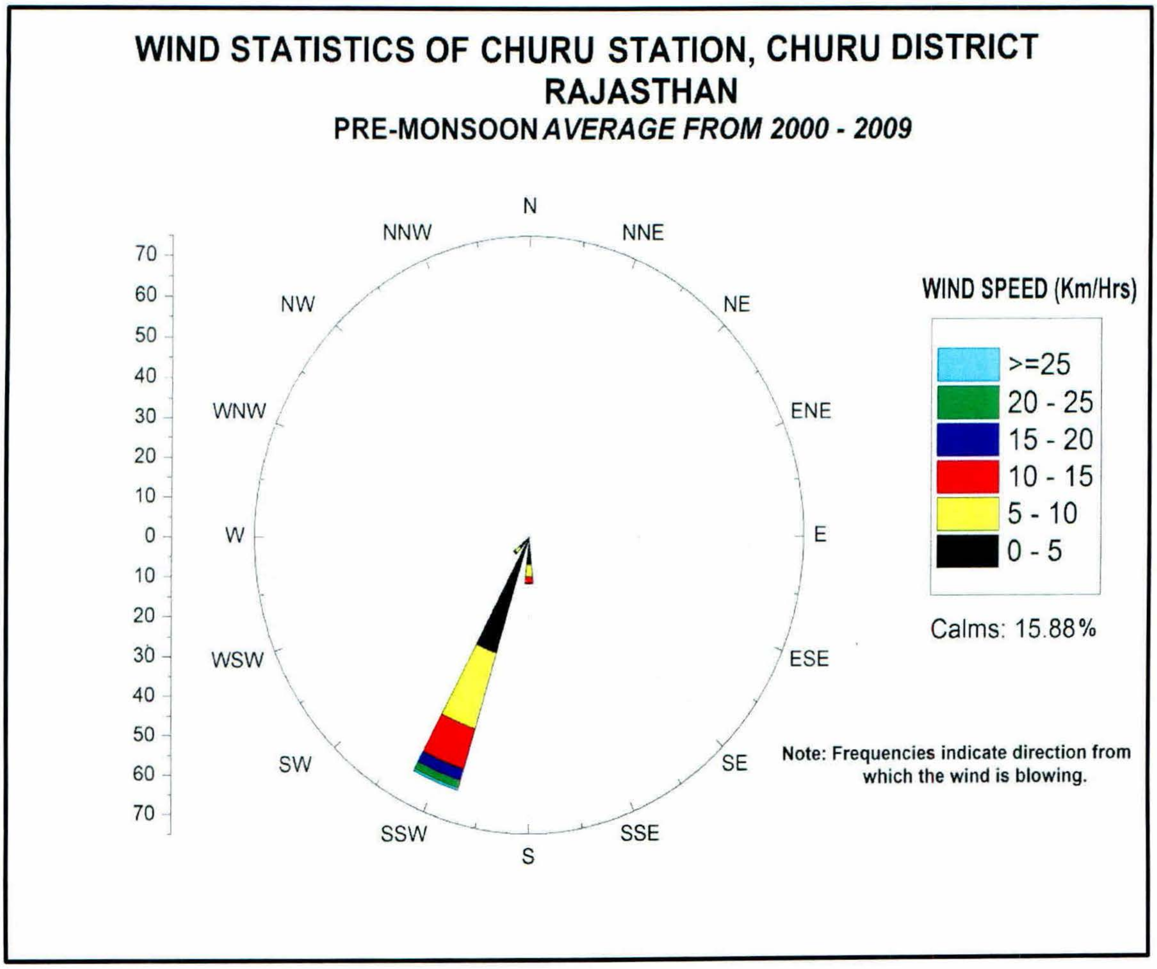


Fig. 4.24: Wind roses, showing wind speed, direction, and frequency of occurrence at Churu Station during Pre-Monsoon Season (2000-09).

Table 4.13: Percentage Frequency of Churu station (Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	9.64	7.20	2.03	0.21	0.08	0.04
202.5 (SSW)	21.55	26.80	11.99	1.86	0.79	0.25
225 (SW)	2.73	0.99	0.33	0.04	0.08	0.00
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

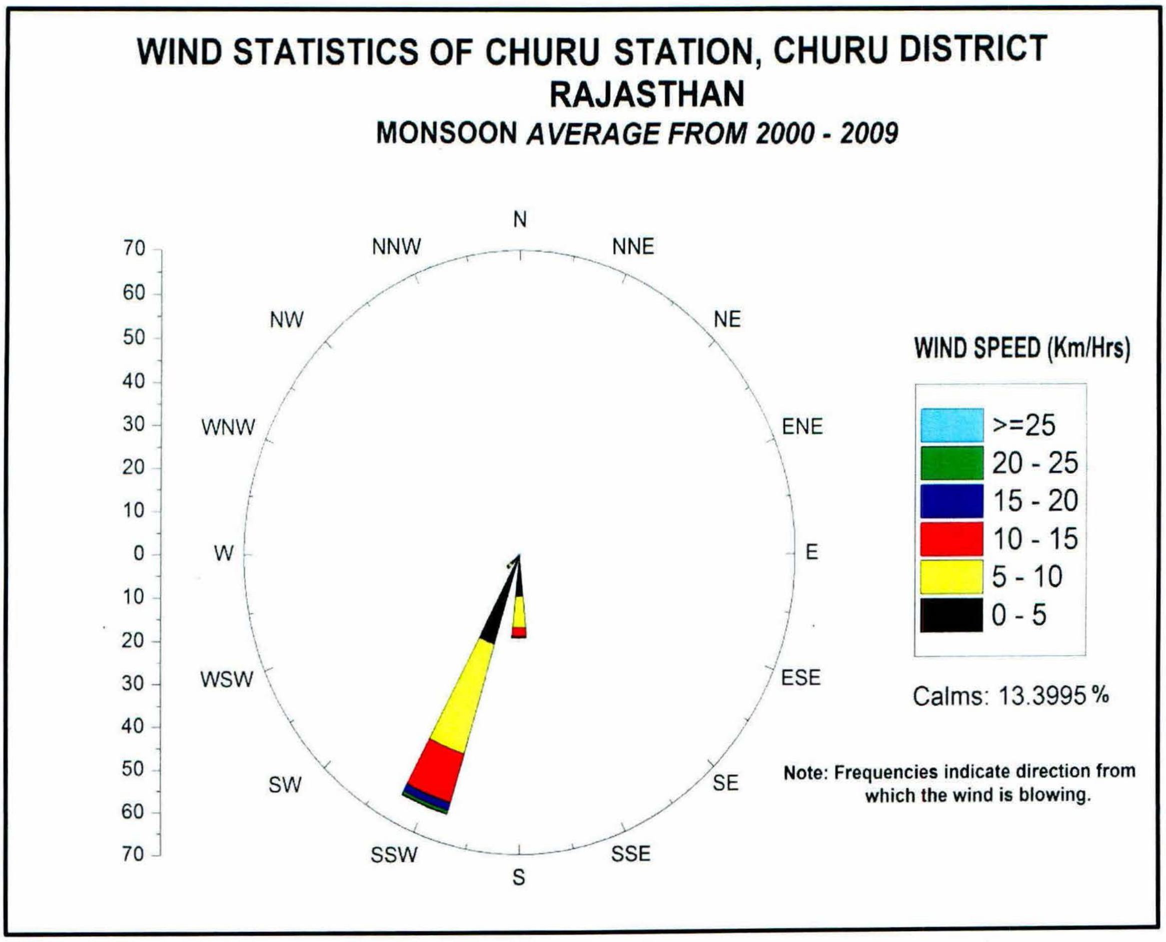


Fig.4.25: Wind roses, showing wind speed, direction, and frequency of occurrence at Churu Station during Monsoon Season (2000-09).

Table 4.14: Percentage Frequency of <u>Churu station</u> (Post-Monsoon Season)

Direction	0 – 5 (Km/hr)	5 – 10 (Km/hr)	10 – 15 (Km/hr)	15 – 20 (Km/hr)	20 – 25 (Km/hr)	>= 25 (Km/hr)
0 (N)	0.00	0.00	0.00	0.00	0.00	0.00
22.5 (NNE)	0.00	0.00	0.00	0.00	0.00	0.00
45 (NE)	0.00	0.00	0.00	0.00	0.00	0.00
67.5 (ENE)	0.00	0.00	0.00	0.00	0.00	0.00
90 (E)	0.00	0.00	0.00	0.00	0.00	0.00
112.5 (ESE)	0.00	0.00	0.00	0.00	0.00	0.00
135 (SE)	0.00	0.00	0.00	0.00	0.00	0.00
157.5 (SSE)	0.00	0.00	0.00	0.00	0.00	0.00
180 (S)	6.75	0.94	0.23	0.00	0.00	0.00
202.5 (SSW)	18.31	3.05	0.29	0.06	0.06	0.00
225 (SW)	5.69	0.59	0.06	0.00	0.00	0.00
247.5 (WSW)	0.00	0.00	0.00	0.00	0.00	0.00
270 (W)	0.00	0.00	0.00	0.00	0.00	0.00
292.5 (WNW)	0.00	0.00	0.00	0.00	0.00	0.00
315 (NW)	0.00	0.00	0.00	0.00	0.00	0.00
337.5 (NNW)	0.00	0.00	0.00	0.00	0.00	0.00

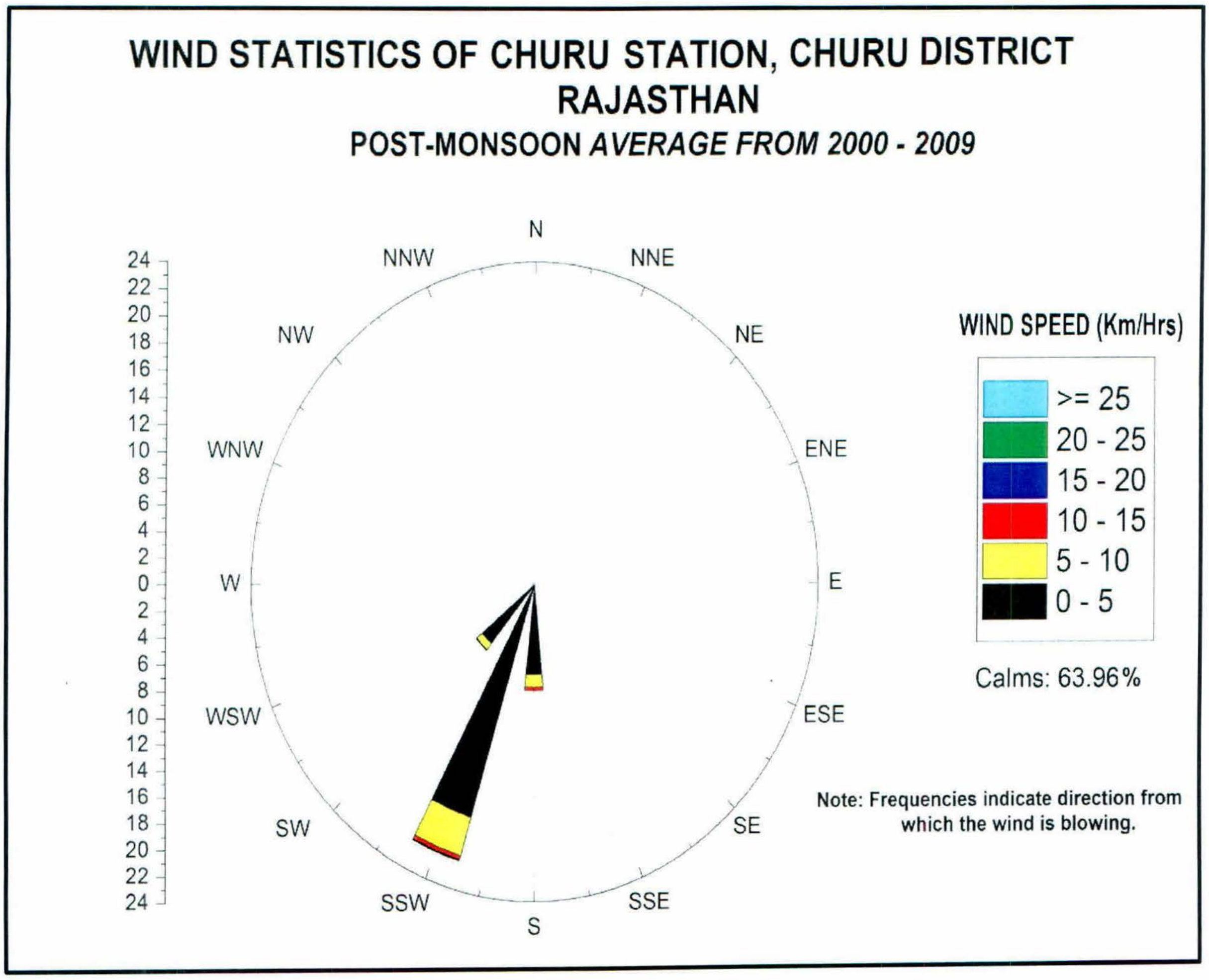


Fig. 4.26: Wind roses, showing wind speed, direction, and frequency of occurrence at Churu Station during Post-Monsoon Season (2000-09).

4.4.2 Relationship between Dune Types and Environmental Variables (Rainfall, Temperature & Wind)

The relationship between different types of sand dunes and environmental variables (Rainfall, Temperature & Wind) has a very positive relationship. **Breed et al. (1979)** relate the wind, precipitation with the types of sand dunes in the eight desertic regions of the world. These variables sometimeseffect sand dunes individually or erstwhile in a combine way. But in order to relate the sand dunes types with environmental variables, the majority of works have been done on the process of wind and their work for theconstructions ofsand dunes. In this direction**Frybergeret al. (1979)**, **Kar (1996)** and **Singh (1981)**are some significant works that had link the wind action with dune morphology.

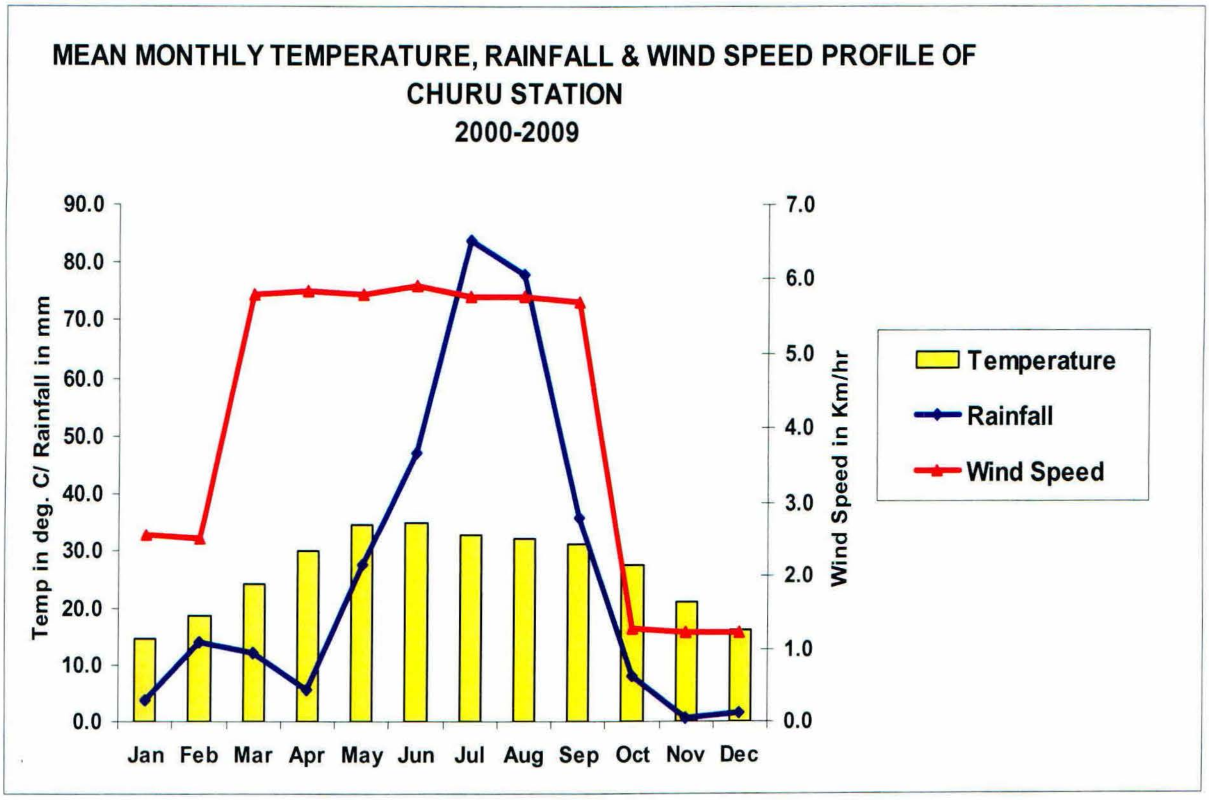


Fig. 4.27: The graphical representation of Mean Monthly Rainfall, temperature and wind speed (km/hr.) of Churu Station, Churu District.

