Identification & Mapping of Palaeo-Channels in the Eastern Fringe of the Indian Thar Desert for Water Resources Augmentation Plan

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List of Abbreviations

BCE	Before Current Era
DEM	Digital Elevation Model
ETM+	Enhanced Thematic Mapper Plus
FCC	False Color Composite
LU/LC	Land use Land cover
GIS	Geographic Information System
IRS	Indian Remote Sensing
LISS III	Linear Imaging Self Scanning 3
mm	Millimeter
MIR	Mid-Infrared
NIR	Near-Infrared
NNE	North-North-East
NDVI	Normalized Differential Vegetation Index
NE	North-East
PCA	Principal Component Analysis
RS	Remote Sensing
SWIR	Short Wave Infrared
SW	South-West
TIR	Thermal-Infrared

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Abstract

Palaeochannels represent the former stream courses along which water may flow for a short distance during rainy season making the internal drainage. Such channels on the surface are almost disconnected with the main streams. The changes in the global climate and neotectonic movements are the responsible cause, which have led to migration and abandonment of several rivers and drainage systems. Some of the rivers of the drainage systems, which were main source of water in the past, have become 'extinct' because of the continuous deposition of sand and silt on the channels. There are several evidences left by them usually to help in providing the existence of geomorphic features in a particular location about their past existence. There are several researches worldwide to trace the past existence of the drainage systems. In western Rajasthan, the tributaries of Luni River reflects such fascinating features, supported by geological, hydrological evidences which are supported by the most modern tools, such as remote sensing through orbiting satellites the history of the river is more or less solved.

The present research is to identify the buried channels in the eastern fringe of the Thar Desert covering Jhunjhunun, Churu, Sikar, Nagaur, Pali, Jalore and parts of Barmer district. These areas suffer badly from depletion of water table due to over exploitation. The area is located between Aravalli hill system and the major palaeo drainage system along the international border with Pakistan. The fringe area is drained by many small ephemeral streams and nallahs, which shrunk in sand after running small distances.

With the help of Remote Sensing technology as widely used tool with the geomorphological observation in the field the potential palaeo zones with the signatures of various old drainage/ palaeo drainage and having good ground water beneath the surface along with the association of structures such as lineaments, dykes, etc has also been identified and field investigations were made at these locations. Extensive aquifer systems containing mostly fresh water have been found along the palaeochannels belts, particularly along the lineament-controlled courses. The occurrence of the fresh water is because of the regular flushing of the channels during rainy season. Still, the water towards depth may be taken as brackish to saline.

As per the flow direction, size, location of the identified palaeochannels along with the interconnectivity of playas and field observations there exists two network of palaeochannelsin

the study area one in association with Kantli river basin flowing towards Ghaggar river bed, another network with the strong signatures in association with the Luni river system draining in to Rann of Kutch in the southernmost part of Jalore district and in North and North Eastern part of Barmer district in continuation from Pali and Jodhpur districts. Numerous channels, interdunal flats, natural depressions, comparatively good quality of ground water, evidences of fluvial and alluvial deposits at some places, and dense vegetation pattern has been observed in these areas.

Chapter -1

Introduction

Palaeo Channels are old drainage systems developed during historical times. Palaeo channels were flowing during centuries BC. They are identified aserosional channels into a basement, which underlines a system of depositional sequences at several times at many places in the world. In Indian sub-continent, a good network of drainage system was flowing during 2500 to 1500 BC through Thar Desert. This region had humid and wet climate at that time, which slowly child up due to numerous reasons and the drainage system has been disorganized. During the process of drying the main courses of drainage has shifted their courses and finally, they become ephemeral or extinct from the surface. As a result, these courses left behind a network of remnants of the old drainage network, which is now found as a palaeochannels. These old network channels are associated with river Saraswati, which originated in the Himalayas and dried up during 2500-1500 BC due to tectonic and palaeo climatic changes. The existence of the holy and mighty river in the Western part of India has been described in the ancient Indian literature viz. Vedas, Brahamana and Srautasutra literature, Mahabharat, Ramayana, Bhagwat Puran, Vamana Purana, and Upanishads etc. Many Hermitages of the famous India sages like Yakyavalka, Dadhichi, Parashurama, Prarasharaetc existed on the banks of the river.

Since ancient times the rivers have been the main sources of living for the people. They play an important role in the development of the environment and in the landscape formation. Both the human cultures and biodiversity rely on the presence of rivers. Water from the rivers is a basic natural resource, essential for various human activities. Rivers corrode the mountains and forms land. Since ancient times the river banks have not only attracted the settlers by means of food (mainly fish) but also as means of transportation and looking for new opportunities to expand their civilization. It has been the lifeline of the people living along its banks. And hence all the historic civilizations may have flourished along the rivers.

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natural resource, essential for various human activities. Hence all the historic civilizations may have flourished along the rivers.

Abundant water and the soil enriched due to floods made the crops to grow in excess beyond the need to sustain an agricultural village. Ganga basin and fertile regions of Krishna and Godavari rivers are good examples of land fertility due to floods. This allowed other members of the society to engage in activities other than agriculture such as the construction of buildings and cities, metal works, trade, and transportation etc.

Spiritual and cultural celebrations on Rivers in India

It is a belief that during the solar eclipse god is in trouble and so the man pray to natural forces to pass this time peacefully and thus the people since ancient time believes that bath in the holy river washes away the ill effects of the Eclipse. The bath is also performed by means to attain salvation.

Bath on Purnima (full moon day):

It is a myth among Hindus that when Lord Vishnu himself resides in river on the full moon day and so even a touch of water takes a person to heaven.

1. MaghPurnima:Mid January
2. Kartika Purnima: Mid October to November
3. Guru Purnima: October
4. Sharad Purnima: October

In fact, people also take a holy dip in rivers on Makar Sankranti, it is a day when the sun moves northward and comes closer to earth and the day becomes longer and warmer.

Activities like fishing are prohibited around the holy rivers and so rich biodiversity here acts as a potential source of stock.

Rivers of Ancient History in India

India is the land of extremes; since Vedic times India has become the country of culture and spiritualism. From pre-birth to post-death, People in India, especially Hindus, perform various rituals to achieve spiritual nourishment, peace of mind, and moksha/salvation. They represent all the natural forces and rivers as god and goddesses and used to worship them.

There are twelve rivers in the country among which seven have cultural and spiritual importance viz. Ganga, Yamuna, Saraswati, Narmada, Godavari, Krishna and Kaveri. Besides this, there are five more rivers namely Sutlej-Beas, Ravi, Jhelum, Chenab and Indus flowing in Punjab.

As per the Hindu mythology, there are three principal gods namely Brahma the creator, Vishnu the sustainer and Shiva the destroyer. The three rivers Saraswati as Brahma, Yamuna as Vishnu and Ganga as Shiva forms the trinity of divinities in the Indian culture. They symbolize knowledge, Dispassion, and Devotion. The Confluence of these three rivers is at Prayag Sangam the most sacred and holy place of the country which is the site of Kumbh Mela festival.

Saraswati River

River Saraswati does not physically exist today but its references are found in the ancient Indian literature of the Vedic era. It shows that it's an ancient river that flowed in northern India during Vedic period. Over 1200 settlements located along the banks of the dried up river bed showed that it traveled across the Himalayan Rivers and the oceans across the Gulf of Bahrain and the Gulf of Khambat. The river joined the Sagara (also called the Hakra or Nara or Mihran or Wahinda and flowed through the Rann of Kutch into the Indian Ocean at the Gulf of Khambat. One of the principal causes of the river migration in Northern and North-West India found was the rise of the Aravalli ranges which was due to the rise of the ocean bed.

The name "Saraswati" has been commonly used to describe more than 30 channels that are located in different unrelated areas like Badrinath in Himalaya to West Bengal in the east and elsewhere in India. And thus to designate mythical river that existed in North West India the term "Vedic Saraswati" is used.

The mythical Vedic Saraswati River is known as the river of wisdom, knowledge, enlightenment& inspiration. It has flourished the most remarkably expansive, Ancient Vedic Civilization and also the important cities like Kurukshetra, Shatrana, Sirsa, Kalibangan, Banawali, Rakhigarhi, Pilibanga, Suratgarh, Lothal, Dholavera, etcalong with its banks. It was the lifeline of northwestern and western India and hence it has been adored in Rigveda in 72 versus and in later literature. In Rigveda it has been described as Ambitame, Naditame, Devitame (the best of mothers, best of rivers and best of Goddess respectively) and celebrated as the holiest river having a healing touch, it purifies and fertilizes the earth. Also, the river is mentioned in Mahabharata describing Balarama's pilgrimage, making offerings to ancestors (pitrs), on the river from Dwaraka to Mathura.

About 5000 years ago, due to a momentous geophysical event, the river Chambal (theYamuna at present) a tributary of the river Ganga captured the Saraswati river at PaontaSaheb and took the Saraswati river to meet Ganga at Prayag (a place famous as " Triveni Sangam"), near Allahabad.

And about 4000 years ago another geophysical event led Sutlej (Satadru) a tributary of Saraswati to migrate towards westwards and join the Indus River. Some part of catchment continues to flow as part of Saraswati catchment as Hakra. These two major events led the drying up of the mighty Vedic Saraswati River and the migration of the people away from the banks of the Saraswati River eastwards and southwards.

Ganga River

River Ganga is known as the river Ganges and is the greatest waterways in India. It is one of the longest rivers of the world and its length is 2525 km(https://en.wikipedia.org/wiki/Ganges). It is known as the daughter of the Himalayas. It originates from Gangotri glacier near Gaumukh in Uttarkashi in Uttarakhand (known as Bhagirathi) and flows into the Bay of Bengal. Alaknanda joins Pindar at Karna Prayag after that it meets KaliGanga or Mandakini at Rudra Prayag; it meets Bhagirathi at Devprayag and forms Ganga. From Haridwar plains, Ganga flows towards south then southeast then east then it splits into the Hugli and Bhagirathi. It has Yamuna and Son as tributaries on its right and Ramganga, Ghaggara, Gomti, Kosi, Gandak, and Mahananda as its left tributaries.

It is the heart of Hinduism. Every Hindu keeps its water by means of rituals. There is a belief that a holy dip in Ganga relieves all the sin, sorrow, and sufferings and also, it purifies the soul and so when a person dies and cremated their remains are released into the river. The river is also inscribed in the Vedas, the Puranas, and the two epics Ramayana and Mahabharata.

There are hundreds of temples in the “City of Temples” (Varanasi), which is on the bank of river Ganga. The largest delta in the world, the Sundarbans Delta is formed at the mouth of the River Ganga. Also, the longest road i.e. “Mahatma Gandhi Setu” is built on the river at Patna. While there are two major dams constructed in the river they are Haridwar dam and Farakka dam.

Yamuna River

Along with Ganga and Saraswati rivers, Yamuna is also considered as one of the holiest rivers in India. It is the fourth longest Indian river of the length 1370 km and westernmost flowing river from YamunotriglacierBunderpunch range. It joins Ganga at Prayag at Allahabad. It flows from Haryana, Uttar Pradesh, Delhi and drains into the Bay of Bengal. Its tributaries Sind, Chambal, Ken, and Betwa are on the right while Hindan, Sengar, Rind, and Varuna are on its left bank.

As per the Hindu mythology, Yamuna is one of the consorts of Lord Krishna and is also believed to be an offspring of ‘Surya’, the sun god. There is one temple at SaptarishiKund dedicated to the goddess Yamuna, which is opened only from June to October.

Holy places like Gokul and Mathura are located on its bank. Alsothe famous historical monument, ‘Taj Mahal’ is situated on its bank in Agra.

Godavari River

The Godavari is the second largest peninsular river In India. It originates from Nasik, Maharashtra and drains out into the Bay of Bengal. It flows from Maharashtra, Madhya Pradesh, Orissa, Chhattisgarh, Andhra Pradesh, and reaches to the south of Polavaram, where it forms a Gorge. A number of pilgrimage places are located on its banks including famous Jyotirlinga at Trimbakeshwar. The river is also well known as ‘Dakshina Ganga’ (the southern Ganga). It represents the saffron color of devotion which has been brought by Lord Shiva from North.

Narmada River

Narmada River originates from Maikala ranges in Western flank of Amarkantak Plateau and flows in Rift Valley between Vindhyan range in North and Satpura in South. Its length is about 1312 km and is one of the seven holiest rivers of India.

The Narmada is believed to be originated from the sweat of Lord Shiva and every pebble in the river bed is a ‘Shivalinga’. To pay tributes, devotees walk along the river from origin to end and cover a distance of 917kms. Hindus believed that to take bath once in Ganga, thrice in Saraswati, seven times in the Yamuna, but only the sight of Narmada is enough for the eternal bliss.