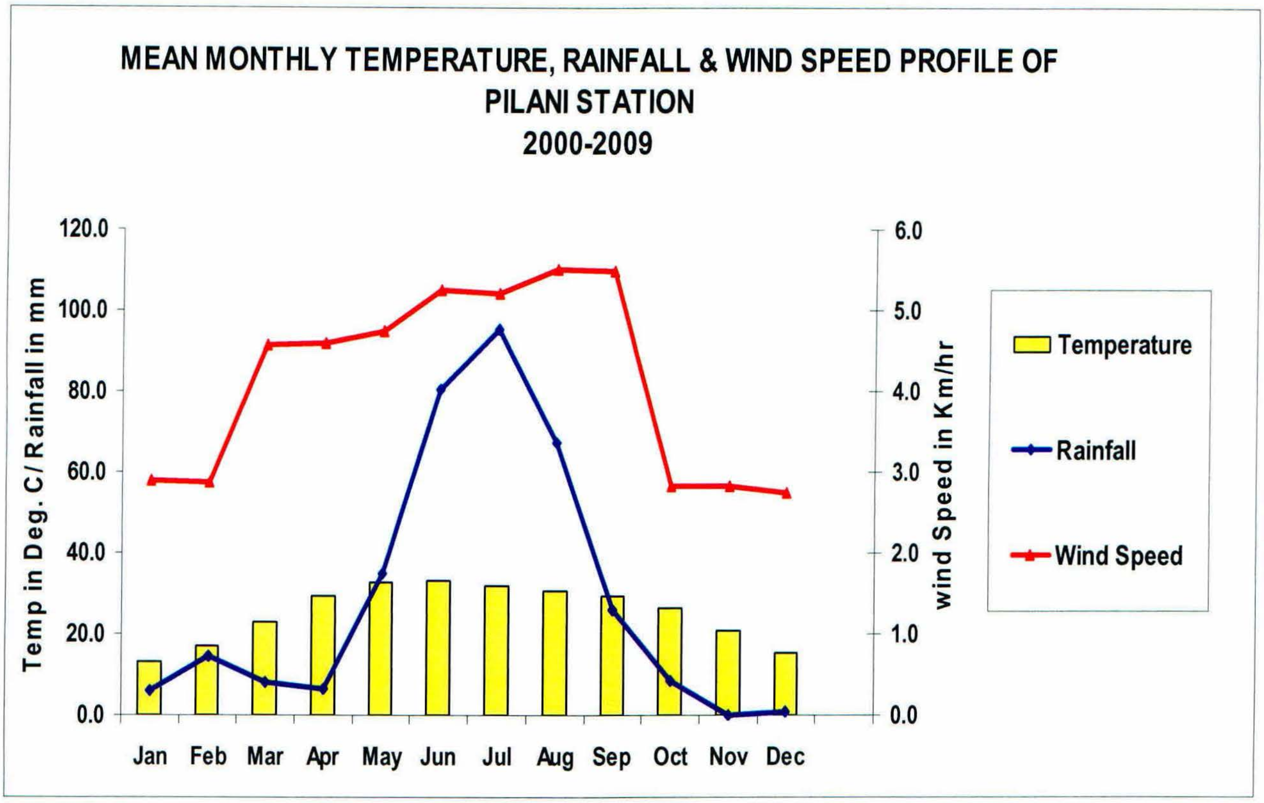


Fig. 4.28: The graphical representation of Mean Monthly Rainfall, temperature and wind speed (km/hr.) of Pilani Station, Jhunjhunu District.

In fig. the maximum rainfallin Churu isfrom the month of July and Augustbut Pilani station has received the rainfall from June to August month in a much long duration as compare to Churu. The trend in temperature shows that Churu station has a maximum temperature as compare to Pilani station. In wind speed the blowing duration of maximum average wind speed also noticed in the Churu station. From March to September the average wind speed is almost same and above the wind speed of 5.5 km/hr. wherein the average wind speeds > 5 km/hr in Pilani station is noticed during the months of June to September. Due to absence of comparative high resolution satellite data the wind speedcannot be link with the modification of dunes but the wind direction can be related with the shape of dunes in different case study of micro level mapping of dune types.

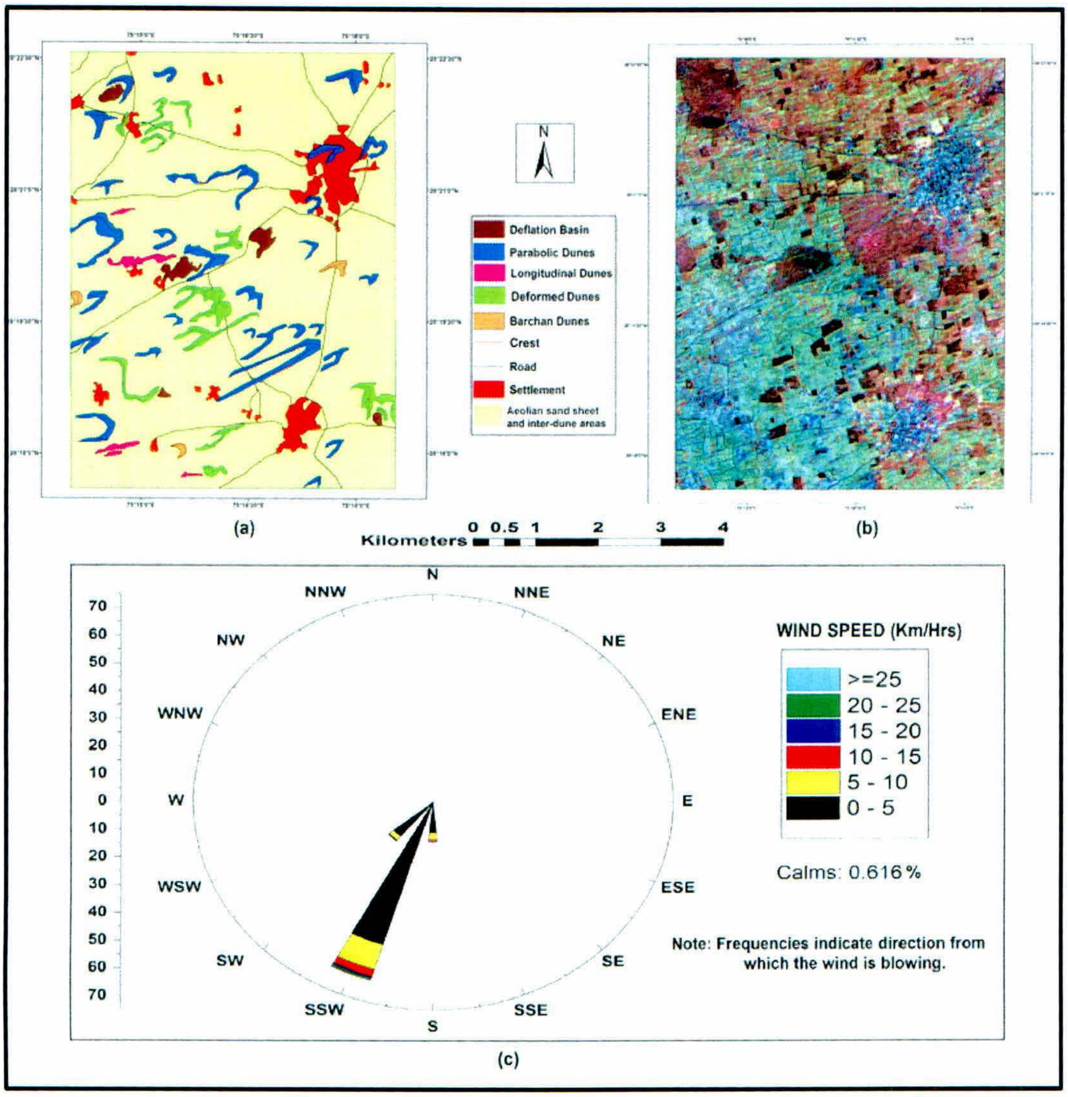


Fig. 4.29: Relation between wind direction & shape of a Dune (a) A map of different types of sand dunes in Alsisiar Village, Jhunjhunu District, (b) RGB fused HRS Cartosat -1 Imagery (c) Wind Roses of Pilani station, Jhunjhunu district (2000-2009) showing the orientation of wind from South-south west and blowing to North-north east.

Thus, there is a relationship between rainfall, temperature and wind. In this study region having an appropriate rainfall and temperature leads to the proper vegetation growth and agricultural practice. In study area (especially in District Jhunjhunu) sand dunes were stabilised by either afforestation cover or by agricultural practice, this has been observed on the filed visit. In the satellite data the spectral reflectance also not able to provide the dunes conditions, the diffused high resolution Cartosat imagery clearly show that the maximum sand dunes cover are either on agricultural land or it was cover up by forestation cover. Thus spectral data set only provide the current land use condition (*more details are discussed in the Next Chapter*) and also notable to quantify the sand dunes shape and size.

4.5 Summary of Findings

1. In Aeolian Environment Sand dunes are the prominent landforms features. There are various types of sand dunes in all over the world and these dunes are classified and studied by the various scholar. In the North eastern Rajasthan desert (study regions of district Churu and Jhunjhunu), six types of dunes viz. Parabolic, Barchans, Longitudinal, Transverse and Deformed dunes are identified on the baisi of shape and size from the study area. The Deformed Dunes category has been formed on the basis of **Mckee et al. (1979)** based classification of sand dunes in which such types are considered as a *complex* and *compound* dunes. Such dunes are hard to categorised in a specific sand dune category, thus due to its deformed shape this type of sand dune has been created.

2. The factor responsible for the development of these dunes is wind. Wind with prominent direction and sufficient strength with prolong duration are responsible for the shape, size and movement of the sand dunes. But in this study it has been observed that the wind is not only responsible factor which affecting the dune, there are other environmental variables as well. This includes Rainfall, Temperature and related climatic factors. The comparative figures of climatic data of Churu and Pilani (Jhunjhunu) station establish the hypothetical assumption that the Jhunjhunu has a better place for the growth of vegetation due to better rainfall condition and low temperaturerelative to Churu.Consequently it had provided the durable conditions for the agriculture and afforestation land use, which indicate that the favourable climatic factors are very much helpful for the stabilising of sand dunes.

Chapter 5

Aeolian landforms and Impact on Land Utilisation

5.1 Introduction

Mapping the change in land use and land utilisation of hot arid and semi-arid areas is very much essential. Since, the region is heading forward for the intensification of agriculture the arbitrary use of ground water. Which has created the counter cycle and reverses its outcome as degradation of natural biomass, wind erosion leads to encroachment of sand into other various land use areas etc. The land use and land cover pattern of an area is a result of various factors which includes environmental and socio-economic factors which vary according to space and time. The word 'Land use' referred to the various uses which occurs on land surface by anthropogenic actives, wherein 'Landcover' denotes to as natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformation. Both land use/landcover are closely related and are not mutually exclusive they are interchange able as the former is secondary based on the land cover and on their contextual evidence[1].

In order to observe the impact of Aeolian features on land utilisation, there are two approaches which are adopted for understanding the impact. These approaches are:

1. *DEM Based analysis* : In this approach, first of all various land use and land cover classesof micro level case study is digitised by using visual interpretation and through CartoDEM the topographic information in different land use and land cover classes (LULC)is extracted. In this information Maximum Elevation, Slope and Aspect is extracted for understanding the distribution of Aeolian landforms (especially, Sand Dunes). Through this

[1]Manonmani R., Suganya G.M.D (2010): "Remote Sensing and GIS Application in Change Detection Study in Urban Zone Using Multi Temporal Satellite", International Journal of Geomatics and Geosciences, Vol. 1, No 1, pp. 60

approach the pattern of Maximum Elevation and Slope signify the dune elevation and slope and its accumulated concentration in different land use classeswhichcan be link with the existing land use pattern. The relationship between slope and elevation also depict the dynamic equilibrium between the erosional and depositional processes.The limitation in this approach is that the availability of high resolution DEM is absent and thus the only source of topographic information is from the toposheet, which are out-dated and not depicting the current pattern of landscape.

2. *Spectral analysis of LULC*: In this approach, the change detection is analysed with the help of spectral data (LISS – III on board IRS-P6 and Landsat TM).The Boundaries of dunesareoverlaid in order to see the change detection within the dunes boundary. In this section the assumption which is taken into consideration is that the shape and area of dunes is static or sand dune is stabilised. This provides a synoptic view of change in land utilisation pattern and the impact of sand dunes in it. In this approach, the limitation is that the spectral data need some correction but without that the information about land use and land cover will be vary. Secondly, the sand dunes boundary can't be recognisable during the cropping season and thus the actual shape of duneis not identifiable during such specific seasons.

By limiting our analysis to spatial analyses, we can focus more rigorously on our objective of understanding the Aeolian landforms and its impact on land utilisation through the analysis of two different data sources. For the better understanding micro level samples of different villages and towns is taken from district Churu and Jhunjhunu.

5.2 Topographic influence on land use and land cover

In this section the topographic parameters are used to know about the position of sand dunes on different LULC. From the high resolution Cartosat-1 imagery different land covers is categorized andfrom CartoDEMthe maximum height and slope value is extracted.The maximum elevation and slope appearson the sand dunes whichis whythe maximum value of elevation, slope and Aspect in all LULC classes have been considered for understanding the distribution of dunes in different LULC classes.

In the study region the prominent topographic feature is sand dune and thus the maximum elevation and slope of this area also denotes the sand dune. Therefore the topography of land use and land cover is required to be analysed to understand the influence of sand dune on land utilisation practice. For this purpose an intensive micro level study has been undertaken to understand the relation between sand dunes with different land use classes.

The intensive micro level study land use will be linked to justify the influence of topography or in this case Aeolian landforms with the land utilisation practise. Later on this intensive micro level study will be applied to all six sample of the study area in order to see the type ofland utilisation practices on Maximum elevation and slope.