The river forms a gorge in marble rocks and Dhunadhar waterfall near Jabalpur. Also, we have Sardar Sarovar dam built on the Narmada. The river meets the Arabian Sea in the south of Bharuch district of Gujarat forming a 27 km long estuary.

River valley civilizations

Rivers are known as the cradle of civilizations. Not only in India but all over the world almost all ancient civilizations were situated on the banks of fertile river plains. The river valley civilizations were the first civilizations that came in river valleys which provided a constant source of water for crops. Perhaps irrigation works led to the creation of first states. And thus a river valley civilization is said to be an agricultural civilization situated beside the river.

The earliest river-valley civilizations began in the Middle East and flourished for many centuries. Their creation of a basic set of tools, concepts of mathematics and political forms persist and spread to other parts of Europe, Asia, and Africa.

Most of the river-valley civilizations were in decline by 1000 B.C.E.

China (along with the yellow river Huang He), Indus Valley (along with the Indus River), Mesopotamia (along with the Tigris and Euphrates river) and Egypt (along with the Nile river) are the world’s first four civilizations and each had many common characteristics such as

- A form of writing
- Cities
- Agriculture and surplus of food

- A form of govt. (usually claiming divine right)
- A polytheistic or henotheistic religion
- Art and architecture

Tigris-Euphrates civilization

This civilization emerged in the part of Middle East called Mesopotamia in the Tigris and Euphrates rivers valley. The region was accomplished by the Sumerians, who had developed the first known human writing, cuneiform (2400 B.C.E).(http://www.essential-humanities.net/history-overview/world-history-timeline/) The Sumerians also had the characteristics of the development of astronomical sciences, intense religious beliefs, and tightly organized city states.

They improved the region's agricultural prosperity by learning about fertilizers and using silver to conduct commercial exchange.Their political structures tightly organized city states, ruled by a king who claimed divine authority. The government helped regulate religion and compel observance of its duties. Kings were the war leaders, and the function of defense and war, including leadership of a trained army, remained essential.

They laid down the procedure for law courts and regulated property rights and duties of family members, setting harsh punishments for crimes. Standardization of a legal system was one of the features of the river valley civilizations in the historic period.

Egyptian civilization

Egyptian civilization emerged in northern Africa along the Nile River by about 3000 B.C.E. People of this Civilization produced their own distinct social structures and cultural expressions.(http://www.essential-humanities.net/history-overview/world-history-timeline)

The Civilization featured very durable and centralized institutions. It was also characterized by mathematical achievements and impressive architectural structures. From 2700 B.C.E onward, the ruler Pharaohs directed the building of the pyramids, which were to function as their tombs. However, the building of this massive monuments could only be accomplished with the use of an abundance of slave labor.

Indus valley civilization

A successful and well flourished urban civilization originated in the Indus River valley by about 2500 B.C.E.(http://www.essential-humanities.net/history-overview/world-history-timeline/) It is the first known Urban Culture in India. The majority of the sites like Harappa have excavated on the banks of river Indus, Ghaggar, and its tributaries. People of Indus valley civilization had trading contacts with Mesopotamia, but they developed a distinctive alphabet and artistic forms.

They had double storied housed made of burnt bricks with kitchen, bathroom, and a well. Agriculture was considered as the major occupation of the people of rural areas while thecity people were engaged in other activities like internal and external trade with the other civilizations(such as Mesopotamia). Harappa, Mohenjodaro, Dholavira, Lothal, Rakhigarhi, and Ganeriwala are some major excavated sites in this Valley.

Chinese river valley civilization

Chinese civilization was developed along with the Huang (Yellow) River in China. They had trading contact with India and Middle East. In addition to the existence, they had carefully regulated irrigation in the flood prone area. They had advanced technology and had elaborated intellectual life by about 2000 B.C.E. China had less of a break between Chinese River Valley society and the later civilizations than in any other region.(http://www.essential-humanities.net/history-overview/world-history-timeline/) By about 1500 B.C.E, the ruler Shang ruled over the Huang River Valley. These rulers were noted for managing the construction of impressive tombs and palaces.

Chapter-2

Rationale of the Problem and Objectives

It is believed that western Rajasthan had a dense network of drainage in its historicalperiod. Due to numerous reasons, this area is dried up and the drainage system has been disorganized These dried-up areas are still available under the thick alluvium and may have good water potentials. Many researchers and institutions like ISRO(Sharma J R et.all 2004,2011)Space Application Centr(Rajawat et all 2005),CAZRI(AmalKar and Ghose,1984),Central ground water board,Geological Survey of India(Bakliwal 1980)have identified such palaeo channels in the areas along the western border. Many more palaeo channels may be available along the Aravalli hill system in Jhunjhunun, Sikar, Churu, Nagaur, Pali, Jalore and parts of Barmer Districts of Rajasthan. These palaeo channels may be useful for supply of drinking water in these districts and may also be utilized for artificial recharge of ground water. Remote Sensing technology along with limited ground checks and geo-electrical investigations found to be useful tool for précised demarcation and mapping of palaeo-channels.

Objectives

The objectives of the study are oriented towards the identification and precise mapping of palaeo channels and behavior of ground water in palaeo drainage in terms of quantity, quality, recharge capabilities etc. The major objectives are as below:

1. Identification and mapping of palaeo-channels in Jhunjhunun, Sikar, Churu, Nagaur, Pali, Jalore and parts of Barmer district of Rajasthan.
2. Verification of palaeo channels by Geophysical survey and field Hydro-geological studies coupled with remote sensing studies.
3. Location of suitable areas for artificial recharge.

Study Area

The study area is located in the eastern fringe of the Thar Desert Rajasthan. The fringe area of the Thar desert covering Jhunjhunun, Sikar, Churu, Nagaur, Pali, Jalore and parts of Barmer districts. These districts suffer badly from depletion of water table due to over exploitation.

This area is situated between Aravalli hill system and the major palaeo drainage system along the international border with Pakistan. This fringe area is drained by many small ephemeral streams and nallahs, which shrunk in sand after running small distances.

These streams may be remnants of old drainage system existed in historical period. Drainage system in this part is most disorganized, discontinuous and drains in various directions. Many channels are flowing in western direction also like Kantli in Jhunjhunun and Sikar districts. These areas are affected by over development of ground water and are being converted into dark zone. These channels may have relations with the major palaeo drainage system and may be useful for ground water development, artificial recharge etc. Extends between latitudes 24º32'24.83" and 29º01'45.19"N and longitudes 70º 08'13.29"and 76º 06'46.61"E.

According to A. R. Nair, S. V. Navada and S M Rao of Bhabha Atomic Research Centre (BARC) have conducted isotope study of selected sites of Barmer and Jalore districts and concluded that shallow aquifers are phreatic condition and deeper aquifers are under confined and semi-confined conditions in Barmer district. In Jalore district it was found that shallow and deep aquifers near the river courses of Luni and Sukali are generally fresh and of $NaHCO_3$ type whereas it is brackish and of NaCl type at distant areas from the river courses.

Climate of the study area is dry and hot with extremes of temperature, low humidity, high evapotranspiration rates, small monsoon season, low and scanty rainfall etc. Rainfall in Thar desert ranges between 150- 500 mm which approximately250-500 in the eastern fringe area (study area). High rainfall variability resulted in frequent draught in the area. Flood events are very fewdue to high intensity rains in small period as observed in Barmer in 2012.

Soils of the study area are mostly older and younger alluvium in Luni and Shekhawati basins. Soils are good and fertile in Pali, and Jalore districts. Lunia river with its tributaries has deposited good alluvium. Limitation in these soils is lack of organic matter. Apart from these basins parts of Jhunjhunu, Sikar, Nagaur and Barmer districts have older alluvium covered by aeolian sand.

Table 1: Area under study

Sr. no	District	Area (Sq.kms as per census)
1	Churu	13858
2	Jhunjhunun	5928
3	Sikar	7742.44
4	Nagaur	17718
5	Pali	12330.79
6	Jalore	1056444
7	Barmer (Parts)	28387
	Total	**1142408.23**

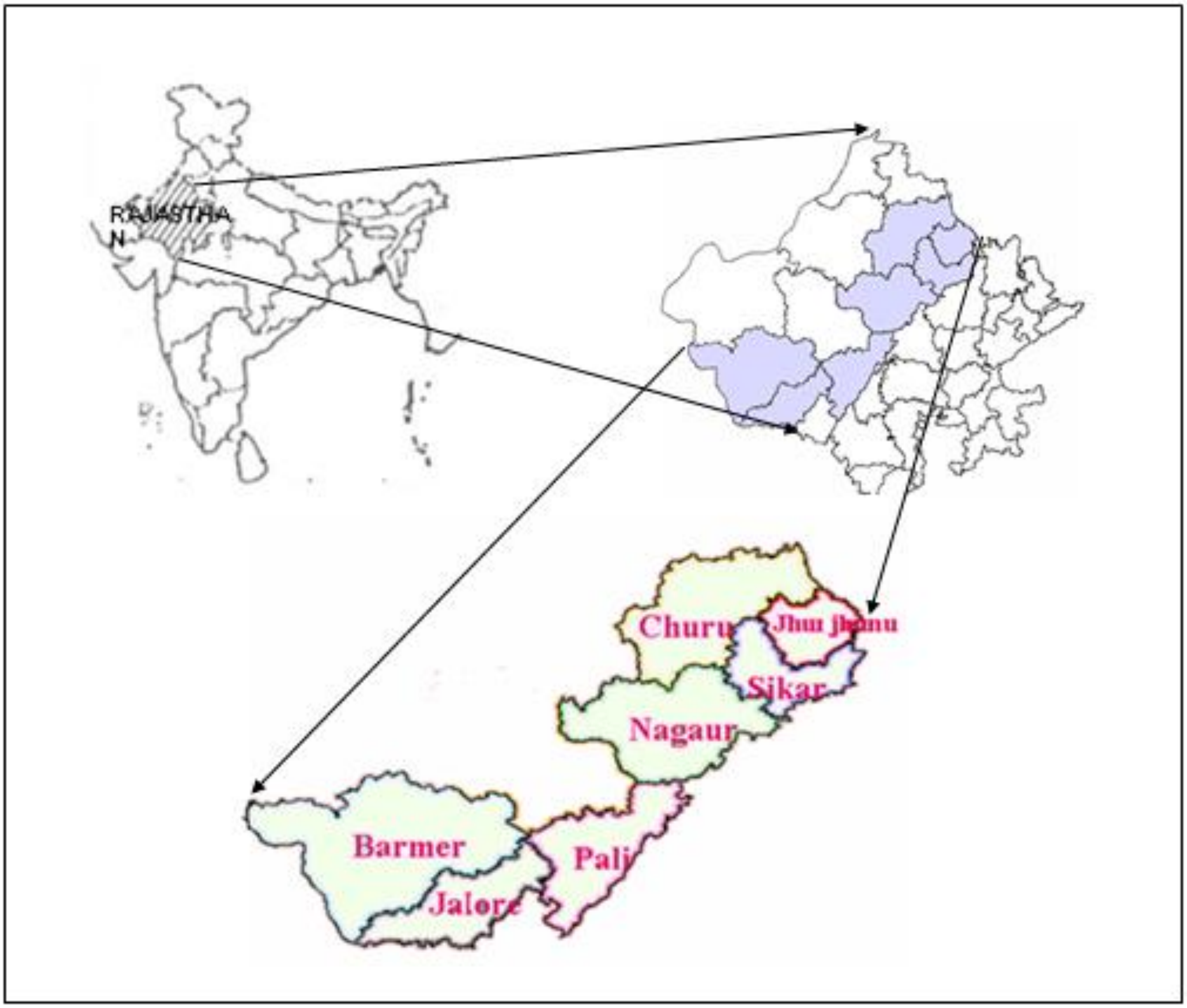


Figure 1: Geographical Extent of area under study

Methodology

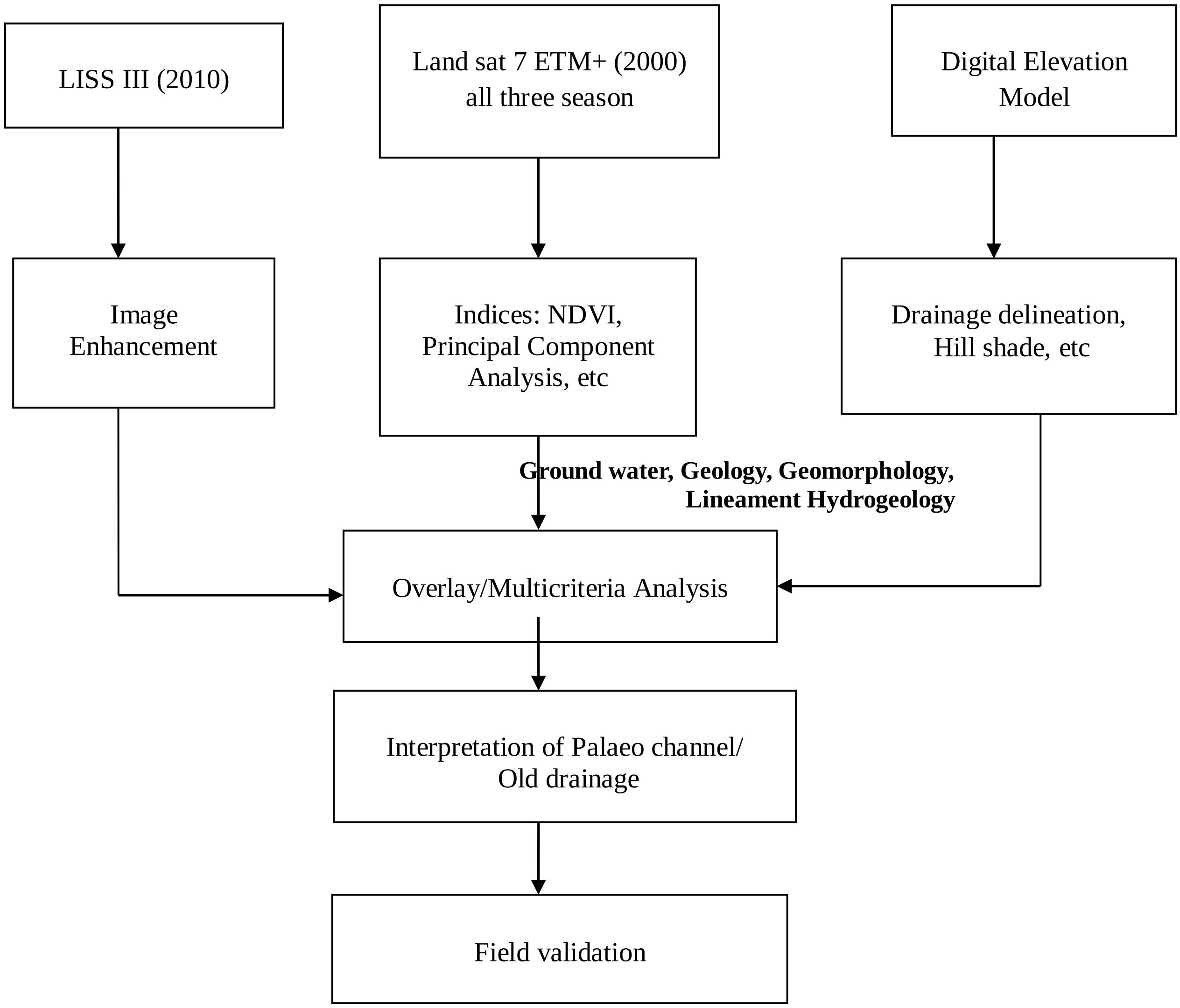


Figure 2: Methodology Flowchart

Remotely sensed data is reliable tool in tracing palaeo landforms in arid and semi arid environment as these landforms gives specific spectral signature in comparison to surrounding terrain because these landforms have generally high level of moisture and moisture holding capacity, different chemical composition, grain size, vegetation pattern, etc. IRS LISS III satellite images have been used for detailed palaeochannels mapping. Hybrid approach of image processing (digital analysis / visual interpretation) has been used for mapping palaeo-geomorphology, hydrology, identification of palaeochannels, land use, etc. in the fringe areas of Thar desert on 1:50,000 scale.

Digital Elevation Model (DEM) has been used for drainage delineation and for precise demarcation of palaeochannels network. Products have also been generated at 1:25,000 scalesfor selection of suitable locations for field verification. Field verification has been performed in two stages i) Reconnaissance survey, ii) Post analysis verification.Thematic outputs are generated by visual/ digital analysis of satellite images, ground truth and secondary information gathered either from field or other departments.

In the present study IRS LISS III image in four bands have been utilized for detailed Palaeo channel mapping. Several image processing and GIS techniques have been adopted for extracting maximum hydro geological information. Image processing software, ERDAS Imagine has been used for georeferencing, mosaicking and inanalyzing satellite images through various image enhancement techniques. Principal Component Analysis (PCA), contrast enhancement, vegetation indices,etc techniquesgave useful hydro geomorphic information. The reference field data of basement elevation has been utilized for the DEM (Ahmad, 1984,Murty and Srivastava, 1990). The remote sensing keys used for potential ground water zones, using satellite image are local and regional relief setting, stream valleys, vegetation indices of moisture anomalies, alluvial plains, flood plains, alluvial fans, braided and meandering streams related to shallow ground water levels, braided and meandered plain, channel-fill, orientation of lineaments, fractures, geologic barriers like dykes, drainages network, weathered zones, orientation of ponds and lakes (playas), land use land cover . Information of archaeological sites have been gathered and analyzed with thematic data. Also along with thematic data, other secondary informationhas beenanalyzed in GIS environment to understand the correlation among various parameters and interdependence of various factors.

Potential zones of palaeochannels have been identified and its analysis has been performed in GIS environment. Finally results were drawn from GIS analysis and thematic information about location and extent of palaeochannels, their characteristics, and points of water availability in various seasons, ground water prospects, probable sites of artificial recharge, etc.

Chapter-3

Review of Research and Development on the Subject

Many institutions and individuals have done significant work on the delineation of buried channels and water resources in Western Rajasthan. Several lines of geological evidence confirm the existence of a high-energy fluvial regime in western Rajasthan during the Late Quaternary period. Geomorphic description of the extinct river system matches well with the Saraswati River described so vividly in the *Rigveda*. . During the initial stages,the Vedic river which presumably flowed parallel to the Aravalli Mountains migrated westward during neotectonic uplift of the Aravalli Mountains. The neotectonic movements had brought about the down sagging of the northern part of Aravalli Mountains and also forced the Yamuna River to swap its original course to flow across. The river presumably pirated the Saraswati waters while it drifted eastward to join the Ganges. The most significant evidence of the presence of a well-drained fluvial system comes from the riverine pre-history of all the saline lakes in western Rajasthan, including that of the Sāmbhar situated in the Aravalli Mountains. In fact, suggestions have been made that the saline lakes are the segmented remnants of the disorganized river. A number of Palaeo-channels have been discovered in the Thar Desert region in recent years using satellite remote sensing.

Since 1972 onwards researchers have done many studies on hydrological analysis using various remote sensing data products. Rango et. al. (1975) shown advantages of remote sensing data over conventional data in water resource evaluation in watersheds in U.S. Cannon (1977) found that remote sensing data (Radar) is very useful and dependable in hydrological and morphometric investigations such as area, perimeter, bifurcation ratio, stream length, stream frequency etc. Few researcher identified palaeo channels in Sahara desert at various depths using radar and microwave data. They found that satellite data are very useful in identification of high moisture areas, vegetation patterns wetlands, marks of old drainage etc.

D.L. Runkle(1985,1997) of U.S. Geological Survey has identified nine alluvial aquifers consisting of sand and gravel are in the valleys of the Little Sioux, Maple, Soldier, Boyer, West Nishnabotna, East Nishnabotna, South Raccoon, Middle Raccoon, and North Raccoon Rivers. These aquifers contain about 870,000 acre-feet of water that is potentially available to wells. Potential well yields generally are less than 50 gallons per minute.

The movements caused drainage anomalies like channel branching or obliteration, channelincision, and shifting of courses. Ghose et al, Kar and Ghose and Kar (1984) recognized three different stages of shifting of courses of the ‘now extinct’ Himalayan rivers. (Figure 1)

(1) The vicinity of Rajgarh, Hardyal, Ratangarh and the present misfit Valley of Jori
(2) Nohar, Surjansar, and Samrau
(3) Sirsa, Lunkaransar, and east of Bikaner.

The Luni River, which flows through the south-eastern part of the Thar Desert region once drained into this Himalayan system. Kar A. (1986) mapped several SW to SSW trending valleys in the alluvial plains between Jodhpur and Pali. He identified these as belonging to those of the Luni River. The discovery of palaeo-valleys indicates a number of easterly courses of the erstwhile Luni River. The points of deflection from the present course of the Luni River are located at places near Malkosni, Mortauka, and Kankan. These, according to Kar A, are the possible successive shifted courses of the Luni. Hediscussed the influence of NE-SW trending lineaments in controlling the present-day stream courses in the Luni–Jawai plains.

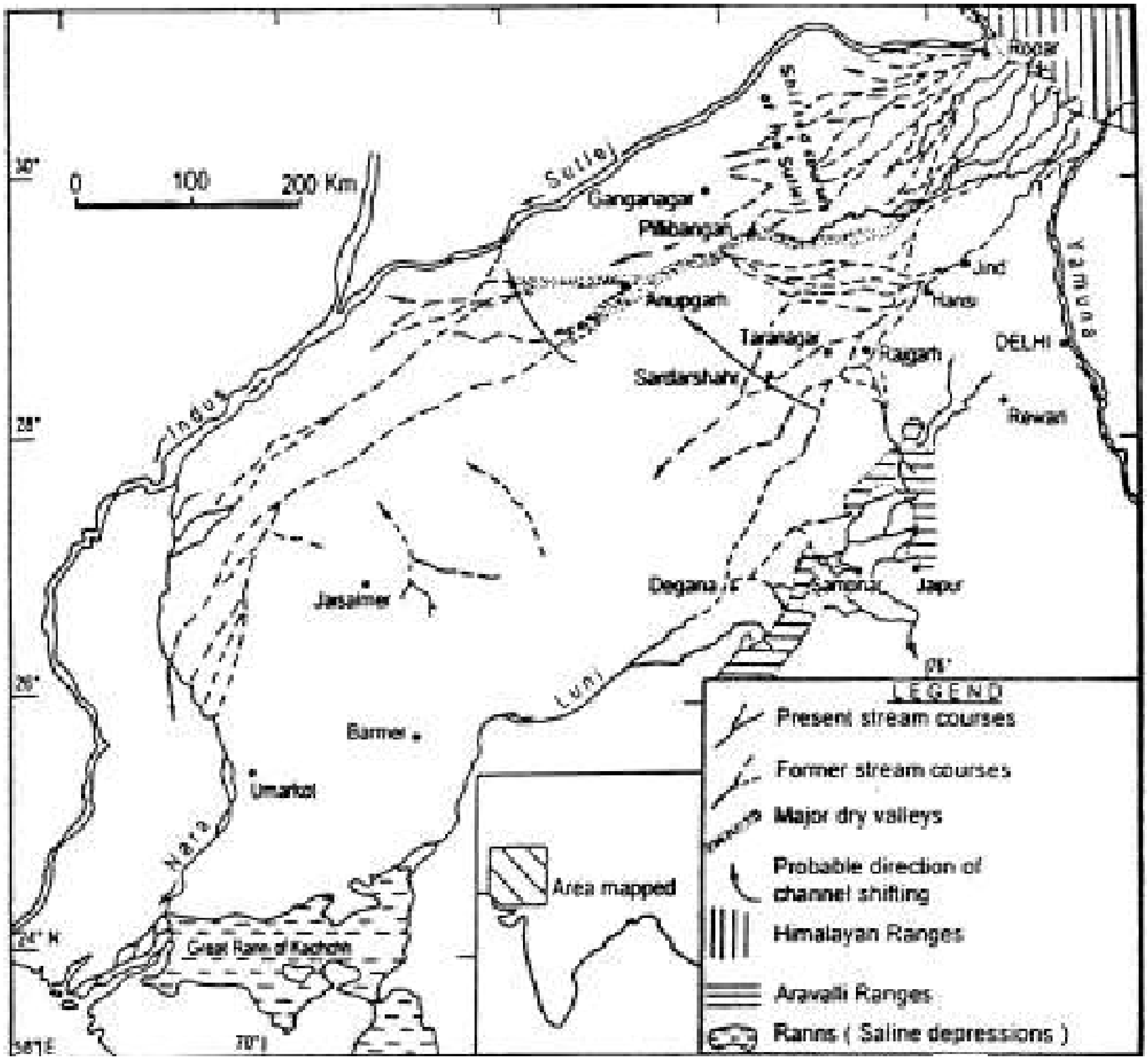
According to Bakliwal and Grover (1998), the Himalayan River initially followed a channel close to the foothills of the Aravalli Mountains. In the southern part, the river followed an easterly course than the present Luni, before its culmination in the Little Rann of Kutch. These authors proposed a number of stages in the shift of river courses in the northwesterly and westerly directions before merging with the present-day dry beds of the Ghaggar It may be pointed out that the shifting of river courses suggested by these authors is somewhat different from those suggested by Ghose and Kar (1984). Nonetheless, all these studies, including those by Mehta et al., Sahai(1993) et al. and Yashpal et al. (1980) not only helped in confirming the course of a mighty Himalayan river but also indicated its migratory nature, implying northwesterly and westerly shifts in its course. The apparent differences in the suggested trends of Palaeo-channels a described by all these authors could be because of the difficulties in piecing together of different segments, due to lack of records on the ages of their formation.