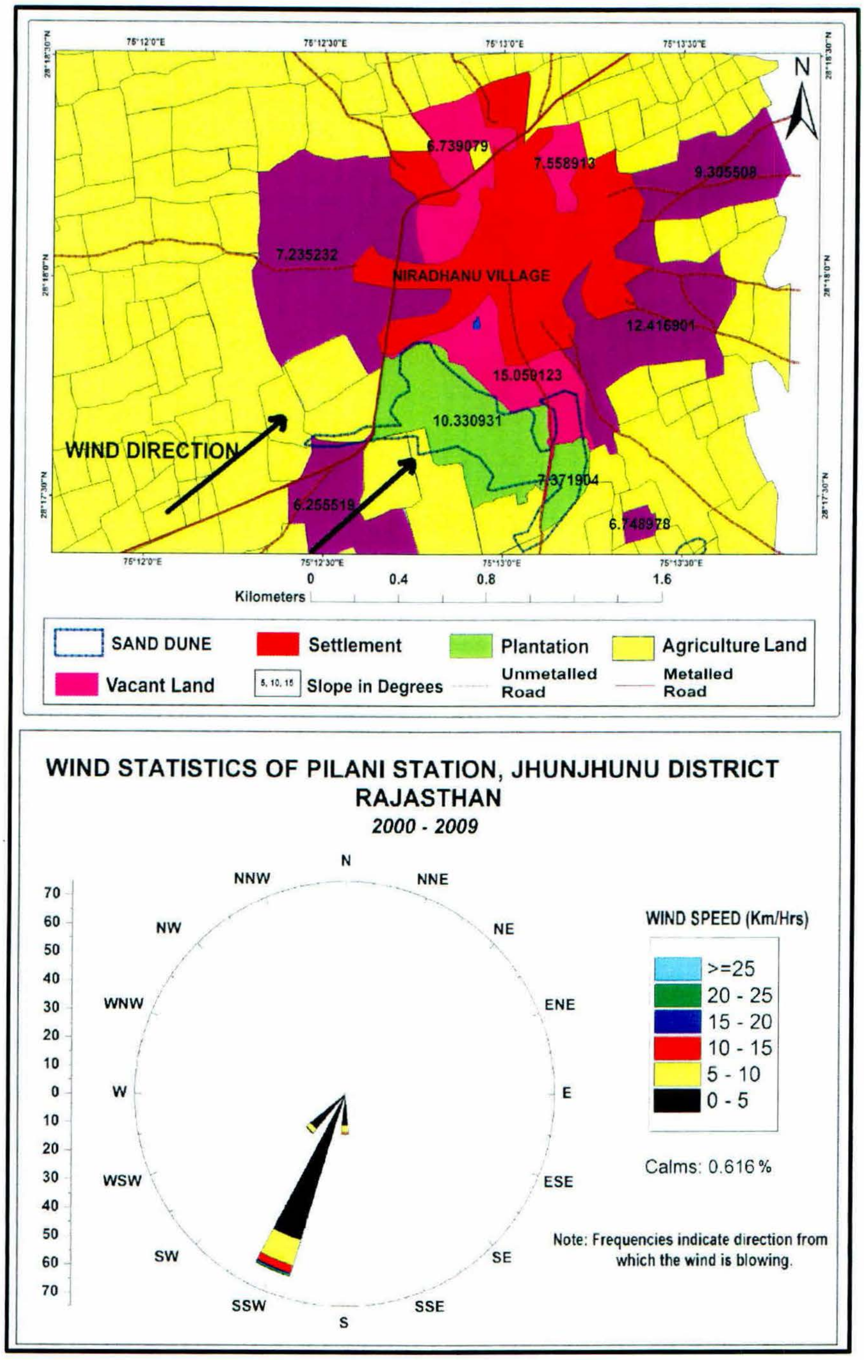


Fig. 5.1: Aeolian landforms impact on land utilisation practice

In fig: the impact of Aeolian landforms on land utilisation practice can be notice. This figure depict the land use/cover of Niradhanu village in which it has been clearly observed that from South to North there is a decrease in the slope, which is extended up to north. In the south portion of this village sand dune is situated which holds forest plantation. If we superimpose these three factors i.e. wind direction, topography and settlement location then it becomes evident that the plantation on sand dune is used to stabilise the dunes and prevent it from further movement into the settlement area. The prominent prevailing wind direction from South-south west to North east direction provides suitable mechanism for shifting of the dune from its present position. Thus the presence of such types of Aeolian landforms extends significant impact on land utilisation practise.

The following samples are taken from north to south direction wise and their increasing elevation clearly signifying the physiography of this region.Table no 5.1 and 5.2 signify the current pattern of terrain in different land use/land cover classes.

Table 5.1: Maximum Aspect of different Land Use/ Cover

Maximum Aspect in Different Land Use/Cover of Sample Area						
	Agricultural Field	***Forest Cover***	***Settlement***	***Vacant Land***	***Waste Land***	***Water Bodies***
Aslisar&Malsisar Town	North	North west	North	North	North	South East
LohsanaBada Village	North	North	North	North West	North	East
Mandawa Town	North	North	North	North	North	North West
Niradhanu Village	North	North	North West	North West	North	North East
Sankhu Fort Village	North	North	North	North	North	North East
NandKa Bas Village	North	North	North	North	North	North

Table 5.2 : Topography of Land-Use Land-Cover

LULC Classes	*Lohsana Bada Village*		*Sankhu Fort Village*		*Nand Ka Bas Village*		*Niradhanu Village*		*Aslisar & Malsisar Town*		*Mandawa Town*	
	ELV	*SLP*	*ELV*	*SLP*	*ELV*	*SLP*	*ELV*	*SLP*	*ELV*	*SLP*	*ELV*	*SLP*
Agricultural Field	246	14	252	13	253	12	271	17	258	13	313	18
Forest Cover	231	9	244	10	240	6	263	10	261	15	292	8
Settlement	240	8	249	8	252	7	277	11	258	10	305	15
Vacant Land	239	9	252	10	247	7	274	15	253	12	301	13
Waste Land	239	10	251	17	256	11	272	13	258	14	304	14
Water Bodies	222	3	222	4	237	4	239	2	246	4	290	2

ELV - 'Elevation' in Metres   SLP - 'Slope' in Degrees

In order to see the better view of topographic pattern in different Land Use/Cover of Sample Area, following are the village and town wise analysis of topographic pattern of land use/land cover.

1. *LohsanaBada Village:* The minimum and maximum elevation of this study area is 204 and 246 metres. This sample area situated in the Alsisar tehsil of district Jhunjhunu, the land use and land cover classes are demarcated from the fused high resolution Cartosat 1 image. For the proper coordination among all six samples a common land use classes are considered, this includes agriculture land, vacant land, waste land, settlement, plantation water bodies, metalled and unmetalled road. In order to understand the distribution of sand dunes in the study area, the maximum elevation and slope in different land use/cover classes are extracted from the CartoDEM. This provides a general view about the existence of sand dunes in different classes and it also helps in recognising the impact of topography on local land use/cover pattern. Following figures show the land use/cover pattern and topographic profile of LohsanaBada village.

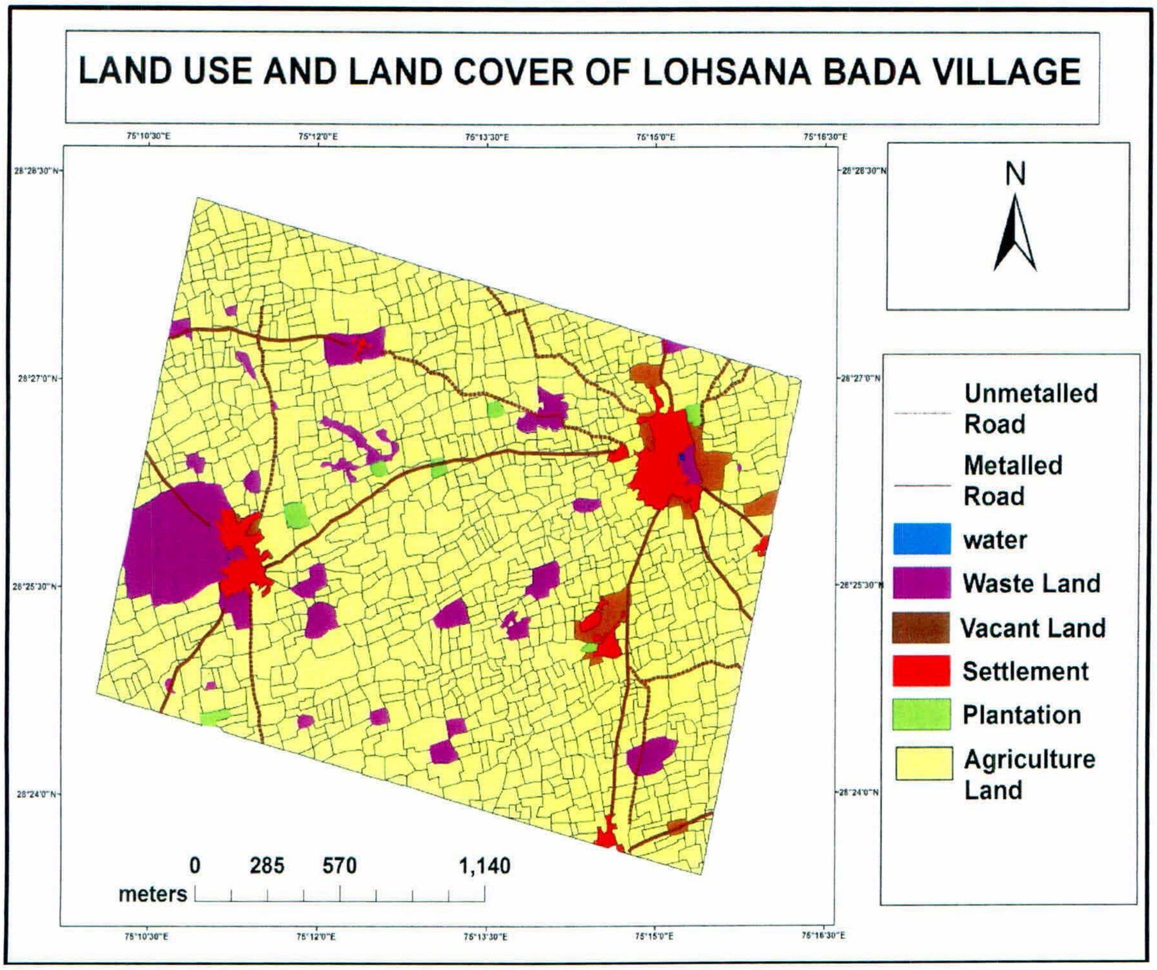


Fig. 5.2: Land use/cover of Lohsanabada village

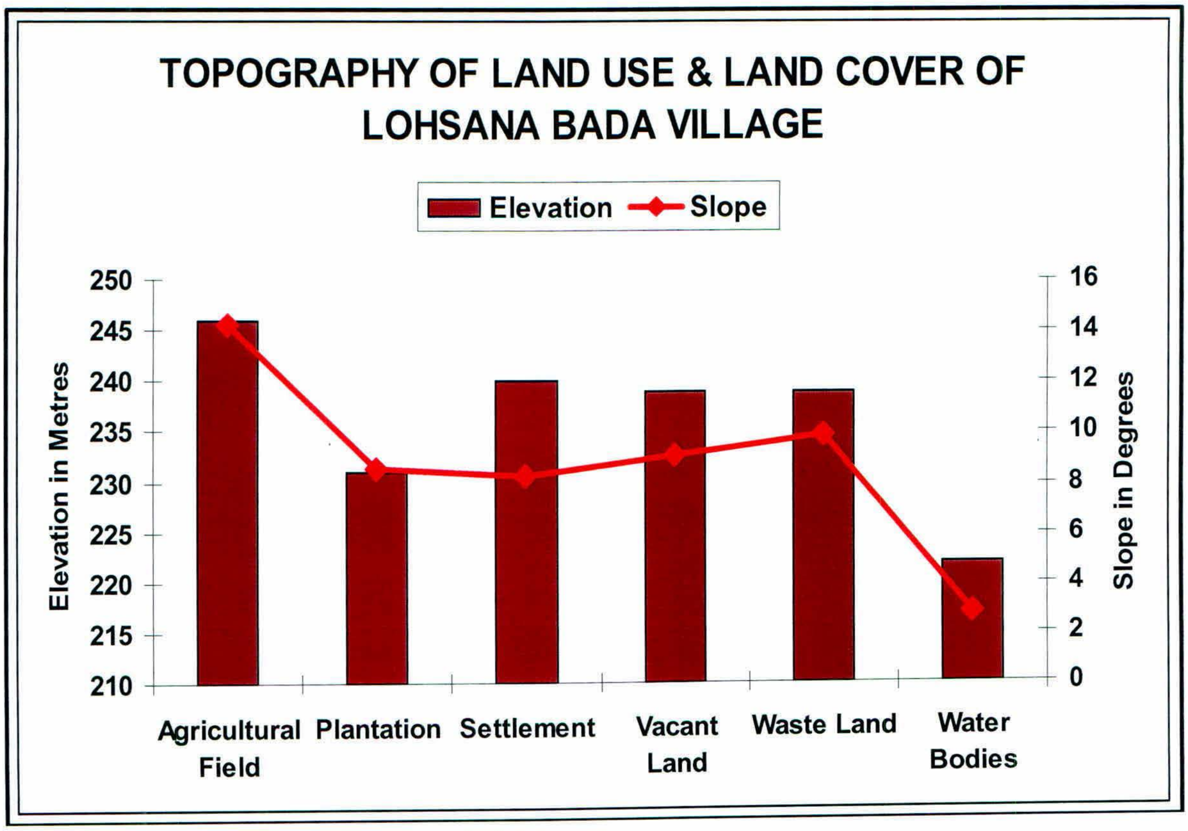


Fig. 5.3: Classes wise elevation & slope Profile of LohsanaBada Village

The general topographic land use/cover pattern depict that the maximum elevation is found in the agriculture class followed by the slope as well. This shows that the agriculture class holding a major portion of sand dunes in this sample area, whereas in other classes the maximum elevation and slope is more or less fluctuating, except water bodies class which hold the lowest maximum elevation and slope in comparison with other classes.

2. *Sankhu Fort Village*: In this sample study the maximum elevation is 252 metres wherein the minimum elevation is 210 meters. In this case study the maximum elevation is found in the agriculture class followed by the vacant land, settlement and wasteland. Plantation and water bodies having a lower elevation as compare to other classes. In term of slope wasteland provides the maximum slope, whereas settlement and water bodies having a relatively low slope.The maximum slope denotes the steepness therefore the agriculture practice on that slope can't be possible. Where in the case of agriculture the elevation is greater but the slope is gentle thus it denotes that the agriculture on dunes is quite broad in this study area.

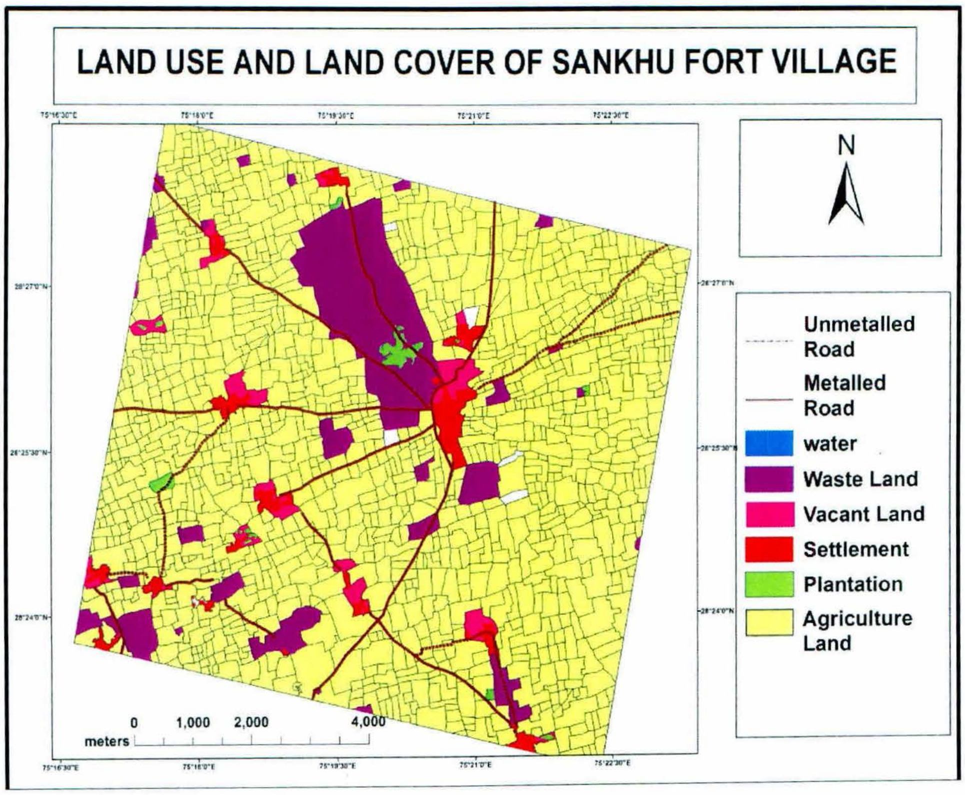


Fig. 5.4: Land use/cover of Sankhu Fort village

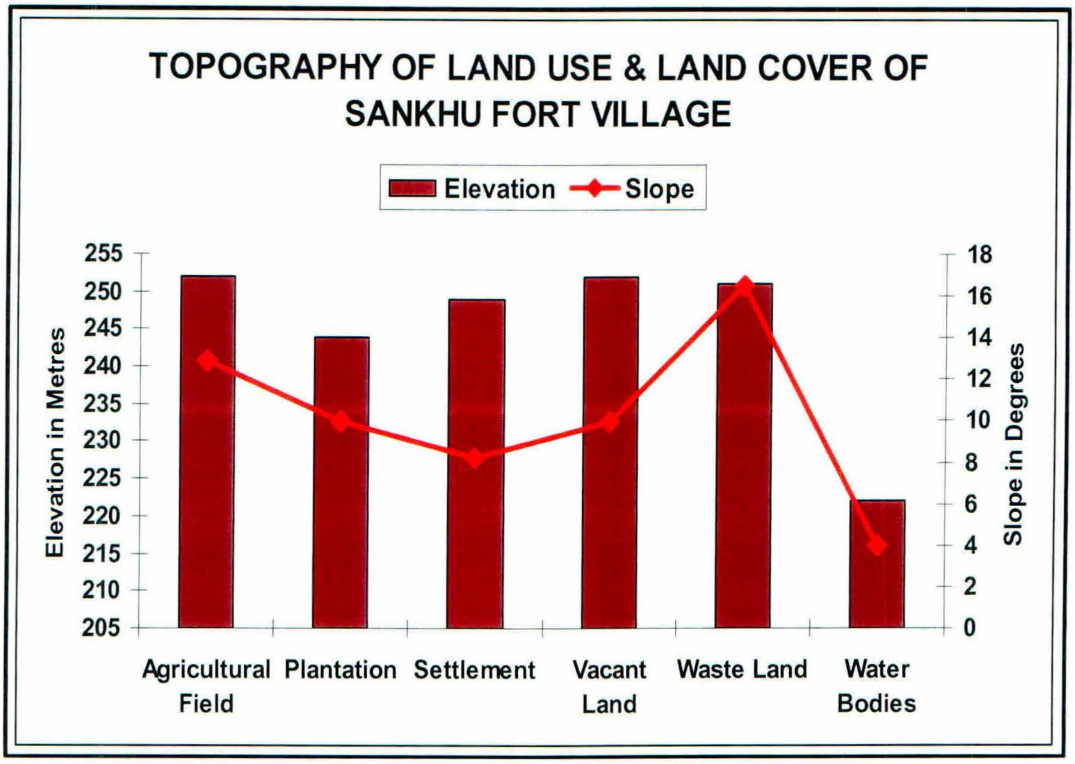


Fig. 5.5: Classes wise elevation & slope Profile of Sankhu Fort Village

3. *Nandka Bas Village:* In this sample area the Maximum and Minimum elevation is 252 and 221 metres respectively. The class-wise topography of this village denotes that the wasteland having a maximum elevation followed by the agriculture, settlement, vacant land and plantation, water bodies. The relation between elevation and slope show the dynamic equilibrium between erosion and deposition processes. The slope in this case study is maximum in agriculture class which clearly show that the modification of agricultural field either by anthropogenic activities or by the natural processes. Such modification in agriculture can be noticed in the comparative low elevation and maximum slope.

The maximum lower slope is observed in water bodies followed by the plantation class, where in the settlement and vacant land having a similar slope. The vacant land is considered as an area near by the settlement, which includes the common resource property and other institutional purposes.

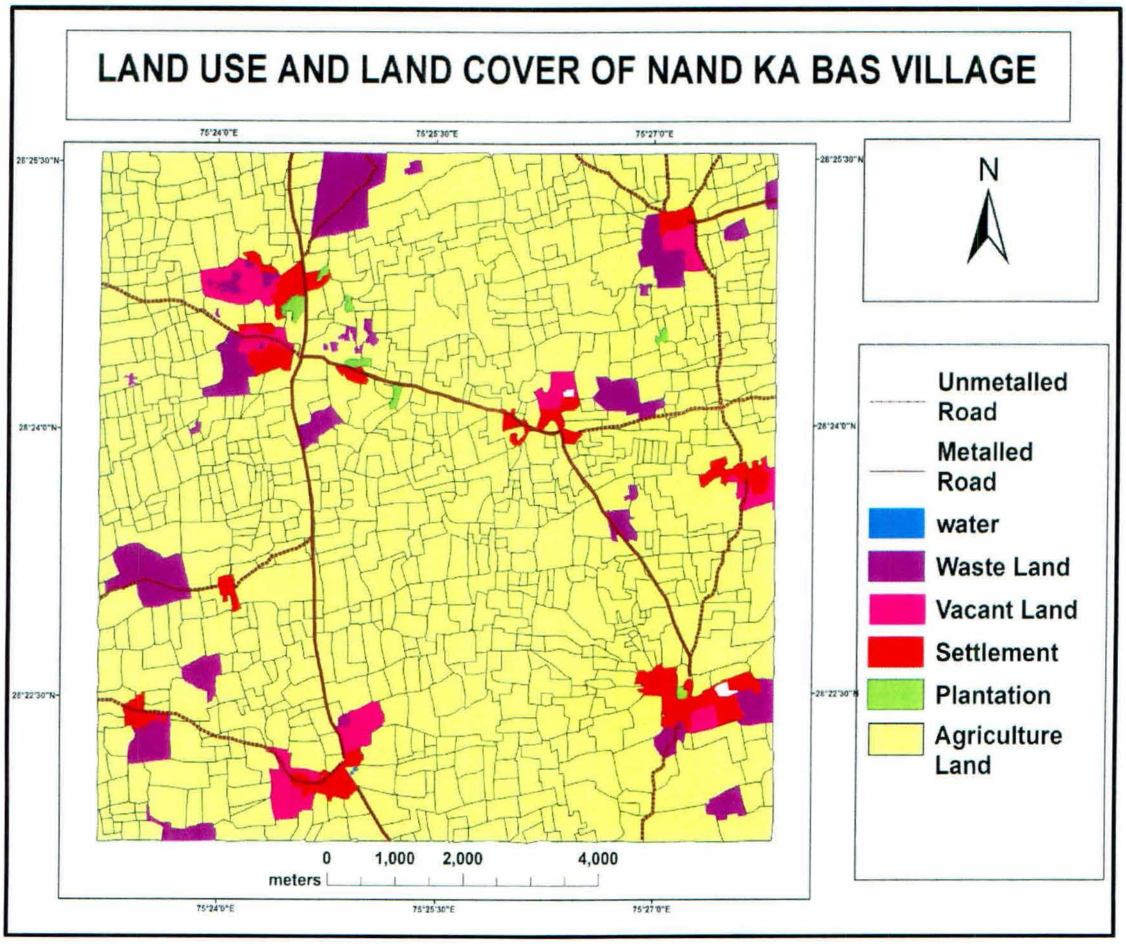


Fig. 5.6: Land use/cover of Nandka Bas village

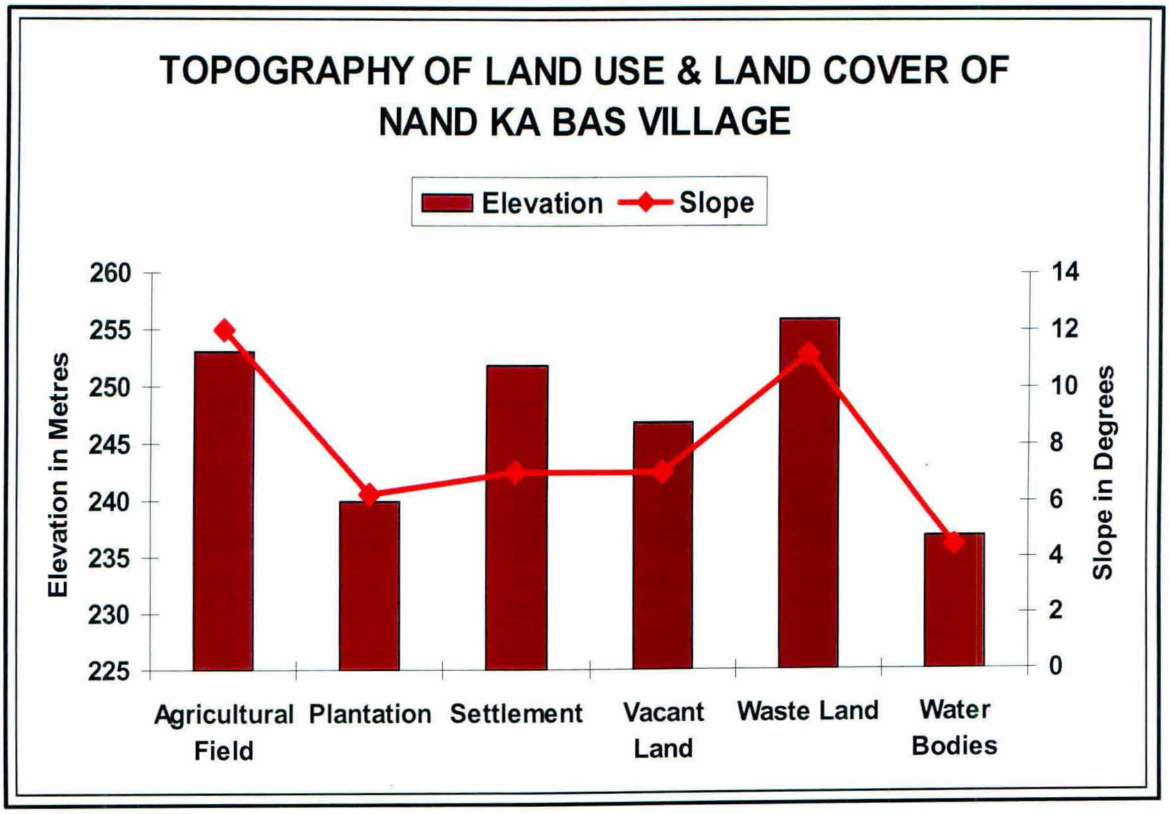


Fig. 5.7: Classes wise elevation & slope Profile of Nandka Bas Village

4. *Nirdhanu Village:* In this study area the elevation vary from 277 to 234 metres respectively. The maximum elevation is found in the settlement class, this figures justify the fact that the Ganiyasar village in this area is one of such villages which is situated on the top of sand dune. But the slope in this class is relatively lesser in this area; this could be due to some changes by anthropogenic activities. The elevation and slope in agriculture are not constant; the elevation is lower as compare to other classes, whereas the slope is greater in agriculture class relatively.

From this case study the maximum slope in different land use class is greater as compare to previous mentioned case studies, this includes elevation as well.