The studies by Rajawat et al. (1999,2013), further confirmed the presence of a large number of segments of palaeo-channels in the region using IRS 1-C data. All these palaeo-channels are presumed to be the relics of a river system that drained western Rajasthan at different times during the Quaternary. In addition to this, the presence of dry valleys (the Ghaggar, for example) in north-western Rajasthan, Haryana and also in the Sindh Province in Pakistan, attests the presence of erstwhile fluvial regimes in the Thar Desert region.

Ajay Srivastava, Nitin Kumar Tripathi and K.V.G.K. Gokhale(1996),Department of Civil Engineering,Indian Institute of Technology, Kanpur have made an attempt to evolve an integrated approach for groundwater exploration in the Genetic alluvial terrain in terms of aquifer targeting and groundwater quality assessment using remote sensing data. This study has established that remote sensing and GIS techniques can be successfully applied for the regional investigations of the groundwater recharge zones. It may be indicated that the most remarkable areas of groundwater availability correspond to the commonly occurring depressions in the bedrock. The subsurface morphology of the basin and the tectonics are the factors which influenced the sedimentation pattern and guided the channels of Yamuna river system.

Dr. M.R. Kumar, Dr. Rajawat et al of space application center, Ahmedabad (2005) have recreated the ancient path of the rivers in Indian Thar Desert by remote sensing technology. They concluded that due to climatic changes and neotectonic have played a significant role in modifying the drainage courses in Thar Desert and a large number of palaeo channels exist in this area. The applied and useful aspects of such studies for ground water exploration to understand the ground water prospective zones or the suitable sites for artificial recharge or in studies related to the palaeo-climate, quaternary geology, archaeological exploration and seismic hazard zonation. The other observed that extensive aquifer systems containing mostlyfresh water have been formed along the palaeochannel belt, particularly along lineament-controlled courses.

A remote sensing study of the Indian Thar desert reveals numerous signatures of Palaeo channels in the form of curvilinear and meandering courses, which is identified by the tonal variations (Bakliwal et. al. 1988). Its initial course flowed close to the Aravalli ranges and the successive six stages took west and northwesterly shifts till it coincides with the dry bed of the Ghaggar River and rivers migrate for various reasons amongst which tectonic movement is one of the main causes. The study has shown that western Indian Drainage Network shows considerable signs of the Quaternary tectonic period (Landsat photographs one 1000,000 scales) the Palaeo channels were interpreted, as linear, curvilinear and loop like features with typical black ribbon like stripes.



Source: Roy A.B. and Jakhar S.R(2001) Current Science Vol.81 No 9 10 November 2001

Figure 3: Courses of present and former streams passing through NW Rajasthan (after Kar 1995).

Seven Stages of Migration of Saraswati River in Rajasthan

1. Along the foothills of Aravalli hills through Rajgarh, Sikar, east of Nagaur, upper reaches of present LuniRiver, follow present Luni and then south of the presetLuni in the lower reaches to meet the Rann of Kutch.
2. Passes through Nagaur, Pachpadra, Thob and meets Luni near Tilwara where Luni takes a sharp turn towards the south and followed the path of present Luni River.

3. Passes through Lunkaransar, Sridungargarh, Bikaner, Phalodi, Ramdevra and meet Luni at Tilwara.
4. Passes through Portugal, Bhikampur to Barmer and Rann of Kutch independently west of present Luni course.
5. Passes through Portugal, NachhaShriMohangarh through JaisalmerRanns and then takes an N- S trend through Gadra road before debauching in the great Rann of Kutch.
6. South of Ghaggar through Kishangarh, Ghotaru with the lower course not well defined.
7. Present dry bed of river Ghaggar flowing through the old Bahawalpur state as Hakra River and latter flows as Nara to meet the great Rann.

Fig4 represents the mouths of three rivers identified as Shatadru (Hakra), Saraswati and Drishadvati (after Malik et al. 1999). The territory now presents a different scenario, characterized by an arid climate and the presence of a thick sand sheet comprising dune deposits and ephemeral and essentially centripetal drainage pattern. Many scholars and earth scientists now believe that the extinct river system was none other than the River Saraswati, which has been extolled in superlative terms in the Vedic and Puranic literature. A number of workers pointed out that the aridity was the main cause of extinction of the Vedic river. From the description of the Saraswati River in Vedic literature, it is apparent that the river in question was indeed a very forceful one, having a perennial flow of glacial water. Extinction of such a glacial-fed river purely due to aridity would be highly unlikely. It may be worth comparing the case of the River Nile, one of the very large rivers in the world today. The river is flowing gloriously through the highly arid region of the eastern Sahara Desert.

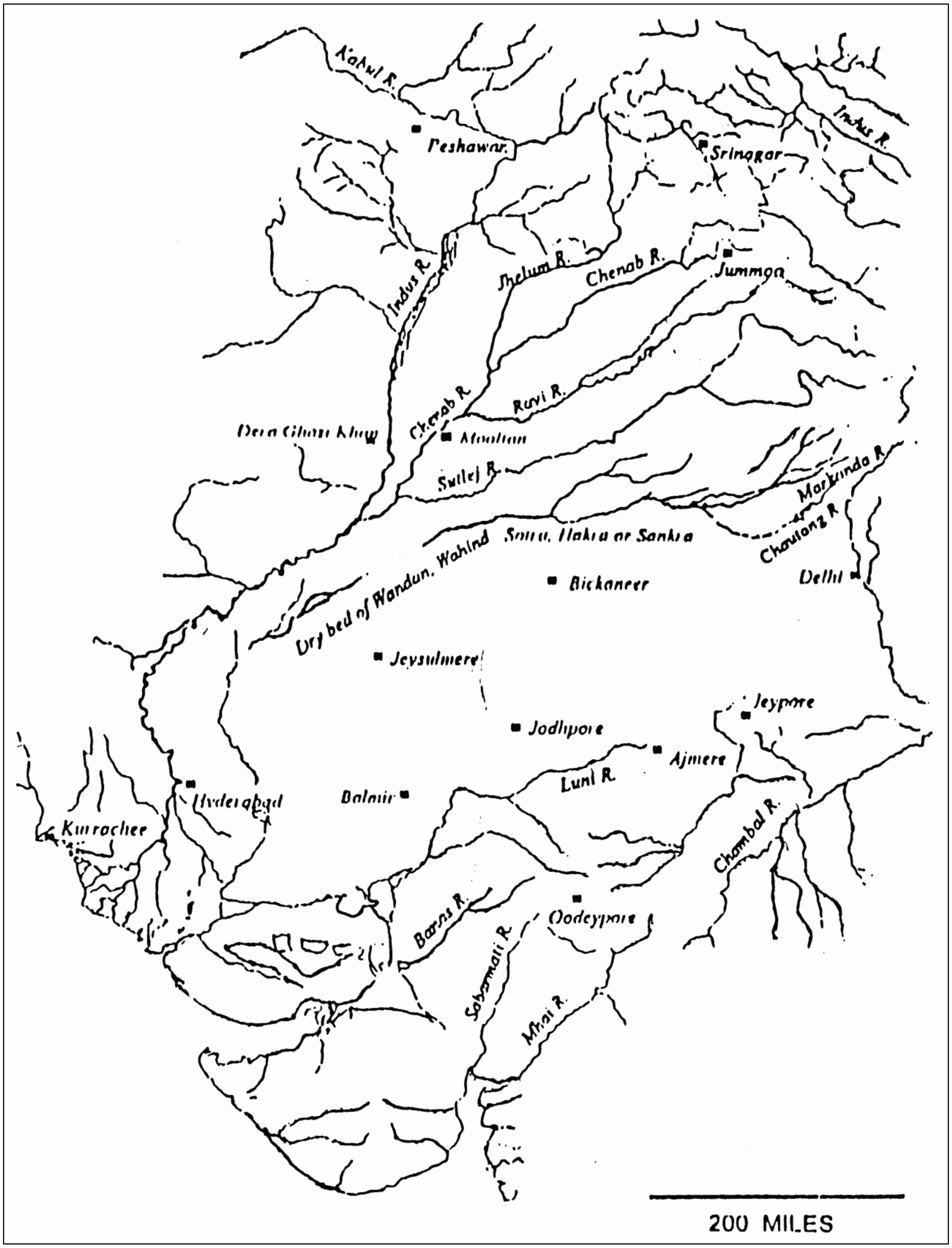
There is absolutely no scientific basis for the belief that River Saraswati plunged underground and is now having a subterranean flow of water. Perhaps this was at the back of the mind of some of the earth scientists who were engaged in the drilling operation, with the hope of tapping the flow of the ‘Vedic River.

Oldham (1886) was the first to prepare a drainage map of this region, which presumably was drained by the Saraswati River system.

Many other earth scientists and scholars firmly believe that the river course now represented by the dry beds of Ghaggar and its southern counterparts, Hakra and Nara basins, constitutes the channel of the Saraswati River referred to in the Vedic and Puranic literature.

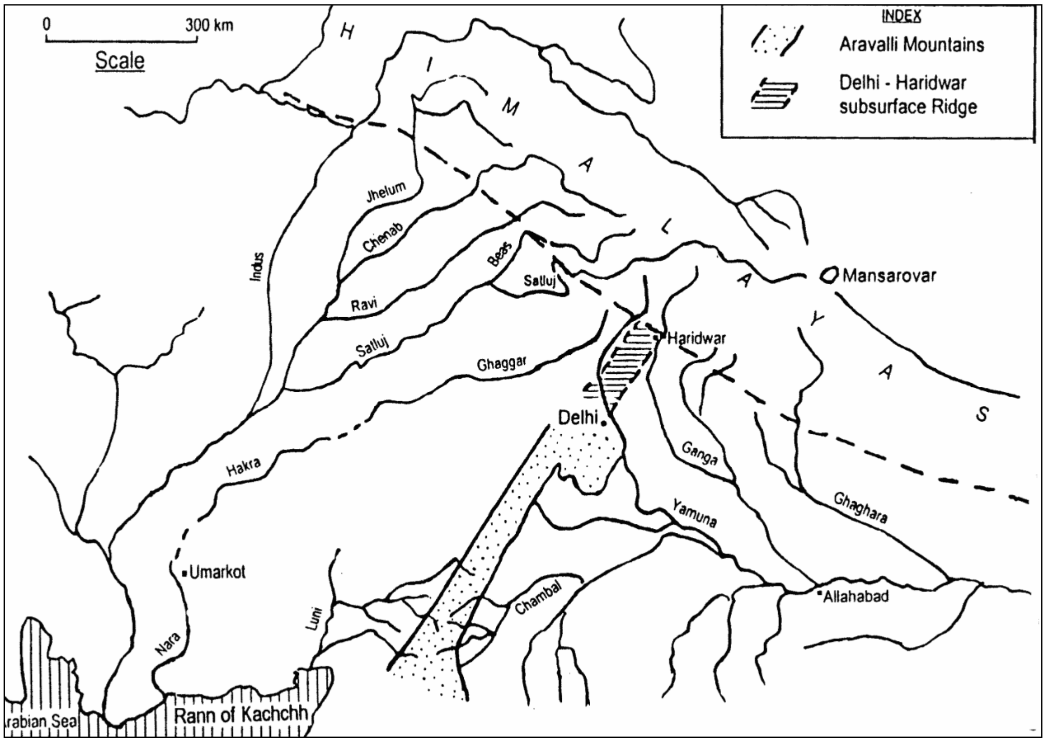
Ramasamy (1991) has analyzed the pattern of the palaeo channels of Saraswati river system in Great Indian Desert and classified them as:

1. Organized near rectilinear palaeo channels,
2. Disorganized convergent Palaeo channels
3. Sprayed Palaeo channels



Source: Roy A.B. and Jakhar S.R(2001) Current Science Vol.81 No 9 10 November 2001

Figure 4: Drainage of North Western India



Source: Roy A.B. and Jakhar S.R(2001) Current Science Vol.81 No 9 10 November 2001

Figure 5: Bipolar drainage pattern of easterly flowing and south westerly-Flowing Himalayan Rivers

H.S. Mann (1980) has prepared water potential map of Gujarat and Rajasthan state. P.C. Chatterji (1980) has pointed out the problem of water resources development in Great Indian Desert. Prof. Yash Pal, D BaldevSahai et. al. (1980) has prepared a detailed map of the lost Saraswati River between rivers Sutlej and Yamuna by remote sensing techniques. They have identified many channels between these two river systems, which were fed by Himalayan mountain systems. Apart from these, all the significant work done by various agencies like Central Arid Zone Research Institute (CAZRI 1984), Jodhpur, Geological Survey of India (GSI), Space Application Centre (SAC 1980), Central Ground Water Board (CGWB 1999), Ground Water Department (GWD), etc. They have established that the river Saraswati has shifted its course at least four times.