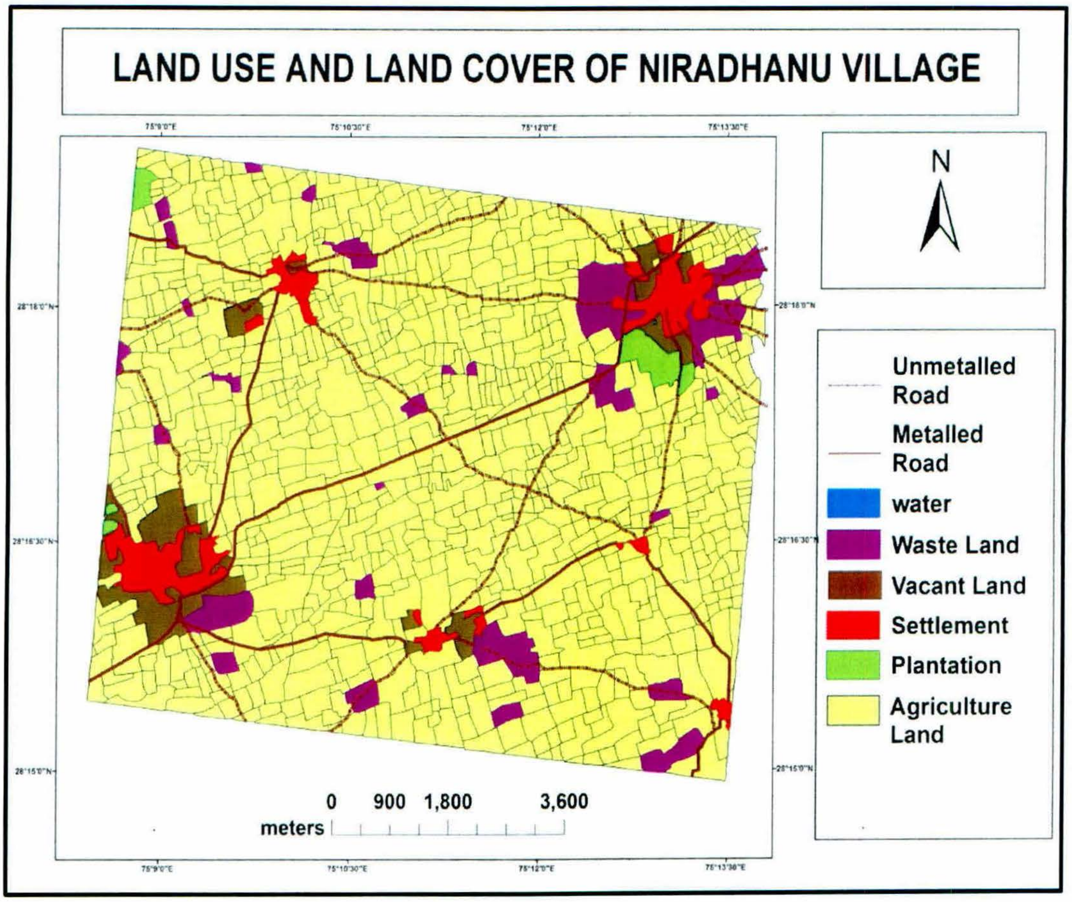


Fig. 5.8: Land use/cover of Nandka Bas village

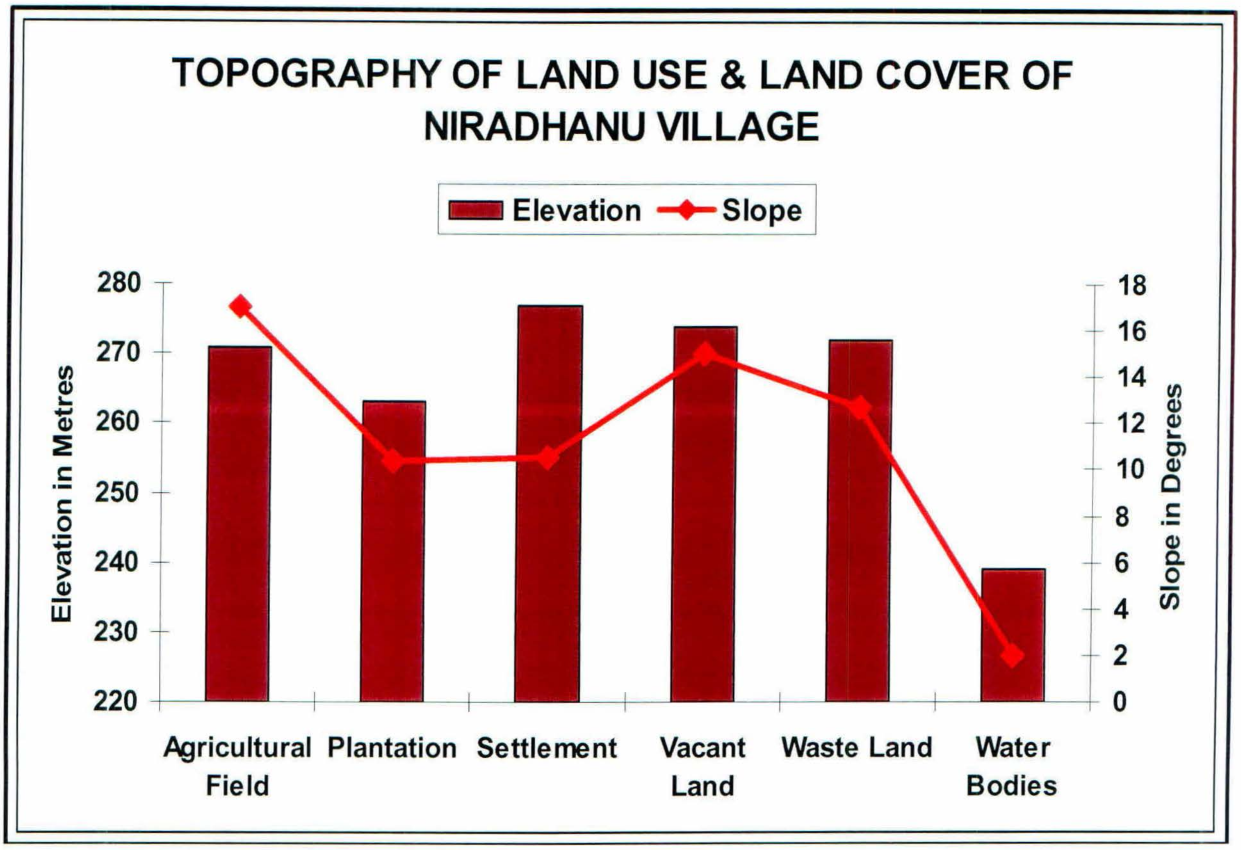


Fig. 5.9: Classes wise elevation & slope Profile of Niradhanu Village

5. *Alsisar and Malsisar Town*: In this sample area the Maximum and Minimum elevation is 261 and 226 metres respectively. The class-wise topography of this village represents that the plantation class is cover up with maximum elevation and slope followed by agriculture, settlement and wasteland class. The maximum sand dune in this case study is situated on the west direction, wherein the concentration of major dunes ismainly observed in agricultural classes.

The maximum slope in this area is holding by plantation justify the fact that the portion in land use/cover class is occupied by the parabolic dune type, whereas the same results also noticed in the wasteland class in which existence of parabolic dunes also justify the fact of maximum slopes in these classes. The presence of dunes near Malsisar town also validate the fact the settlement having a relatively grater elevation. Thus the different land use/cover class completely effected by the presence of sand dunes, which is not only affected the settlement structure but also land utilisation practice.

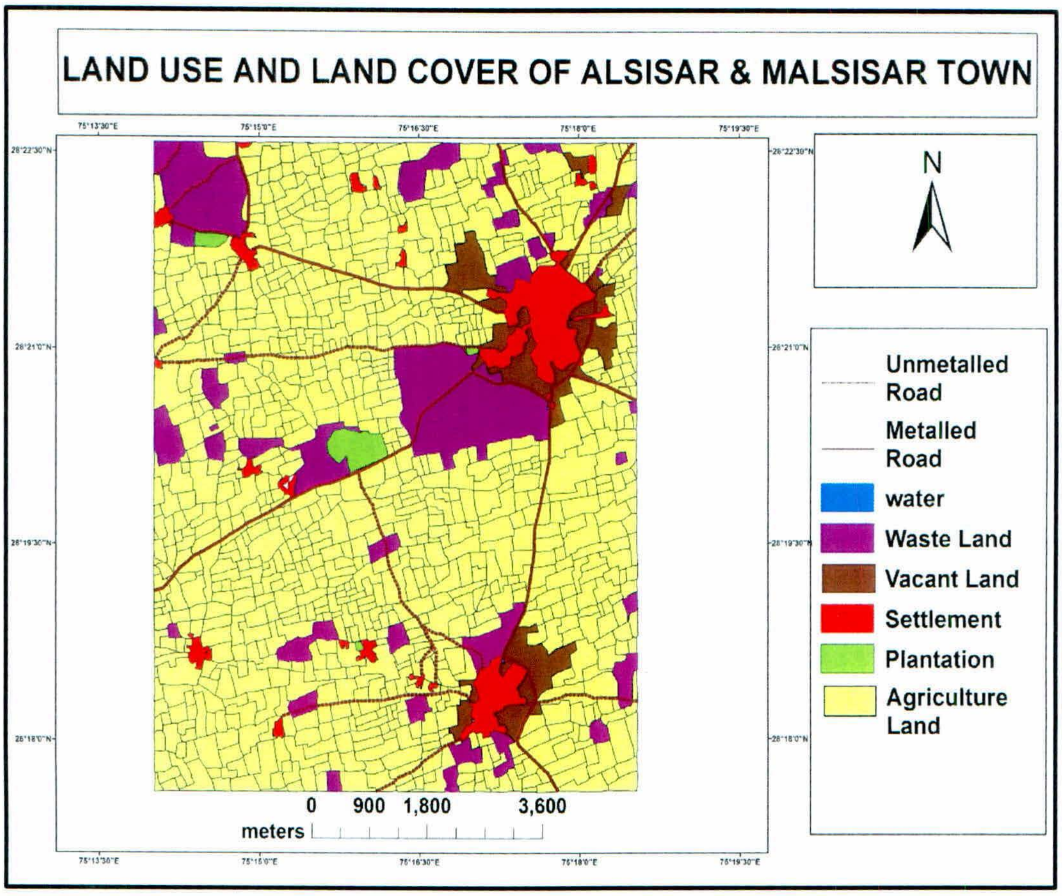


Fig. 5.10: Land use/cover of Alsisar and Malsisar Town

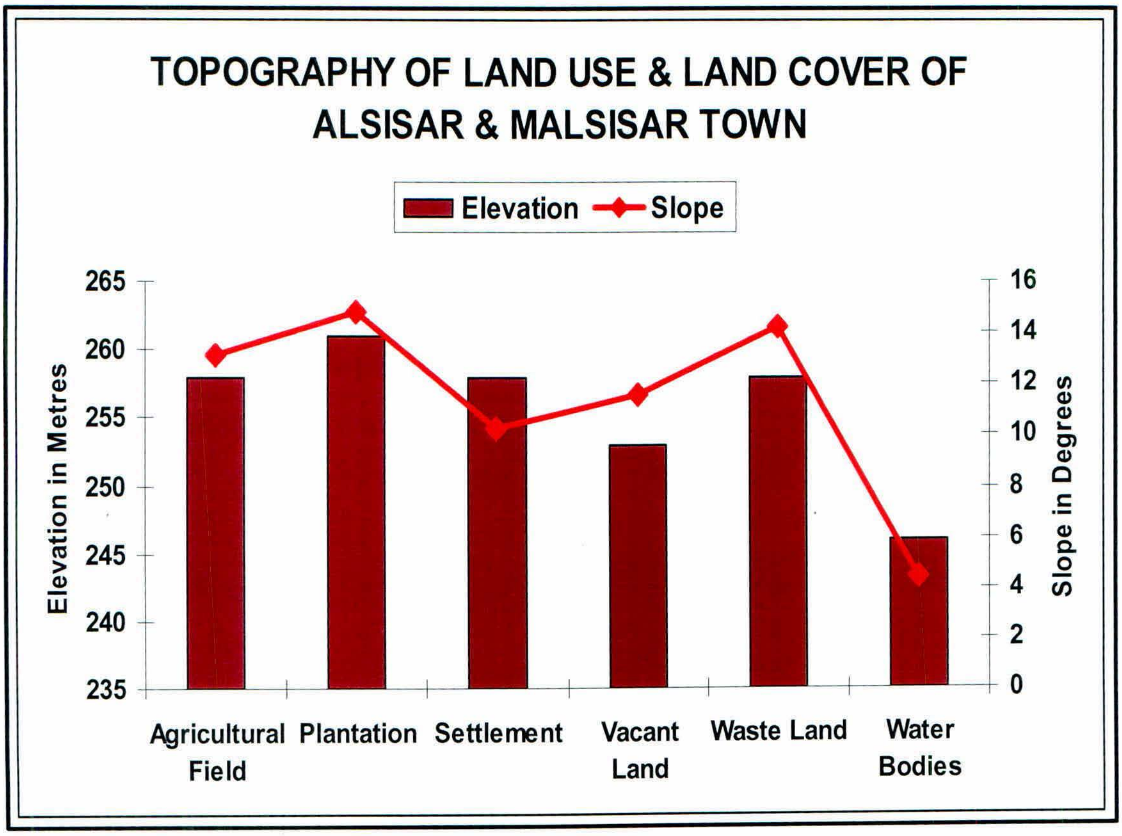


Fig. 5.11: Classes wise elevation & slope Profile of Alsisar and Malsisar Town

6. *Mandawa Town*:It is situated in the extreme south of Alsisar tehsil, the case study of Mandawa town shows that the elevation in this area is comparatively much larger than any other area of the case study. As per the physiography which confirms that the elevation decreases from south to north. This suggests that the sand dunes elevation is also much greater than the other part of case study.The maximum and minimum elevation of this area is 313 and 271 metresrespectively. The maximum elevation is hold by the agricultural class followed by the settlement, wasteland and vacant land, water bodies, in terms of slope the same trend also noticed.

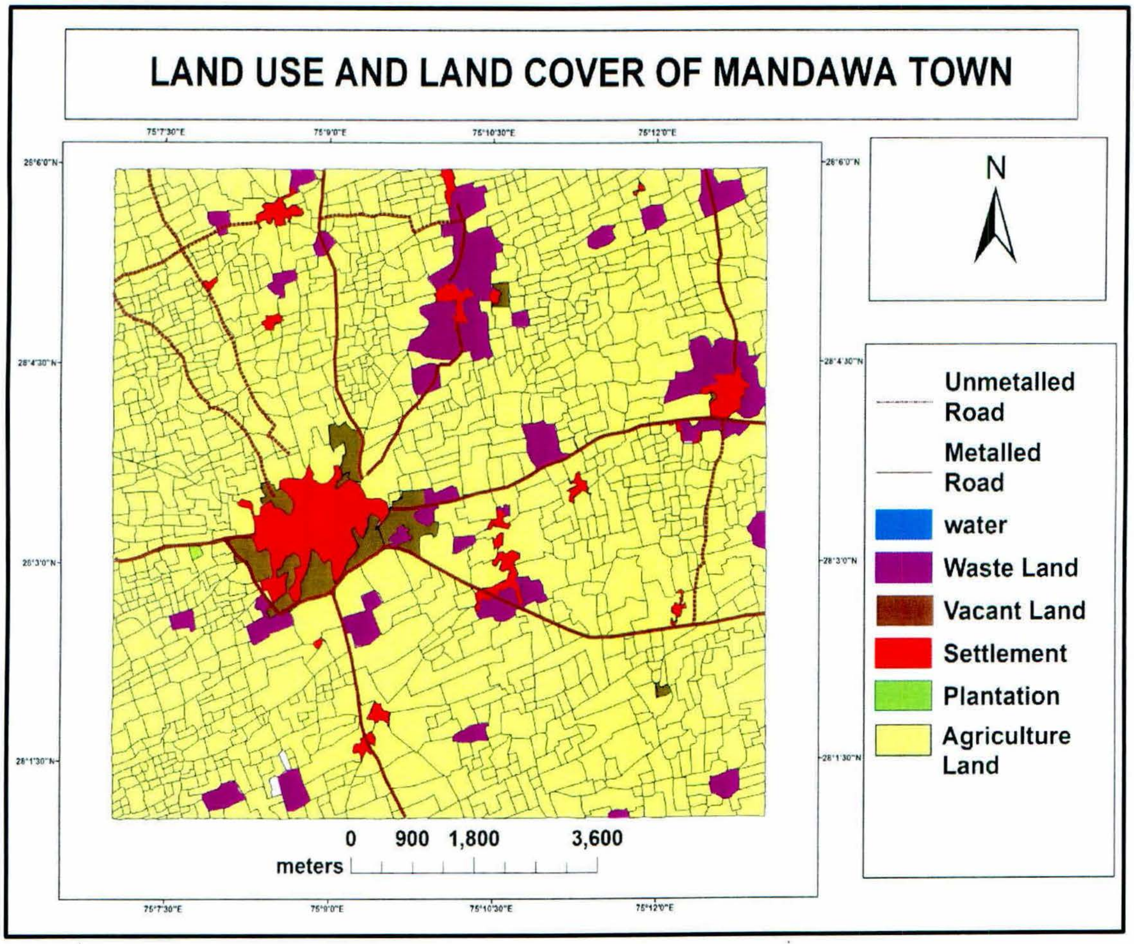


Fig. 5.12: Land use/cover of Mandawa Town

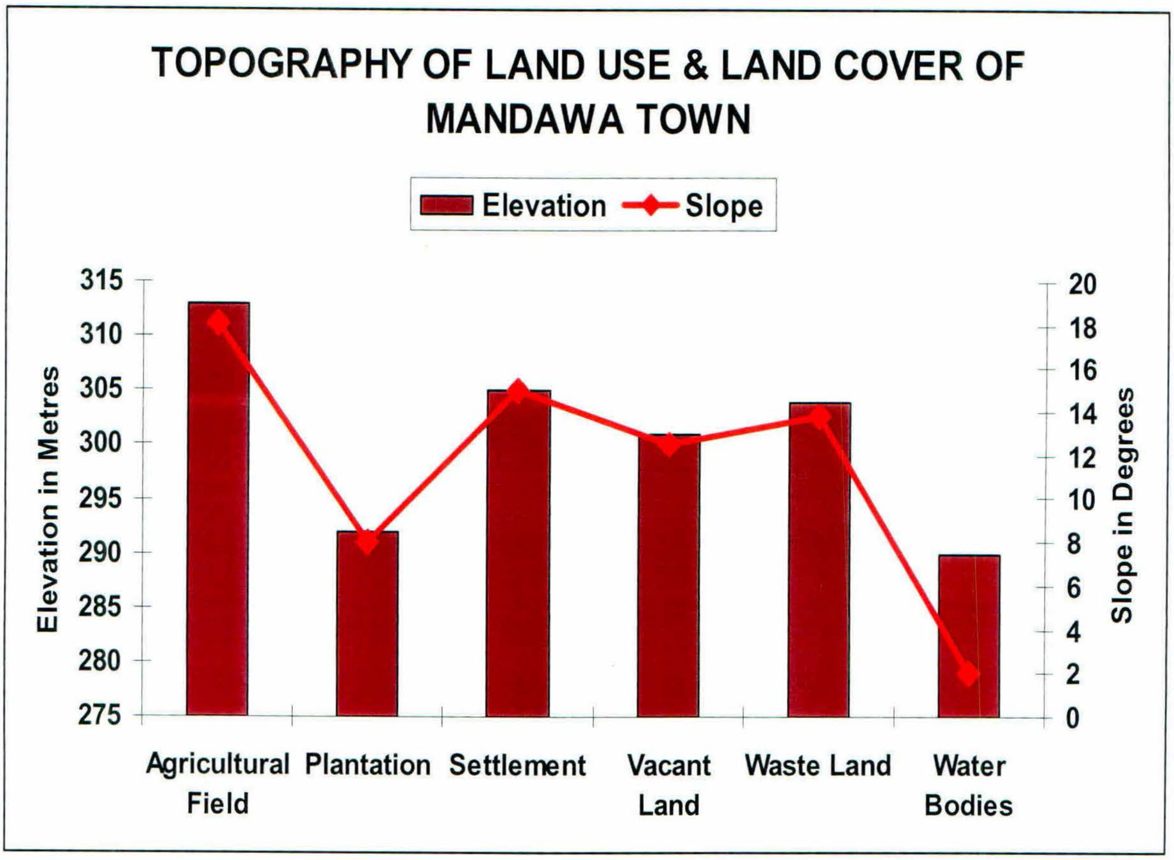


Fig. 5.13: Classes wise elevation & slope Profile of Mandawa Town

The overall land utilisation practices in all six sample study are analysed and it is linked up with the topography to see the maximum land use practice on the maximum elevation and slope. In table: the average maximum elevation and slope are taken from all same study in order to see the general picture of the land use practice on sand dunes. In this analysis a broad view will be generated about the topographic influence on land utilisation practice.