These courses were shifted somewhere between 10,000 to 3800 B.C., Dr. A.K. Gupta, Dr. J.R. Sharma et. al. (2004),Sharma J.R and Bhadra (2009,2012) of RRSSC, ISRO, Jodhpur has analyzed IRS-LISS-III and PAN images digitally and a dense network of Palaeo channels is identified in the area parallel to Aravalli hills and in the area adjoining to Pakistan border Five drainage courses joining Rann of Kutch have been worked out. Authors have concluded that the river Saraswati had its course through the river Ghaggar and did not drain along the Aravalli hills. Also, it did not shift its course drastically and continuously from east to west. The authors have verified the results with drilling data also. Dr. M.P. Punia and R.R. Saini (2005) have identified a palaeo channel (Anokhi buried channel) in Jaipur district through interpretation of satellite images. The palaeo channel was confirmed by geoelectric survey and drilling methods. The authors have concluded that remote sensing and geoelectric survey are useful tools for precise identification of palaeo channels in arid and semi-arid regions. A good amount of fresh water was found in drilling in this palaeo channel.

The Landsat studies conducted by Amalkar of CAZRI(1984), Sharma J.R et.al of ISRO shows that the Indus river has a very wide flood plain on either side of its courses up to a maximum width of 100-200 km. in the east and south east, to have such a wide flood plains on only one side shows that the Indus river has preferentially migrated towards the north west in the northern parts and towards the west in the central and southern parts and the Saraswati river once flowed close to the Aravalli hill ranges and met the Arabian sea through the Rann of Kutch, that it has migrated towards the west, the north-west and the north and has ultimately got lost in the Anupgarh plains. The study of remotely sensed data in the desert tract of Rajasthan shows that there are plenty of Palaeo channels with well sprain up tentacles throughout the desert. On the northern edge of the Thar Great Indian Desert at the Ganganagar-Anupgarhplains, a well-developed set of Palaeo channels are clearly discernible in satellite photographs

Ghose (1978) studies the role of Aravalli and Himalayan river systems in the fluvial sedimentation of the Rajasthan desert. Bakliwal and Sharma (1980) studied the history of migration of river Yamuna in the tract lying between Delhi and Agra using Landsat MSS images and aerial photographs, migration has been observed to be generally towards last with the extent varying from 10 km. to about 40 km. study of isolated old meanders for reconstructing successive stages in the migration based on their overall geometry suggests that earliest river channel passed through Kaman, kumbher, Bharatpur and last of ages, the next stage of migration took upon course passing between nandgaon and barsana east of govardhan and then flowing between Mathura and Gokul, there are successive stages of migration, but they could not be linked up due to isolated nature of old channels.Interpretation of aerial photographs and satellite imagery covering the North West India has been carried out by numerous investigators to identify and map Palaeo channels as well trace the migratory evolution.

Chapter-4

Thematic Mapping / Characteristics of the study area

Various thematic layers such as Roads, Railway, Drainage and settlements have been prepared from LISS III data. Besides this other data used for analysis are

1. Geology and Structures
2. Geomorphology
3. Hydrogeology
4. Land use/Land cover
5. Vegetation Pattern
6. Groundwater

1. Geology and Structures

The northwestern part of the Thar Desert is bounded by flood plaindeposits of the Indus river system while southwestern part is delimited by the Rann of Kachchh. The southern part is bounded in parts by the Aravalli Mountains and Erinpura granite. The northeastern part is constrained by theJaipur upland. The Luni, Kantli, Sabi, Banganga, Bandi, Sota ephemeral riversdrain these areas. The Luni and Banas rivers have their outlet in to the Rann of Kachchh and Yamuna river system, respectively, whereas others getdisorganized inland. The Mendha and Rupangarh rivers drain in to theSambhar salt lake occurring east of the Aravalli axis.The central part of the area is covered by different types of dune fieldswhich are separated, at places, by rocky pediplains.

The western desert plain is a sandy desolateexpanse of dune fields and rocky pavements. The plain, lying to the west of Aravalli hills, covers1, 75,000 sq km area of the Rajasthan. It is affected by scanty rainfall. The Luni and Sukri rivers,ephemerally flowing in a southwesterly direction, form the main drainage of the area. A large part of western Rajasthan is characterized by its inland drainage and carries some of the largest salt-lakes, viz., the Sambhar, Didwana, Kuchaman and Talchapar lakes.

The Aravalli hills of Rajasthan traverse the State in a NNE-SSW direction almost from end to end dividing Rajasthan in two unequal parts, three fifth of which constitutes the western Rajasthan, two-fifth constituting the eastern Rajasthan. This mountain range exposes principally rocks of the Delhi Super group and comprises alternating hill ranges and valleys extending from Delhi on the NE to the plains of north Gujarat on the SW for a distance of about 650 km.

The area to the east of the hills is covered by the eastern plains and the Vindhyan plateau.There are low (up to 500 m high) and localized groups ofPre-Cambrian volcanic hills (Malanis) in Barmer and Jalore district sinselbergs of Aravalli metamorphic in Sikar, Churu, Nagaur and Pali districts.

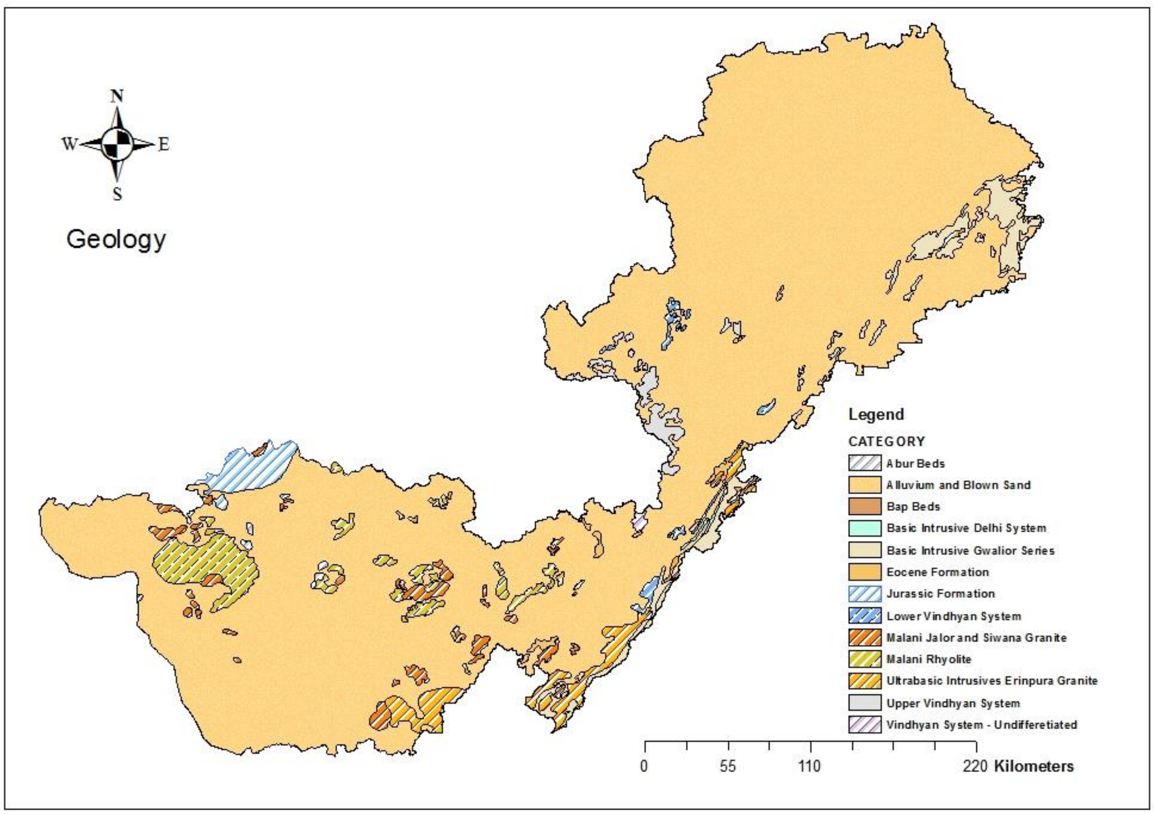


Figure 6: Geology of the study area

Over much of the desert, there are only seasonal and ephemeral streams.The streams arising from the NE-SW trending Aravalli drain the eastern andnortheastern fringe of the Thar Desert and die out in the vast expanse of sands.Luni, originating from the Aravalli, is the only flowing river of the Thar, in itscentral and southern part, before debouching in the Rann of

Kachchh.The eastern and southeastern parts of the Thar Desert are delimited bythe Precambrian rocks of the NNE-SSW trending Aravalli hill ranges. Thewestern and eastern parts of these hills are covered by rocky pediplains at different erosion levels with development of shallow depressions. These shallow depressions are filled up with the Quaternary sediments of fluvial,lacustrine and aeolian nature.

The lower Luni sub-basin in Barmer district is characterized by aeolian and fluvial alluvium, gritty-pebbly sandstone, calcrete and gypsum bed soccurring in the intervening parts of isolated hillocks of Mesozoic and Proterozoic sequence (Malani).

Lakes and Playas

The territory of Rajasthan west of the Aravalli Range abounds in anumber of small and large natural depressions which are the sites ofintermittently dry and wet salt lakes depending upon seasonal changes. A greatmajority of these basins are small in size but the one holding the lake at Sambhar is the largest one, Didwana in Nagaur and Lunkaransar in Bikanerdistrict are the second and third largest lakes, respectively.

The continental Quaternary deposits of Thar Desert are primarily of fluvial,aeolian and lacustrine origin and they rest unconformably over the pre-Cambrianbasement. The maximum thickness of the deposits recorded in boreholes, wellsand pit sections is over 100 m. The sedimentation pattern and style, mostlygoverned by the basement tectonics differs from one region to the other in theThar Desert. The Ghaggar basin (Palaeo Saraswati), in north and NW, Kantli basin in the east and north east and Luni river basin in the central and southern parts are predominantly aggradational basins and contain thick sequence offluvial-aeolian sediments.

Structural or Lineament Analysis

Lineaments, being surface manifestations of structurally controlled linear or curvilinear features are identified in the satellite imagery by their relative straight tonal alignments. Lineaments can be joints, fractures, dyke systems, straight course of streams and vegetation patterns. In hard rock terrains, lineaments represent areas and zones of faulting and fracturing resulting in increase in secondary porosity and permeability. They are good indicator for the accumulation and movement of ground water. Lineaments provided the pathways for groundwater movement and are hydrologicaly very important (Sarkar et al., 2001).

Kar (1986) mapped several SW to SSW trending valleys in the alluvial plains between Jodhpur and Pali. He identified these as belonging to those of the Luni River. The discovery of palaeo-valleys indicates a number of easterly courses of the Erstwhile Luni River. The points of deflection from the present course of the Luni River are located at places near Malkosni, Mortauka and Kankan. These, according to Kar(1984), are the possible successive shifted courses of the Luni. Kar discussed about the influence of NE-SW trending lineaments in controlling the present day stream courses in the Luni-Jawai plains.

Palaeochannels are associated with structural features like faults and lineaments (Nandini, 2014). A closer look at the lineament pattern in the Rajasthan indicated that the present-day drainage pattern is truly influenced by two conjugate sets of lineaments, trending NE-SW and WNW-ESE. The WNW-ESE lineaments have controlled the courses of the tributaries, which drain through the southwestern Pedi plains of the Aravalli Mountains.

Kar reported the presence of two fluvial terraces along many streams in the plains of the Luni drainage system. He related this feature to the movements along a number of NE-SW running faults that pass through the Aravalli foothills and further south. He traced eight major faults (lineaments) in the Luni Basin, along which both vertical and transcurrent movements have taken place during the Late Quaternary.