Table 5.3: General land use practice on Topography

AVERAGE MAXIMUM ELEVATION & SLOPE OF MICRO LEVEL STUDY		
	Elevation	Slope
Agricultural Field	266	15
Forest Cover	255	10
Settlement	264	10
Vacant Land	261	11
Waste Land	263	13
Water Bodies	243	3
Elevation in Metres, Slope in Degrees		

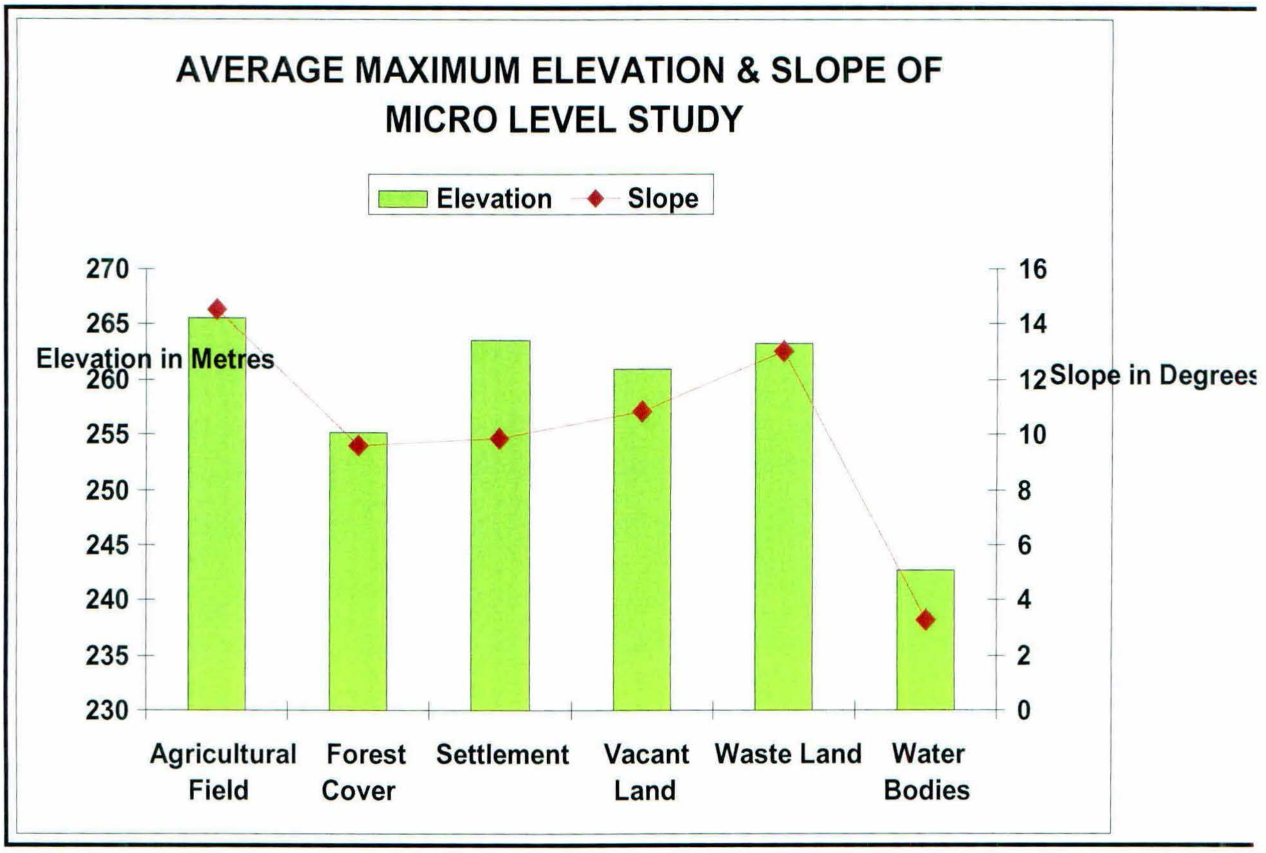


Fig. 5.14: The overall view of different land use on topography

After analysing the average maximum slope and elevation from each land use classes, the concluding fact is that in the overall sample area the agricultural field is a one of the most significant land use which took place on the both average maximum slope and elevation. In terms of elevation settlement land use is the second most significant land use which is situated in the study area, but the slope of this land use is relatively smaller which might be the result of anthropogenic factors. Wasteland occupied the third largest position on elevation and the second largest in terms of slope, the maximum slope indicate that the existence of sand dunes in this class is also very prominent. The fourth largest elevation and third largest slope detected on the vacant land use class. The forest cover or plantation land use experience the lowest maximum elevation and slope relatively. The forest cower are generally found on the gullied erosion sites as mentioned observed near Malsiartown.Thus the land use practice is the outcome of topographic influenceor vice-versa.

5.3 Change detection of land use and land cover

In this section to see the change in land utilisation practice, the change detection technique is used to analyse the results. Change detection analysis includes the various methods to quantify the change in different temporal satellite images or individually. Different land cover classes provide various kinds of reflections and generate a typical signature of individual class. The preferred information could be accomplished from satellite imageries in an effective method by operating several basic interpretation keys.Cropland in imagery appears in bright red to red colour with non-contiguous pattern; wherein the fallow land itseem like in bluish /greenish colour with smooth texture. The plantation and forest class are difficult to categorise because of the same reflectance and pattern of texture but the shape and some field based knowledge helps to classify these classes.Finally the dark red to red tone with sharp edge are taken as plantation class, while bright to dark red with smooth to medium texture are considered as a forest class. In the waste land class the salt affect land are taken and considered, it having a white to light blue tone with smooth and irregular patches. For scrubland brown to bluish greenin irregular patches. Settlement appears in bluish to dark bluish green and water light blue to cyanish blue tone.

In this part of analysis change detection is analysed with the help of spectral data (LISS-III and Landsat TM) of Alsisar tehsil.The reason for taking this tehsil for change detection analysis is that the area is visited during the field observation which provides information regarding the land use classes. Later on, the Boundaries of dunes are overlaid in order to see the change detection within the dunes boundary as well.

5.3.1 Supervised Classification

Supervised classification has been performed on the IRS-1C LISS III of the year 13/01/2010 and 12/12/1998 Landsat TM of the year 1998 of Alsisar tehsil. Eight landcover classes were identified from the satellite images. These classes consist of Crop Land, Fallow Land, Forest, Plantation, Wasteland, Scrubland, Settlement and Water bodies. Two different classified images were generated (Figure 5.15). The classified images were subjected to statistical analysis as defined below:

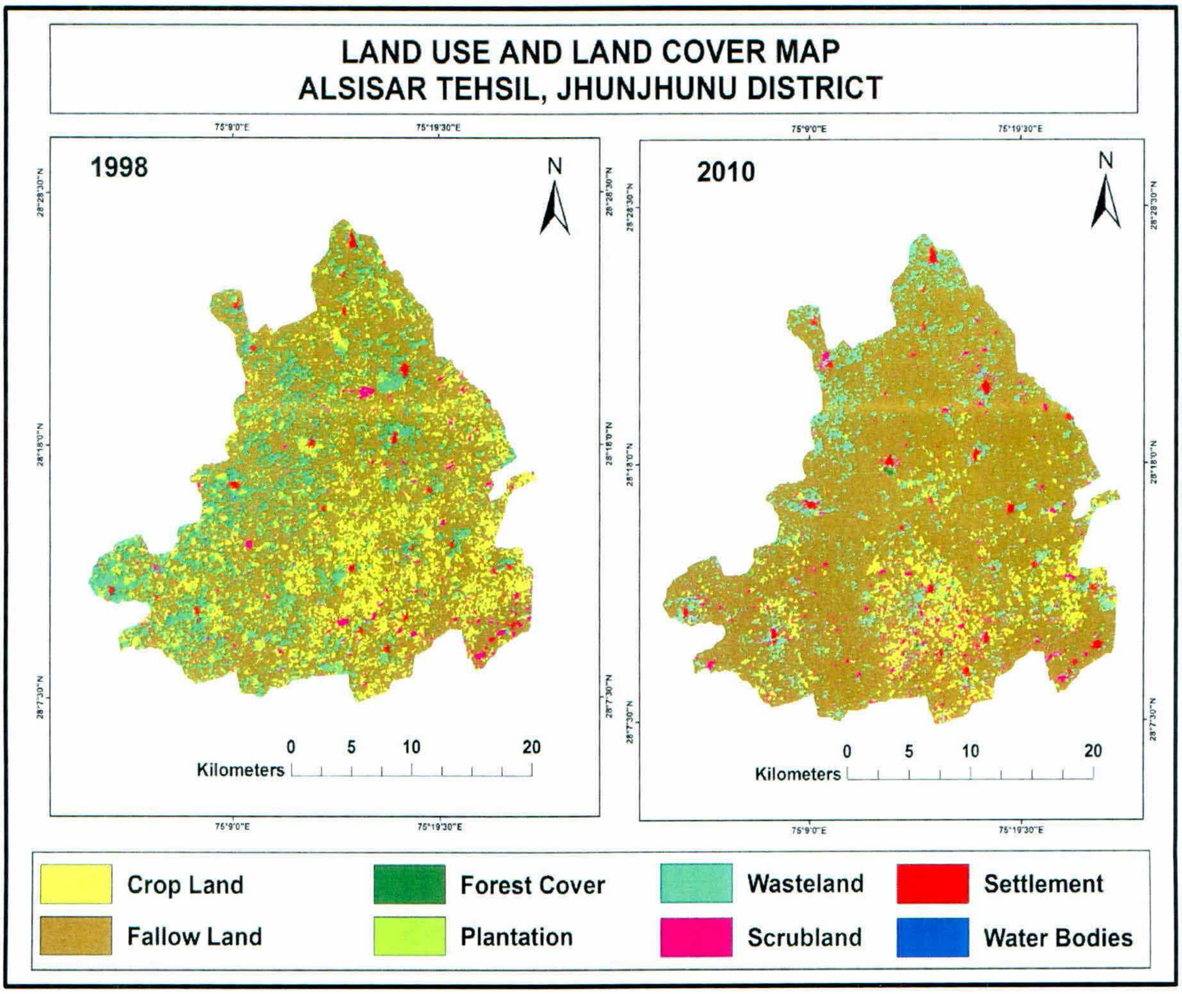


Fig. 5.15: Temporal Land Use and Land Cover Map, December, 1998&January, 2010

5.3.1.1 Accuracy Assessment of the Classified Images

Before going to see the change detection resultsover the period of time, it's important to validate the results through accuracy assessment technique. The classified images were calculated quantitatively through the accuracy assessment of all the land use/cover classes. In table: shows the details of accuracy assessment of the 1998LULC classified image. The overall accuracy inthe year 1998 classified image was 82.50%and the overall Kappa coefficient calculated to 0.7794, wherein table: show the overall accuracy of the year 2010 classified image was estimated to be 87.50%, while the overall Kappa coefficient was estimated to be 0.8328.

Table 5.4: Accuracy assessment of the 1998

Accuracy Assessment 1998						
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics
PLANTATIONS	1	1	1	100%	100%	1.000
SETTLEMENT	3	4	3	100%	75%	0.730
CROP LAND	7	8	7	100%	88%	0.849
WATER	0	0	0	---	---	0.000
FALLOW LAND	9	14	9	100%	64%	0.539
SCRUB LAND	8	5	5	63%	100%	1.000
FOREST	0	0	0	---	---	0.000
WASTE LAND	12	8	8	67%	100%	1.000
Overall Kappa Statistics = 0.7794						
Overall Classification Accuracy = 82.50%						

Table 5.5: Accuracy assessment of the 2010

Accuracy Assessment 2010						
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics
SETTLEMENT	2	3	2	100.00%	66.67%	0.649
WATER	0	0	0	---	---	0.000
PLANTATION	3	3	3	100.00%	100.00%	1.000
FOREST	3	3	3	100.00%	100.00%	1.000
FALLOW LAND	20	16	16	80.00%	100.00%	1.000
CROP LAND	4	4	4	100.00%	100.00%	1.000
SCRUB LAND	4	4	3	75.00%	75.00%	0.722
WASTE LAND	4	7	4	100.00%	57.14%	0.524
Overall Kappa Statistics = 0.8328						
Overall Classification Accuracy = 87.50%						

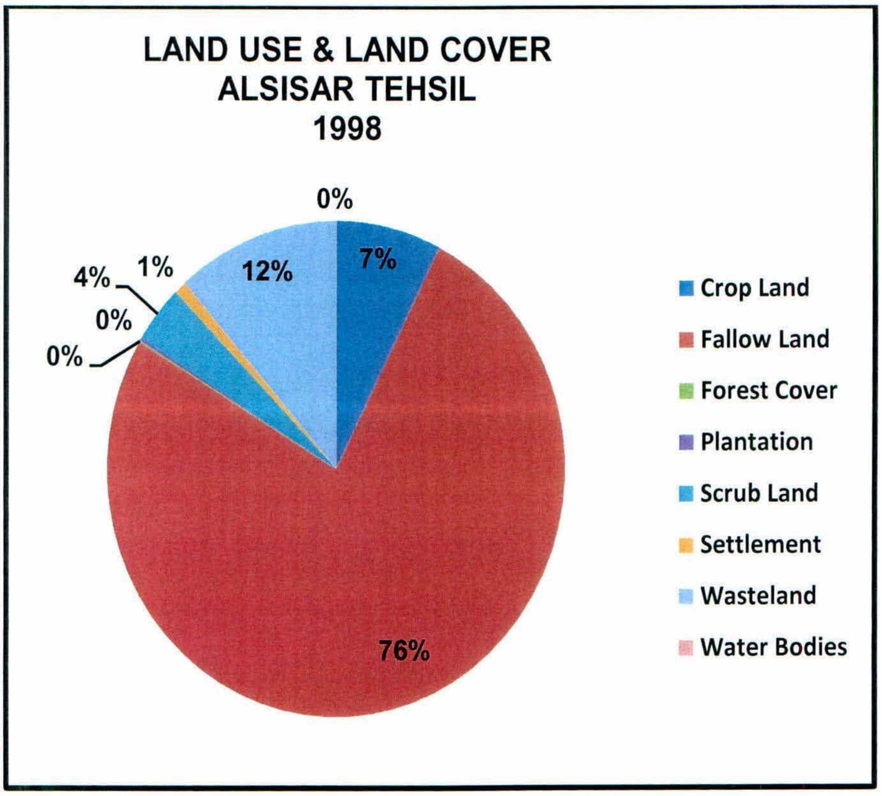
5.3.1.2 Change Detection of the Land use/cover Classes

The statistics ofspatial distribution of land use land cover for each study year has been derived from the maps are given in the table 5.6. The percentage area of classified classes in the study area is shown in Figure. 5.16.

In percentage change from 1998 to 2010 of Alsisar tehsil can be noticed in table. The Crop Land and Wasteland show the negative change in area. The percentage change in these two classes is -12.7 per cent and -2.6 per cent respectively. In terms of percentage area the Crop land in 1998 was 20.17 per cent which has further decrease to 7.45 per cent in 2010. The Fallow land observes with the increase decadal percentage change of 14.1 per cent from 1998 to 2010. Such fluctuating decrease and increase trend in the agricultural inputs can be the outcome of seasonal variation. In the Waste land percentage is from 1998 to 2010 is 14.11 to 11.49 per cent correspondingly. The decadal percentage change is negligible in the forest, plantation, and settlement classes, which show the percentage of 0.1 in each, whereas the water bodies having a nil decadal percentage change.

Table 5.6: Change detection of various classes from the year 1998 to 2010

Classes	1998 Area (ha)	2010 Area (ha)	1998 Percentage to total Area	2010 Percentage to total Area	Percentage Change 1998-2010	Annual Rate of Change Percentage
Crop Land	15263.70	5622.07	20.17	7.45	**-12.7**	-1.27
Fallow Land	46979.30	57451.50	62.07	76.12	**14.1**	1.41
Forest Cover	1.08	76.10	0.00	0.10	**0.1**	0.01
Plantation	64.80	159.49	0.09	0.21	**0.1**	0.01
Scrub Land	2125.62	2850.94	2.81	3.78	**1.0**	0.10
Settlement	565.20	638.13	0.75	0.85	**0.1**	0.01
Wasteland	10682.30	8671.93	14.11	11.49	**-2.6**	-0.26
Water Bodies	3.42	1.77	0.00	0.00	**0.0**	0.00
Total	75685	75472	100.00	100.00	**0.0**	0.00



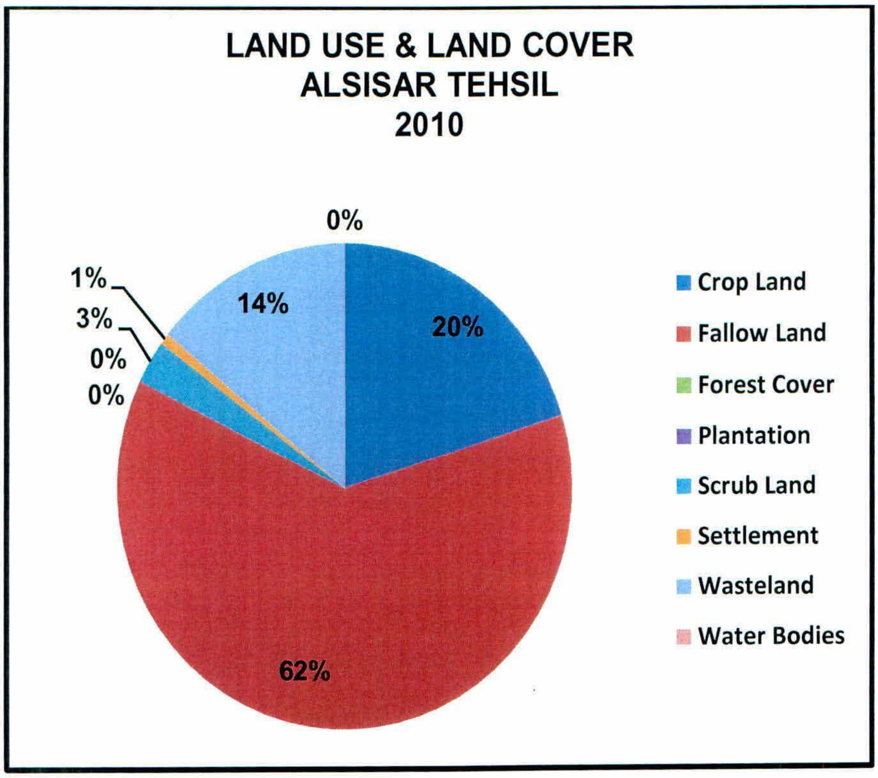


Fig. 5.16: Area in percentage of various classes from 1998 to 2008.

5.3.1.3 Change Detection of the Land use/cover Classes on types of Sand Dune

In this section a spectral based analysis has been carried out to see the pattern of land utilisation practice and boundary of sand dunes taken from the CartoDEM is overlaid in order to see the change in land utilisation practice in the different types of sand dunes. For this analysis the land use land cover map is used from the above mentioned analysis. In this section from six sample area two sample areas are taken to see the change detection of land utilisation practice on sand dunes. The outcome provides an over view regarding the changing patterns of land utilisation on sand dunes.

In this part Niradhanu Village and Alsisar, Malsisar Town are taken as case study to observe the changing pattern on sand dune. The boundary of these sand dunes are carved out from CartoDEM dataset, and it has been assumed that the sand dunes in this area are stabilised. According to **Roy et al (1970)**[2]and**Kumar et al. (1993)**[3] the expansion of sand dunes in eastern portion of dune is not observed.

1. *Sand Dunes of Niradhanu Village*: The temporal land use and cover of total sand dune area in Niradhanu village are given in the table. The spectral based analysis show that the plantation, settlement and forest cover are among few classes in which change are negligible, whereas scrubland and wasteland are observed negative decline. The agriculture is observed with the mixed response of positive and negative growth. Thus the pattern of land use on sand dunes is very dynamic in this part of the case study. The Decrease in waste and scrubland by 11 and 1 percentage points respectively. This signify that sand dunes is stabilised and the factors affecting soil conditions such as wasteland has decrease over the period of time wherein the other land use also evolving minutely which show the sign of its stable nature.

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[2]Roy B. B, and Pandey S (1970), "Expansion or Contraction of the Great Indian Desert", Proceedings of the Indian National Science Academy, Vol.36, B, No.6, pp. 331-343

[3]Kumar M, Goossens E, Goossens R (1993), Assessment of Sand Dune Change Detection in Rjasthan (Thar) Desert, India, International Journal of Remote Sensing, Vol. 14, NO.9, pp. 1702

Table 5.7: Change detection of various classes on the total area of Sand Dunes, Niradhanu Village

Land use Classes	1998 Area in (Km sq.)	1998 percentage to total Area	2010 Area in (Km sq.)	2010 percentage to total Area	Percentage Change 1998-2010
Plantation	0.15	3	0.02	4	1
Settlement	0.23	4	0.27	5	1
Crop land	0.66	13	0.13	3	-10
Fallow Land	2.66	51	3.69	70	19
Scrubland	0.10	2	0.05	1	-1
Forest Cover	0.00	0	0.22	4	4
Waste Land	1.46	28	0.91	17	-11
Total Area of Sand Dune	5.26		5.31		

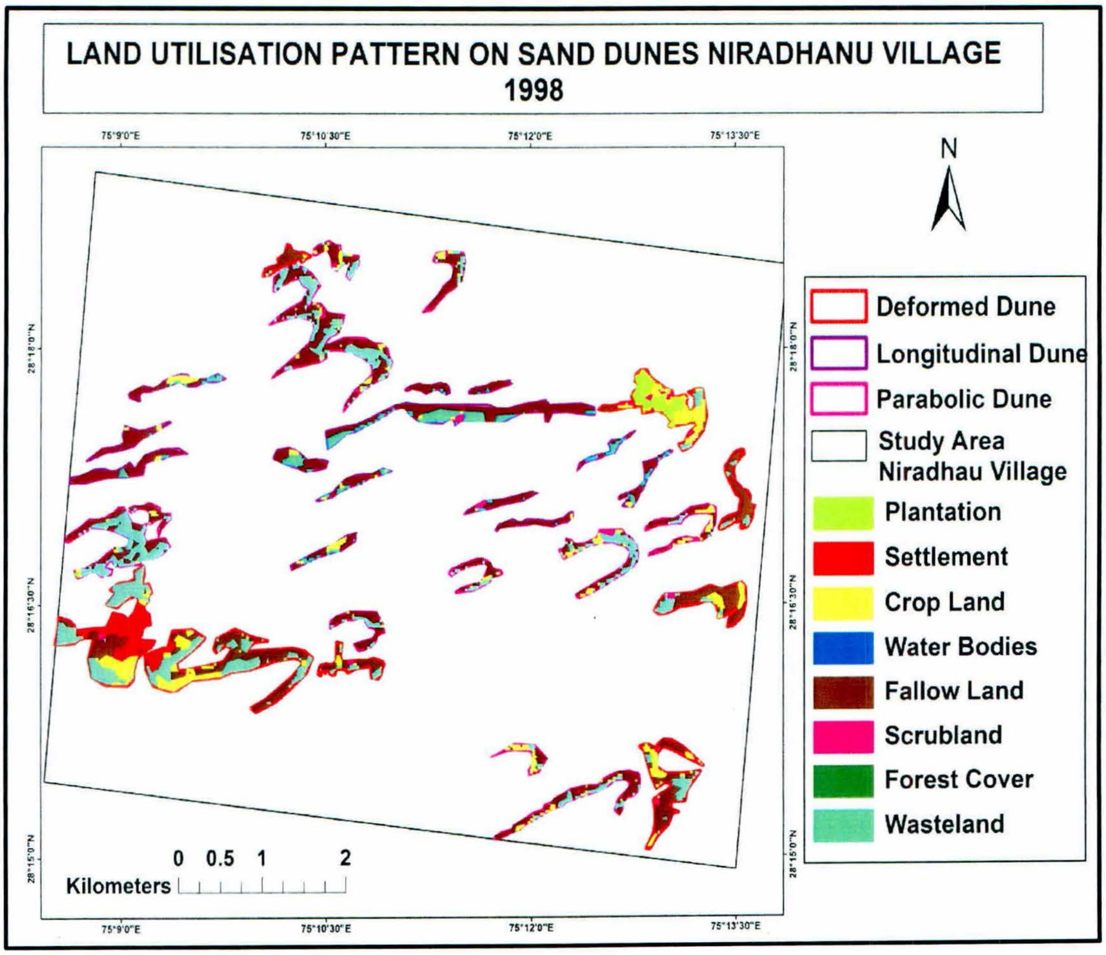

Fig. 5.17: Types of Sand Dunes and its Land use and Land Cover, 1998

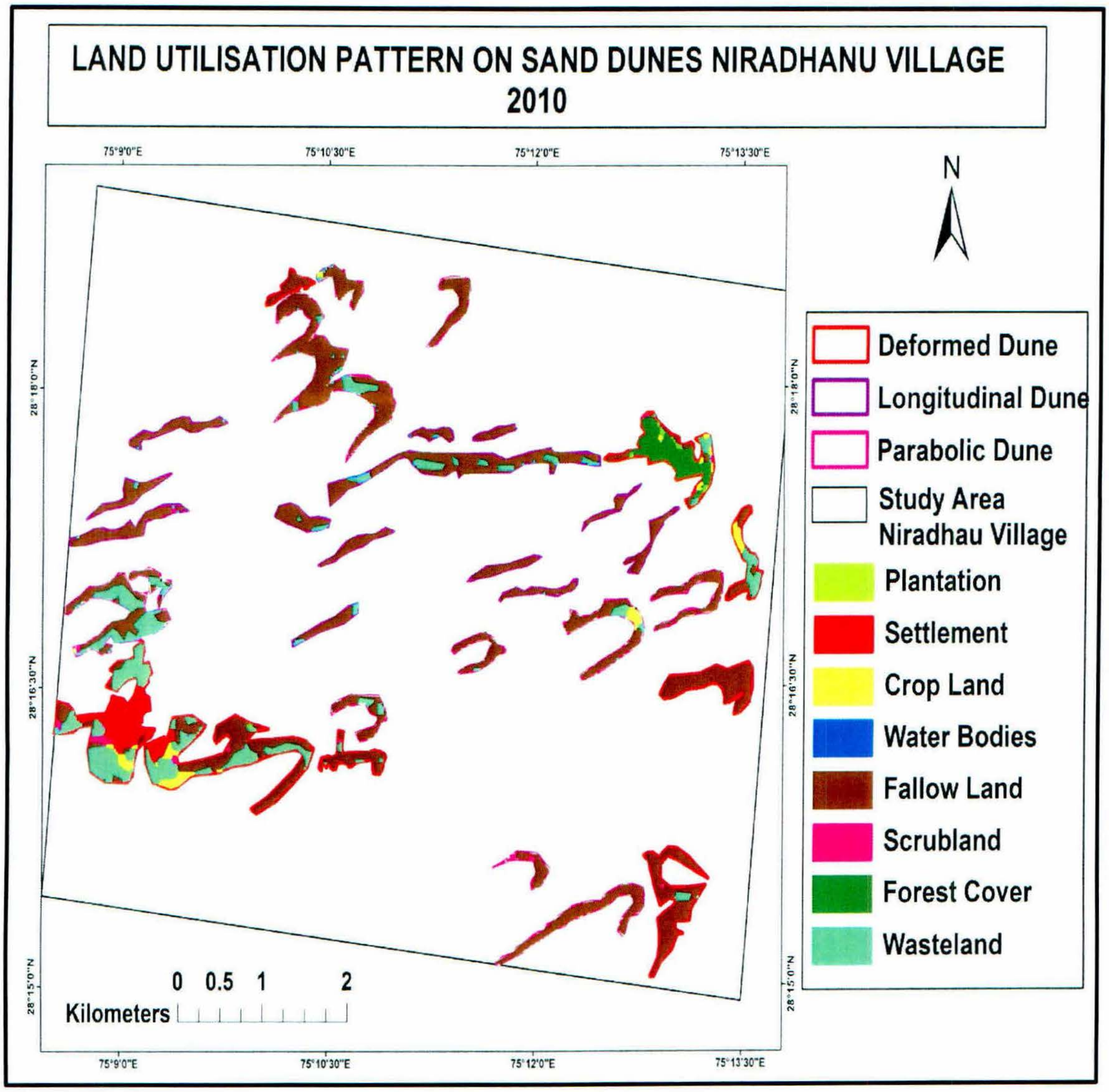

Fig. 5.18: Types of Sand Dunes and its Land use and Land Cover, 2010

2. *Alsisar and Malsisar Town:* The Land use pattern of sand dunes in Alsisar and Malsisar town is given the table :, the analysis show that the plantation, settlement and forest cover are among few classes in which change are negligible, whereas scrubland and wasteland are observed negative decline. The agriculture is observed with the mixed response of positive and negative growth. Thus the pattern of land use on sand dunes is very dynamic in this part of the case study.