Luni-Sukri lineament

Amongst the ENE-WSW and NNE-SSW trending lineaments, the 750 km long Luni-Sukri lineament aligned along the Luni and the Sukri rivers, forms asignificant linear/curvilinear feature. It extends from the Great Rann of Kachchh to the Sambhar Lake. In the southwest it makes the contact between the Great Rann and the dune fields and controls the northern extent of the Great Rann-between Bakhasar and Sambhar Lake it partly controls the course of Luni River and Sukri River. Absence of Delhi outcrops to the northwest of thislineament might represent the northwestern limit of the Delhi basin. Absence of Cambrian sediments of Marwar Super groups to its southeast, on the other hand, suggests its control on spatial distribution of the Cambrian basin in the southeast.

Occurrence of earthquake epicenters along it in the Kachchh area suggests its neotectonic potentiality. A sub-parallel lineament between Mokalsarand Deganaand another from Sikar toDelhi and beyond through Indo-Gangetic alluvium seem to be a part of thislineament system.

It finally meets the Ganga fear fault in the Siwaliks to the southeast of Dehradun (Bakliwal and Ramaswamy, 1987).Vast areas around eastern and western parts of the Aravalli range arecovered by Quaternary sediments which are products of fluvial, aeolian,lacustrine environments.

The Quaternary sedimentation in the Jaipur upland area begins withcolluviums and loess deposits of the Middle to Late Pleistocene period (Raghavet.al., 1995). During this period the present day lakes, like Sambhar, Didwanaand Kuchaman probably constituted part of well organized drainage.

The onset of aridity, as evidenced by the presence of loess deposits in the areareduced river discharge which resulted in unloading of sediments, in the localdepressions. The neotectonic evidences also suggest that these localdepressions, lakes and playas became the site of deposition which hasrejuvenated the slopes and generated colluviums and fan deposits. Sedimentsthus deposited caused formation of playa and lakes along various river channels.As aridity increased rivers of Fl stage dried-up and possibly became a source ofaeolian sands contribution to A-1 to A-3 dunes and sand sheets.

Presently, Ghaggar River isflowing towards west where it cuts across the sand dunes of recent period. TheKantli River, the major tributary of Ghaggar, originates from Aravalli hills andflows northwesterly, presently, its confluence with the Ghaggar is lost in Sand Dunes River, and the distribution pattern of the palaeodrainage of the Ghaggar andKantli river systems also suggests northwest migration of the palaeodrainage.

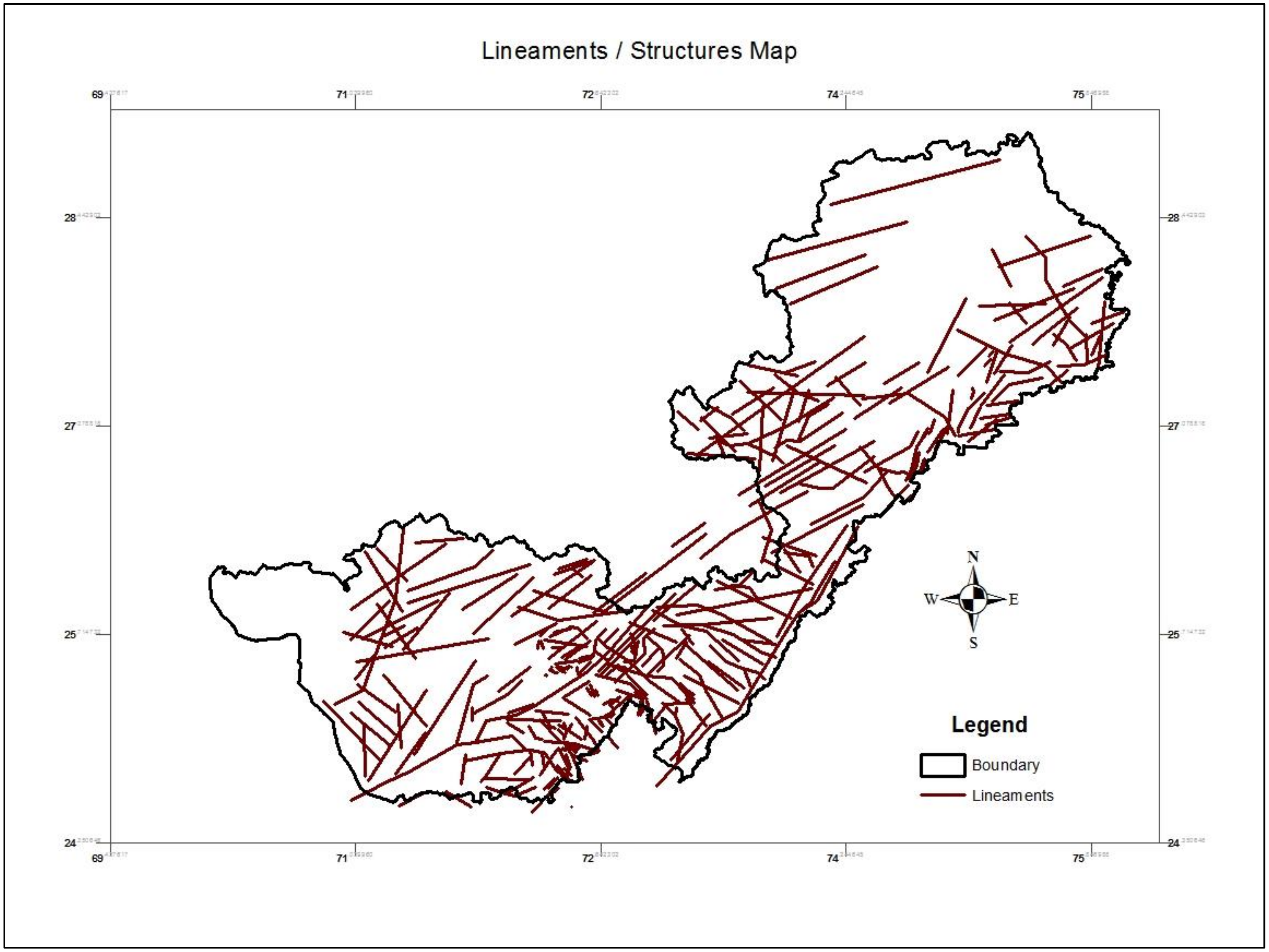


Figure 7: Lineament Map of the proposed area.