Table 5.8: Change detection of various classes on the total area of Sand Dunes, Alsisar and Malsisar Town

Land use Classes	1998 Area in (Km sq.)	1998 percentage to total Area	2010 Area in (Km sq.)	2010 percentage to total Area	Percentage Change 1998-2010
Plantation	0	0.0	0.08	1.3	1.3
Settlement	0.24	4.1	0.30	4.8	0.7
Crop Land	0.50	8.5	0.08	1.3	-7.2
Fallow Land	3.91	66.2	5.06	80.7	14.5
Scrubland	0.36	6.1	0.11	1.7	-4.4
Forest Cover	0.00	0.0	0.03	0.5	0.5
Waste Land	0.89	15.1	0.62	9.8	-5.3
Total Area of Sand Dune	5.91	0.0	6.27		

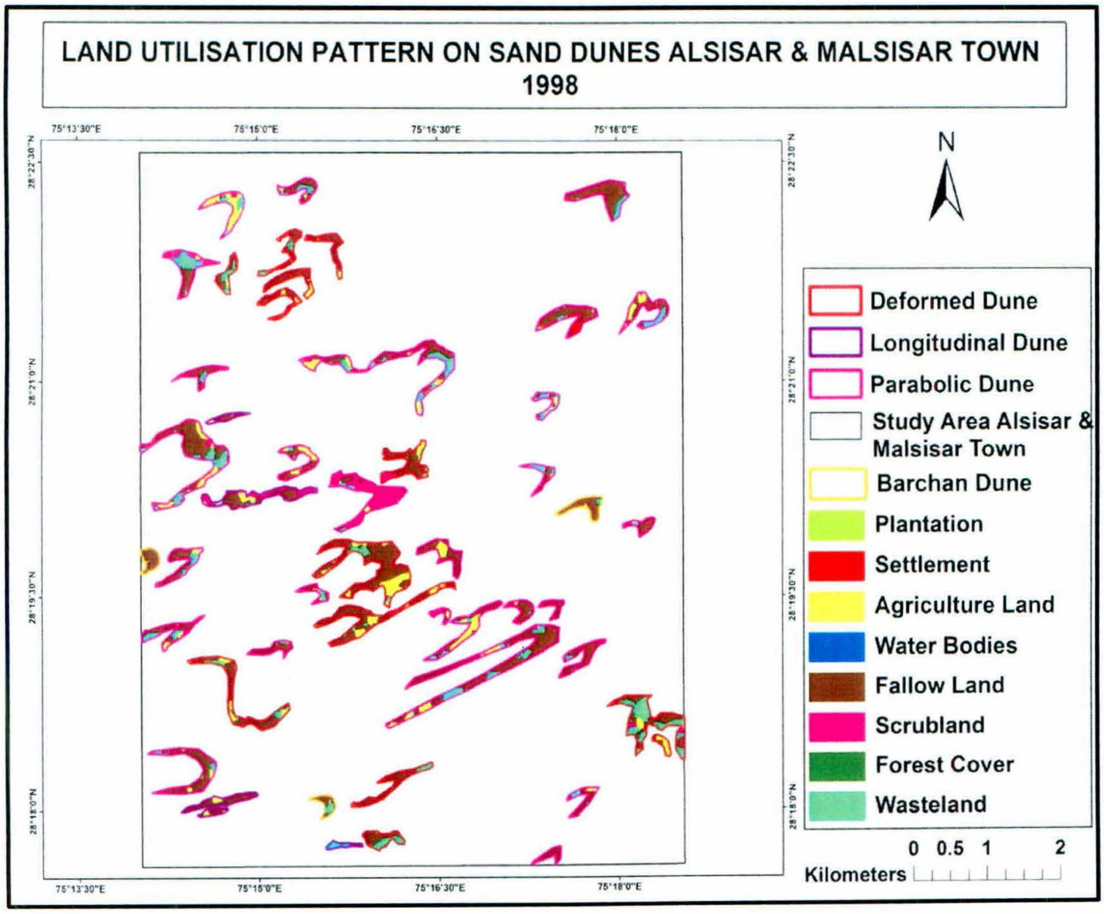

Fig. 5.19: Types of Sand Dunes and its Land use and Land Cover, Aslisar&Malsisar, 1998

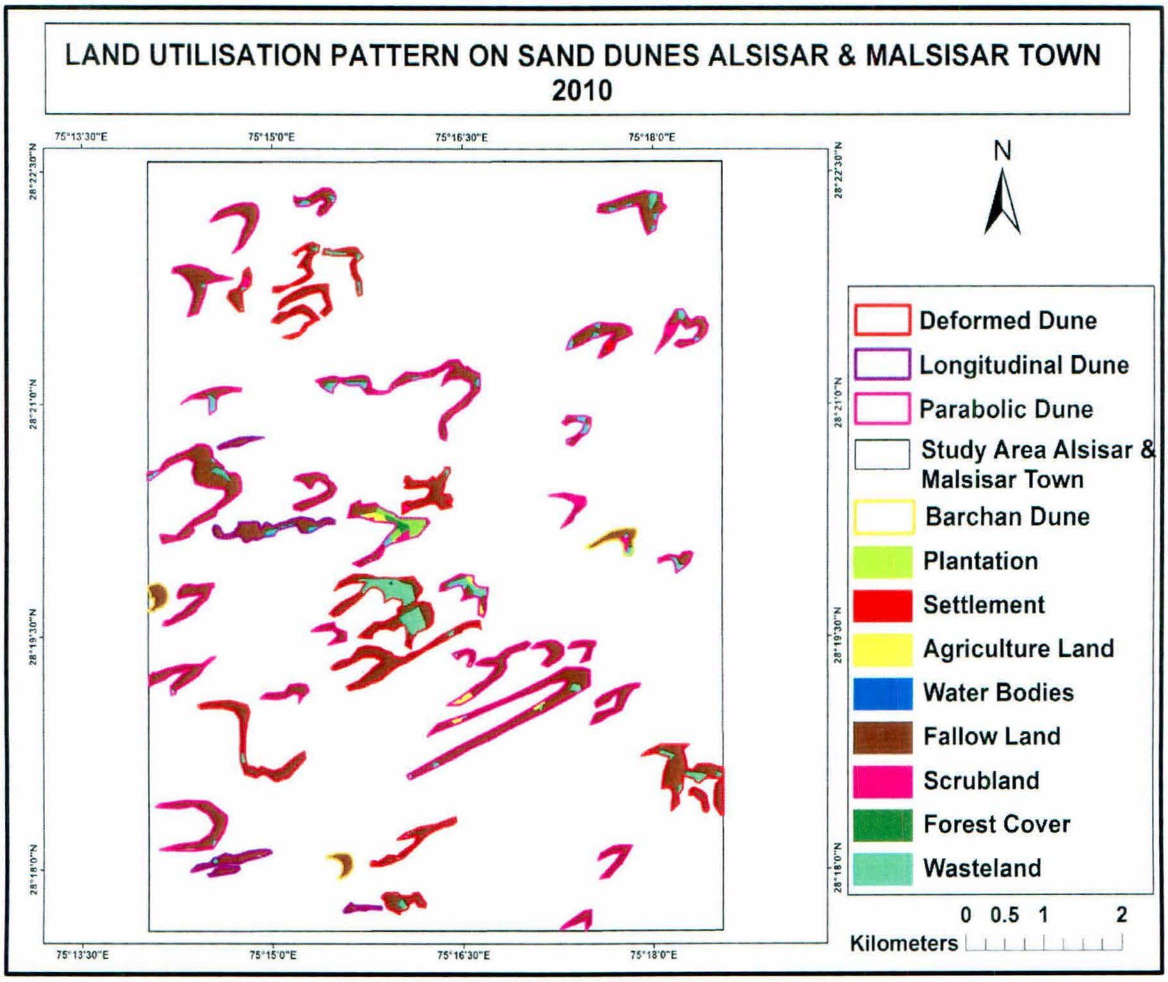

Fig. 5.20:Types of Sand Dunes and its Land use and Land Cover, Aslisar&Malsisar, 2010

5.4 Summary of Findings

1. In order to see the impact of land utilisation on sand dunes, it is important to study topography so, thatthe pattern of land utilisation practices can be linked with the Maximum elevation and slope and establish a relationship between topography and land utilisation practices. The prominent topographic feature in the study region is sand dune and thus the maximum elevation and slope of this area also denotes the sand dune. Therefore the topography of land use and land cover is has been studied to understand the influence of sand dune on land utilisation practice. The final outcomes denote that the Maximum elevation and slope are found in agriculture fields, which mean that the sand dunes on these classes are either affecting agriculture or agricultural practice affecting parameters of sand dunes. As same trend also observed in the

wasteland class. In concluding remarks the topography of an area initially is very much responsible for the arrangement of land utilisation practice butlater on these land utilisation practice also affecting the topography as well. Hence current topographic features are the outcome man and his environment interaction.

3. The spectral based analysis of land use and land cover of Alsisar tehsil show that the wasteland in the area is decrease by 2.6 per cent in between the 1998 to 2010, whereas the maximum percentage of landcover is noticed in the agriculture classes, which include cropland and fallow land. The same trends also notice on the types of sand dunes in the sample region of study. Thus this signify that sand dunes is stabilised and the factors affecting soil conditions such as wasteland has decrease over the period of time wherein the other land use also evolving with some minute changes, which show the sign of its stable nature.

Chapter 6

Summary of Findings and Conclusion

The Present Study focused on the understanding, interpreting and analysing the types and forms of Aeolian Landforms in the Study region. An Attempt has also been made to understand the dynamics of Aeolian landforms and impact of land utilisation in the parts of district Churu and Jhunjhunu respectively. The Study is based on the multi temporal satellite images from different sources including the meteorological data which has been linked with the landforms condition in order to see the impact of climate on landforms as well. Geographical information system (GIS) has proven as an effective approach for mapping the Aeolian Landforms (especially, Sand dunes), wherein extracted information from remote sensing platforms resulted into dynamic changing landscape. The major Findings of the study have been summarised below:

1.1 The introductory part deal with the significance of Aeolian studies and with the objectives, research question, data base, methodology and organisation of the study. In this Chapter the biggest focus was to choose the perfect required source for elevation. SRTM and ASTER are few sources of Digital Elevation Model (DEM) which provide elevation information. But these sources are not so good (due to resolution) for the proper identification of Aeolian landforms. Thus the need for high resolution DEM grabs the attention.

1.2 The panchromatic Cartosat-1 data was used for generating the high resolution DEM, black and white Cartosat image was fussed with RGB for the proper understanding the landscape and for enhancing spectral properties to - understand surface characteristics. For DEM generation -GCP are collected from field by using D-GPS instrument rather than simple Hand-held GPS. The comparative evaluations of elevation show that D-GPS points prove to be very useful for making almost accurate DEM and thus identification of landforms.

3.1 Aeolian landforms and processes are mostly concentrated in desert regions of the world, and these desert conditions are the outcomes of variety of desert-producing factors such as descending drying air currents, rain shadows, distance from oceanic moisture sources or effect of continality, and cold ocean currents are influential, sometimes individually, more often in combination, as primary forces producing arid lands. But apart from desertic region, Aeolian landforms and processes also appear in a variety of environments such as in cold desert, coastal zone and poor land use practice. These environments are characterised by some common structures such as sparsely vegetation cover, strong winds and a supply of fine sediments particles. Hence, beaches, glacial outwash plains, deserts, dry lakes, loess plains are usually regard with the Aeolian features.

3.2 In India, Aeolian landforms and processes are prominent in the Thar Desert of India. It took round millions of years to shape the present form of Thar Desert. The Aeolian bed form in the Thar Desert of Rajasthan is divided into arid and semi-arid environment. In western Rajasthan due to arid environment the sand dunes are completely fragile. Thus lack of vegetation, moisture made sand dunes mobile. These Aeolian processes are well active and continuous, which are responsible for the changing of sand dunes shape. While in the eastern portion of Rajasthan sand dunes are well stabilised and static. The Thar Desert comprise with various landforms which is, sand sheet and sand dunes, inter-dunal trough, rocky and mounded hills, palaeochannels, salt lakes or playas.

3.3 In order to understanding of Aeolian landforms and its processes, a case study from district Churu and Jhunjhunu of Rajasthan has been taken. Remote sensing and GIS technology is used to analyse the spatial pattern of Aeolian landforms and its pattern. During filed observation it has been noticed that the sand dunes in the study sites are mostly under agricultural areas. While proper management of soil conservation practice make people to exercise agriculture on a sand dune. They had stabilised the sand dunes through various soil binding techniques, including the Shelterbelt technology. The land use practice on them varies area wise but in general majority of sand dunes are observed under agricultural fields. Remote sensing and GIS technology prove very useful tool for the analysing the spatial pattern of Aeolian landforms.

4.1 In Aeolian Environment Sand dunes are the prominent landforms features. There are various types of sand dunes in all over the world and these dunes are classified and studied by the various scholar. In the North eastern Rajasthan desert (study regions of district Churu and Jhunjhunu), six types of dunes viz. Parabolic, Barchans, Longitudinal, Transverse and Deformed dunes are identified on the baisi of shape and size from the study area. The Deformed Dunes category has been formed on the basis of **Mckee et al. (1979)** based classification of sand dunes in which such types are considered as a *complex* and *compound* dunes. Such dunes are hard to categorised in a specific sand dune category, thus due to its deformed shape this type of sand dune has been created.

4.2 The factor responsible for the development of these dunes is wind. Wind with prominent direction and sufficient strength with prolong duration are responsible for the shape, size and movement of the sand dunes. But in this study it has been observed that the wind is not only responsible factor which affecting the dune, there are other environmental variables as well. This includes Rainfall, Temperature and related climatic factors. The comparative figures of climatic data of Churu and Pilani (Jhunjhunu) station establish the hypothetical assumption that the Jhunjhunu having a better place for the growth of vegetation due to better rainfall condition and low temperaturerelative to Churu.Consequently it had provided the durable conditions for the agriculture and afforestation land use, which indicate that the favourable climatic factors are very much helpful for the stabilising of sand dunes.

5.1 In order to see the impact of land utilisation on sand dunes, it is important to study topography so, thatthe pattern of land utilisation practices can be linked with the Maximum elevation and slope and establish a relationship between topography and land utilisation practices. The prominent topographic feature in the study region is sand dune and thus the maximum elevation and slope of this area also denotes the sand dune. Therefore the topography of land use and land cover is has been studied to understand the influence of sand dune on land utilisation practice. The final outcomes denote that the Maximum elevation and slope are found in agriculture fields, which mean that the sand dunes on these classes are either affecting agriculture or agricultural practice affecting parameters of sand dunes. As same trend also observed in the wasteland class. In concluding remarks the topography of an area originally is very much responsible for the arrangement of land utilisation practice but later on these land utilisation practice also affecting the topography as well. Hence current topographic features are the outcome man and his environment interaction.

5.2 The spectral based analysis of land use and land cover of Alsisar tehsil show that the wasteland in the area is decrease by 2.6 per cent in between the 1998 to 2010, whereas the maximum percentage of landcover is noticed in the agriculture classes, which include cropland and fallow land. The same trends also notice on the types of sand dunes in the sample region of study. Thus this signify that sand dunes is stabilised and the factors affecting soil conditions such as wasteland has decrease over the period of time wherein the other land use also evolving with some minute changes, which show the sign of its stable nature.

Finally in conclusion, Aeolian landforms are the product of geological processes and these processes are still working with prevailing climatic conditions. Sand dunes in the eastern Rajasthan show that the climatic and anthropogenic factors have affected the dune orientation and forms. In the sample study of district Churu and Jhunjhunuit has been observed that wind direction has shape the sand dune in a large extent, wherein others factors such as climate has also offerthe durable conditions for the agriculture and afforestation land use. This indicates that the favourable climatic factors are very much helpful for the stabilising of sand dunes. The Aeolian landforms impact on land utilisation can be observed through topography of an area which is very much responsible factor for the current arrangement of land utilisation practice.In the Study area the prominent topographic feature is sand dune and thus through topographic analysis of land use and land cover it has been found that the major chunk of land cover is under the agriculture field,whereas per the meteorological data the conditions of rainfall and temperature has sustained the proper agriculture in this region.This shows that the impact of Aeolian landforms on land utilisation is negligible, the spectral data also clarify the fact that waste land over the dunes is also decrease over the period of time wherein the other land use also evolving with some minute changes, which show the sign of its stable nature.

Although a sincere affords has been made in the present study to deal with Aeolian landforms and impact on land utilisation. An enormous scope remains exits in exploring the issue further details. This includes with the classification of dunes which are very intricate in terms of its shape and size. There is an also need for the details analysis of land utilisation practice on sand dunes and also need to understand the whether there is an impact of sand dunes on land utilisation or vice versa. Thus the Aeolian studies demanded the attention not because of its influence on earth but also in other planets.

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