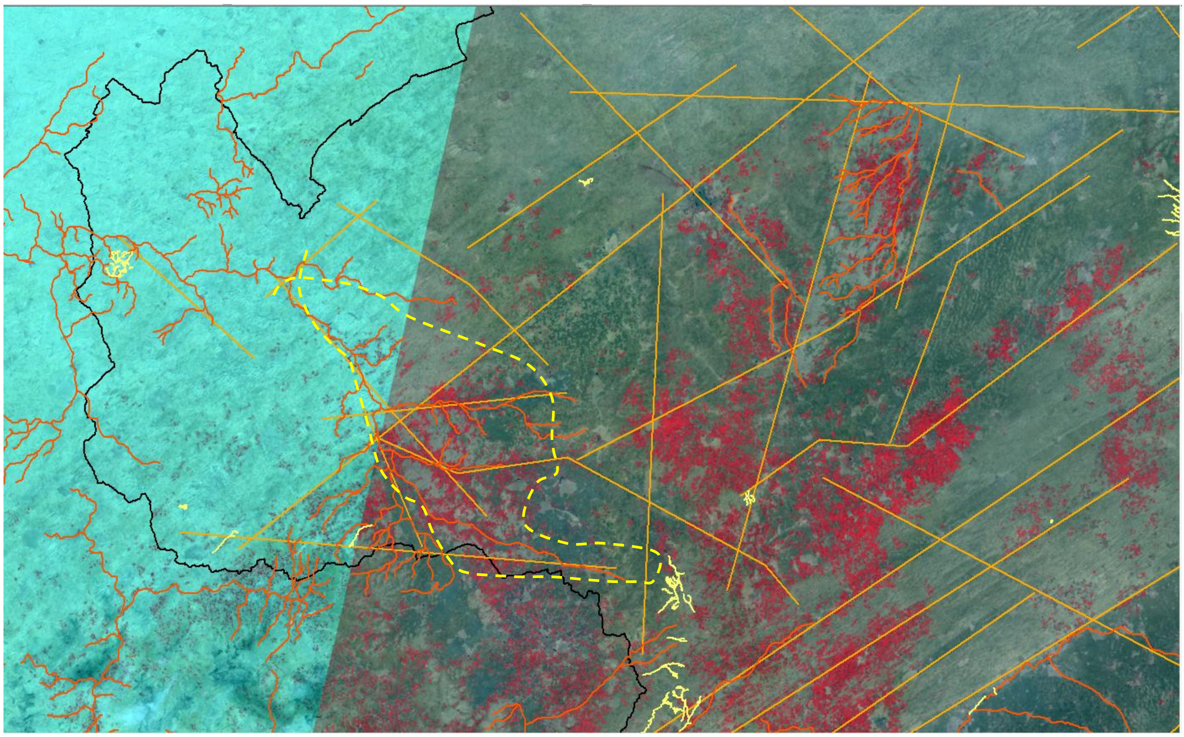


Figure 8: Correlation of Lineaments along the interpreted Palaeochannels; Nagaur

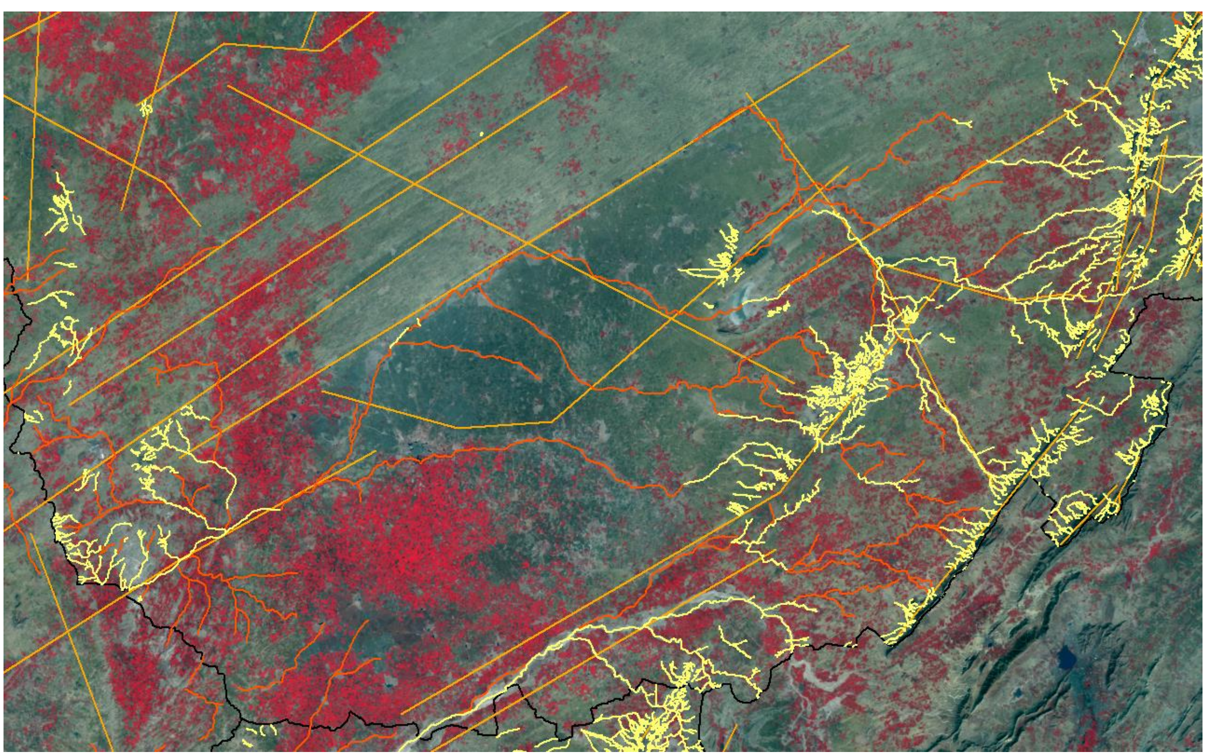


Figure 9: Lineaments near Merta; Nagaur

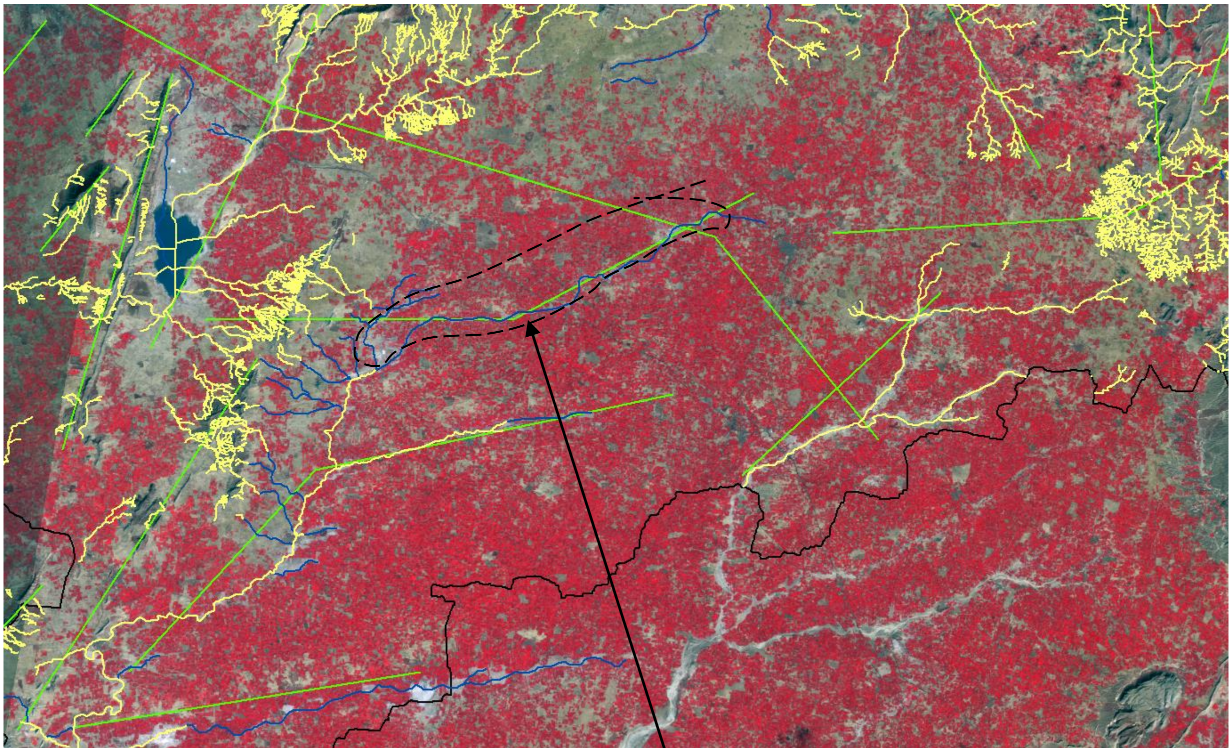


Figure 10: Lineament and identified Palaeochannels in Sikar

Intersection of Lineament with the Palaeochannels

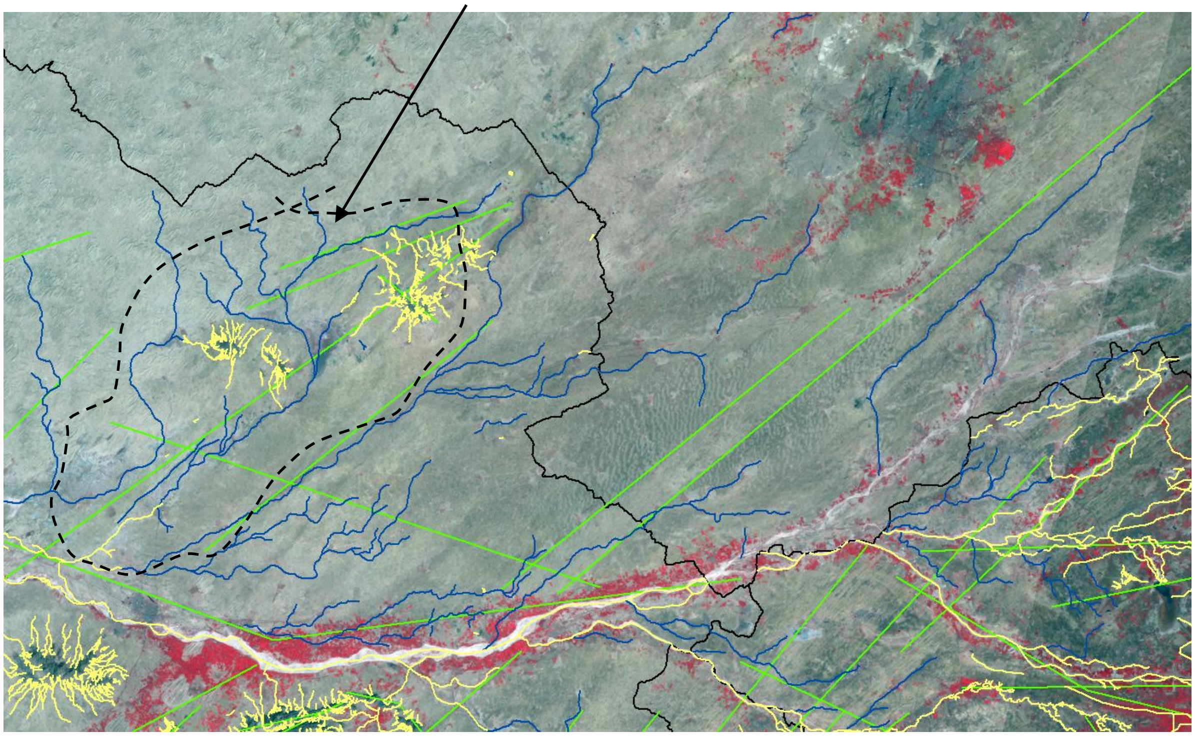
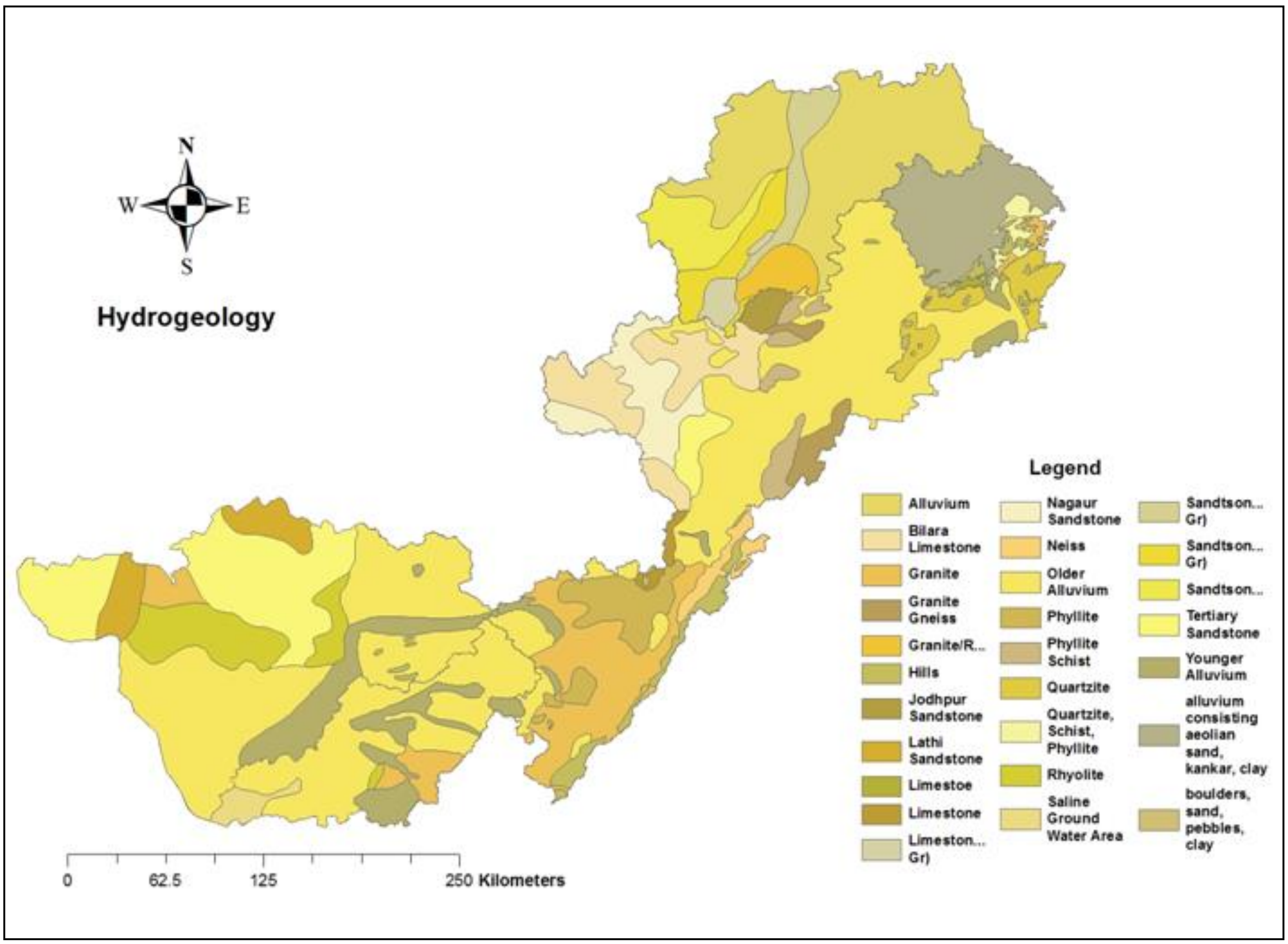


Figure 11: Palaeochannels in blue colour and lineaments in green in Barmer

Around 483 structures including lineaments, faults/fractures, and dykes were identified and mapped from IRS LISS III data. These structures vary from few meters to kilometres in length. The general trend of lineaments is NE- SW and ENE – WSW directions. Luni river bed is one of the peninsular rivers flowing westwards that didn’t form valleys and instead it flows through faults (linear rift, rift valley, and trough). Many lineaments are found associated with identified palaeo drainage in the study area. A good correlation of these structures is found in areas of Sikar, Nagaur and Barmer districts.

2. Hydrogeology



Source: Hydrogeological Map of Various Districts Prepared by Central Ground Water Board

Figure 12: Hydrogeology of the study area

Hydrogeology is the area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust.

Table 2: Hydrogeology of Study Area

Type	Area(sq.km)
Older Alluvium	34160
Alluvium	10061
Younger Alluvium	5616
alluvium consisting of aeolian sand, kankar, clay	4708
Bilara Limestone	4093
boulders, sand, pebbles, clay	20
Granite	6733
Granite Gneisses	954
Granite/Rhyolite	1063
Hills	1769
Jodhpur Sandstone	515
Lathi Sandstone	1959
Limestone	339
BilaraLimestone	609
Nagaur Sandstone	2765
Gneisses	780
Phyllite	2263
Phyllite Schist	1224
Quartzite	1715
Quartzite, Schist, Phyllite	521
Rhyolite	3398
Saline Ground Water Area	638
Sandstone(Jodhpur Gr)	1529
Sandstone(Nagaure Gr)	1546
Sandstone(Tertinary)	2025
Tertiary Sandstone	8336

Alluvium (Quaternary):

Major part of the Churu district is covered by quaternary alluvium. South western and southern part and localized area surrounding Sujangarh are exempted where area is occupied by other type of rock units. It comprises of sand, kankar, and clays interspersed gravel beds. Thickness of the lithounit is more in the western part where it overlies tertiary formations.

Besides Churu, quaternary alluvium is also the principal water bearing formation in Jhunjhunun district. While ancillary aquifers are formed by hard rock of Delhi super group including post Delhi intrusive in the district.

In Sikar, groundwater occurs in the pore spaces and interstitial spaces of Quaternary alluvium while in hard rock formations, occurrence and movement of groundwater is controlled by secondary porosity (through the bedding planes, fissures, joints, fractures, solution cavities, and other structurally weaker planes.

Major part of the study area is covered by different type of alluvium (54545 sq.km) such as older alluvium(34160 sq.km), alluvium(10061 sq.km), younger alluvium(5616 sq.km) and alluvium consisting of aeolian sand, kankar and clay(4708 sq.km).

While, the groundwaterin Barmer occurs under semi consolidated to unconfined conditions, in semi consolidated tertiary and mosozoic formations occur under unconfined to confined conditions and in weathered and fractured zones in hard rock under pheratic conditions.

Tertiary Sandstone (Eocene):

This lithounit is confined to Dungargarh block. It is loosely consolidated, coarse to gritty sandstone intercalated with shales, claystone and gravel beds and overlies Nagaur sandstones. The lithounit has maximum thickness southwest of Dungargarh and gradually reduces eastward.This categories occupied(8336 sq.km) area covering in Barmer(7498 sq.km) and Nagaur(837 sq.km) districts.

Nagaur Sandstone (Marwar Super Group):

It is coarse to fine grained, loosely cemented with gravel at basal part which act as good aquifer and occupies mainly the part of Nagaur, Jayal, Mundwa and Merta blocks. The associated rocks are siltstone and shales. Its thickness varies from 140-240 m.

It also covers extensive area in Dungargarh and Sujangarh blocks and spreads in the peripheral part of Ratangarh and Sardarshahar blocks of Churu district.This category is covering 2675 sq.km area in the above mentioned blocks of Nagaur district.

Bilara Limestone:

It is grey to buff colored hard and compact dolomite limestone interbedded with shale and cherty bands. It occurs in Sujangarh block of Churu district where it covers southern peripheral area and it also encompasses Sojat and Jaitaran blocks of Pali district. This caterory covers 4095 sq.km area in Churu and Pali districts.

Also it is the most important and potential aquifer comprising limestone, dolomite and shale in Nagaur district. However, it is cavernous at places and susceptible to solution activity which gives rise to high discharge in wells. These cover western and north-central part of Nagaur block, central part of Mundwa block, west central and eastern part of Jayal block, part of Ladnun block. Thickness of limestone is varies from 100- 300 m.

Jodhpur Sandstone (Marwar Super group):

It is generally of red, brown, and pink colour, fine to coarse grained gritty sandstone. This lithounit is hard and compact and at places intercalated with shales. it encloses small area on the northern peripheral part in Jataran block of Pali district.Total area covered under the area is 1529 sq.km

Granite Rhyolite (Post Delhi Intrusives), Phyllite, Schist and Quartzite (Delhi Super Group):

Rhyollite is generally massive, fine grained with wide spaced open joints and fractures. Granite is dark grey in colour, coarse grained and at places have joints. Phyllite and Schists are green to dark grey colour and well foliated and jointed. All lithounits together occupy small area in southern part of Sujangarh block.

Quartzite, schist, phyllite, gneisses and limestone of Delhi Super Group including granites, amphibolites and pegmatites of post Delhi intrusives form the ancillary aquifer and occupy the south eastern area of the Jhunjhunun district covering parts of Khetri and Buhana blocks. Ground water occurs under unconfined condition in the weathered mantle (ranging in thickness from 10 to 15 m) and under unconfined to semi-confined conditions in deep seated secondary porosity i.e. fractures, joints, contacts etc. of hard formation. Granite/Rhyolite category is covering 1063 sq.km area and quartzite, Schist and phyllites collectively covered 5723 sq.km area in Jhunjhunu and Churu districts.

Granite aquifers occur predominantly in Jaswantpura tehsil of Jalore district. Few intrusives are also found which have low permeability. Groundwater is retained in weathered zones, fractures joints etc. Depth in open wells tapping these aquifer ranges from 20 to 50m. Yield of wells varies from 20m3/day to 188m3/day. The depth to water level in the area tapping this aquifer ranges from 11m to 31m.

Phyllite aquifers also occur predominantly towards Jaswanpura tehsil. Groundwater occurs under water table condition and is mostly tapped by dug wells. Depth of wells ranges from 20m to 30m. The depth to water level ranges from 11m to 18m,bgl. Yield of wells is generally very poor ranges from 30 to 80m3/day.

Younger Alluvium (Quaternary):

It mainly comprises stream laid deposits consisted of sand, gravel with some silt, clays and at places pebbles and cobbles. It occurs along drainage courses and flood plains of rivers Luni, Sukri, Lilri, Bandi and Jawai. Also it covers major part of the Jalore district. It is confined to riverbeds and riverbanks. The depth to water level is less than 10m,bgl near river courses but exceeds 40m in other areas. Yield ranges for dug well are 60-150m3/day and for tube wells 80-560m3/day

Exploratory drilling in Jalore reveals the depth of Alluvium up to 362m at Jhab. Yield of tube wells ranges from 10-40m3/day with a drawdown of 1.28-16.28m.Transmissivity varies from 370-5696m2/day

Older Alluvium (Quaternary):

It is heterogeneous mixture of semi consolidated to consolidated sediments comprising sand, silt, clay, kankar and silt. It covers Jaitaran, Pali, and Rohat blocks and parts of Sojat and Sumeru blocks. In Jaitaran and Sumerpur blocks alluvial aquifer cover extensive area.

Malani Suite of igneous rocks (Post Delhi & Delhi Super group):

These comprise Erinpura, Jalore, Siwana granites and Malani rhyolite of Post Delhi group. Granites cover major part of the Pali district. Central and western and some pockets in the north eastern and south western parts are only exception where other litho unit occupies the area. Granites of Aravali and pre aravalis are found in Pali, Jhunjhunu, Nagaur and Barmer and Jalore districts in scattered patches the area under this category also available in patches in almost entire study area as mentioned in above table.

Aravalli Super Group and pre Aravallies:

Aravalli Super group comprises dark brown, grey and purple slates with thin bands of quartzite, phyllite and schist and cover extensive area in central part and occupies small area in northern and south western parts. Pre Aravalli gneisses and schists occupy small area along the Aravalli foot hill zone on the eastern periphery.

The availability occurrence and movement of groundwater is mainly controlled by the topographic features, physical characteristics and structural features present in the geological formations.

Groundwater in Sikar district occurs under unconfined to semi confined condition. The principal aquifer in the area is quaternary sediments covering major part of the district except in western and central part of the district. Whereas quartzite, schist, phyllite, limestone, and dolomite limestone of Delhi Super group also constitute important aquifers except in eastern and north central parts of the district mainly in Neem Ka Thana, Khandela, Danta Ramgarh and part of Piprali block.

3. Geomorphology

Nagaur district is conspicuous in the absence of high hills. Dots of hillocks, particularly in the south eastern sector, are sporadically scattered. At Jayal and Khatu, the hillocks are utilised for stone extraction. There is no vegetation anywhere. Here, Tikli hills are situated near Raisinghpura village in Didwana. Hills near Kuchaman and Nawa attain some height. There are also numerous clusters of hillocks in Parvastar tehsil.

Pali district almost resembles an irregular triangle with undulating plains. Several eastern parts of the district may be called sub-mountainous and have undulating plains with scattered hills. The district is surrounded by high Aravalli ranges in the south-east. The general slope of the district is from east to west direction. There are no perennial rivers in the district. Four tributaries of the river Luni which rise in the Aravalli such as Sukri, Lilri, Bandi and Jawai flew through the district.

District Jhunjhunun consists mass of rolling hills and the remaining part nearer to the South-eastern border contains some offshoots of the Aravalli ranges, running in South-Eastern direction. A range of Aravalli hills enters the district in the extreme South of Udaipurwati tehsil and extends up to Singhana and Khetri in the east. In general elevation above mean sea level is between 300 to 400 meters. The highest peak is 1,051 meters high in the south of Lohagarh village.

The Aravalli hill ranges attain significant height at Chappan-ka-Pahar near Siwana 975 meters and Roza hills at Jalore 730 meters. Aravalli ranges attain the gradual height in Sirohi district outside the desert boundary in Western Rajasthan. Another important feature of Western part of the Aravalli is that they give rise to nearly all streams which rush down the steep slopes including the Luni system. Luni is the only recognizable river in the Rajasthan desert and its run-off depends upon the intensity of rainfall in the Aravalli catchment.

The streams are filled with sand dunes to different erosional activity which has produced relief features along the foot hills of the Aravalli. The resultant landform is known as Godwar plains. These plains are fertile mostly in the district of Pali, Jalore and Nagaur. While Barmer district containsSand Dunes mostly covered by Aeolian sand and also it contains Alluvial Plains, Ridges and Hillocks.

4. Land Use/Land Cover

The study area is located in the Eastern Fringe of Thar desert of Rajasthan and it extends between latitudes 24o32’24.83” N and 29o 01’45.19” N and longitudes 70^{o}08’13.29” and 76^{o}06’46.61”. The districts covering the study area are Churu, Jhunjhunun, Sikar, Nagaur, Pali, Jalore and Barmer. The total area under study is approximately 98985.464829 sq km.

Table 3: Location of the districts under study

District	Latitudes	Longitudes
Churu	28^{o} 06’ 55.73” Nto28^{o} 31’ 20.80” N	73^{o} 38’ 16.40” Eto75^{o} 40’ 19.84” E
Jhunjhunun	28^{o} 12’ 16.26” Nto28^{o} 08’ 58.48” N	75^{o} 01’ 31.70” E to76^{o} 05’ 47.41” E
Sikar	27^{o} 40’ 09.67” Nto27^{o} 49’ 39.11” N	74^{o} 40’ 58.19” E to76^{o} 05’ 34.61” E
Nagaur	27^{o} 14’ 24.41” Nto27^{o} 05’ 51.49” N	73^{o} 05’ 13.36” Eto75^{o} 21’ 57.11” E
Pali	25^{o} 48’ 07.98” Nto26^{o} 15’ 57.76” N	72^{o} 46’ 41.67” E to74^{o} 23’ 58.44” E
Jalore	24^{o} 39’ 02.89” Nto25^{o} 27’ 56.31” N	71^{o} 11’ 29.46” Eto73^{o} 05’ 27.60” E
Barmer	25^{o} 50’ 21.67” Nto26^{o} 02’ 07.07^{o} N	70^{o} 05’ 18.78” Eto72^{o} 50’ 58.45” E

Table 4: Land Use pattern

District	Land use Pattern (2004-2005)	Area (Hectares)
Barmer	Area Under Forest	31677
	Area under non agriculture use	433489
	Permanent Pastures & other grazing lands	202739
	Miscellaneous trees, crops and Groves not included in net area sown	301
	Non agricultural areas including fallows	654452
	Net area sown	1454491
	Area sown more than one time	90762
	Total Area sown	1545253
Jhunjhunun	Area not suitable for cultivation	35592
	Hilly and hilly forest	39614
	Pasture Land	40174
	Barren Land	6591
	Others	7900
	Area under cultivation	646323
	Un irrigated Area	419532
Nagaur	Forest	18271
	Land for non agricultural use	86791
	Barren and uncultivated land	58582
	Other uncultivated land excluding fallow land	72854
	Cultivable waste	14353
	Fallow land	259361
	Net area sown	1254256
	Double crop area	228999
Pali	Forest	80311
	Land put to non agriculture use	58241
	Barrani and uncultivated land	108045
	Fallow Land	227237
	Total area sown	624247
	Double crop area	40760
	Actual Sown area	583487
Sikar	Forest and hills	70379
	Barren land	8915
	Non agricultural use	35825
	Pasture and grassland	40285
	Cultivable wasteland	3846
	Fallow Land	78383
	Net sown area	526108

Source:District Ground Water Brochure

5. Climate characteristics of the study area

Climate has great impact on the inhabitants of any region. Their social, cultural, economical and other aspects of life are directly or indirectly governed by the climate. Thar Desert is a very fragile and is subjected to excessive stresses due to frequent drought and low rainfall, which occurs once in two to three years and exerts extreme stress to fauna due to limited seasonal grazing resources.

District wise climate characteristics:

The climate of Jhunjhunun district is semi arid and is characterized by very hot summers, chilly winter season, and general dryness in the air except in monsoon season, and poor rainfall during south monsoon period. In May and June, the maximum temperature may sometimes goes up to 48o C and the potential evapotranspiration rate is very high, especially during May and June. The total annual evapotranspiration of the district is 1502.6mm.

The mean annual rainfall of the district based on 36 years data from 1971 to 2006, works out to be 485.6mm. However normal annual rainfall (1901-71) of the district is 459.5mm. It can be inferred that the rainfall in the district has significantly increased in the recent years. The coefficient of variation is on higher side at 36.6% indicating that the rainfall is slightly unreliable. A perusal of the figure reveals that the district experienced very poor rainfall between the periods 1979 to 1991 with the exception of few years in between. Thereafter, the district was fortunate to have very good spell of rainfall continuously for a period of 7 years from 1992 to 1998. The year 1996 was the best with annual rainfall exceeding mean annual rainfall by 85.4%. The district again experienced drought conditions from 1999 to 2002. The year 2002 was the worst with rainfall being 62.3% less than mean annual rainfall.

In Jalore district, average annual rainfall for the period 1977 to 2006 is 422.7 mm. However normal rainfall for the period 1901 to 1970 is 400.6 mm. The annual rainfall gradually decreases from southeastern part to northwestern part. The maximum average rainfall is 469.6 mm at Jaswantpura and minimum average rainfall is 388.7 mm at Ahore. The district experiences either mild or normal drought once in two years. Severe type of drought has been recorded at Ahore block. Most severe type of drought has been recorded at Bhinmal (1980, 87), Sanchor (1987, 2002) &Jaswantpura (1987) block in the district.

Spatial Distribution of Rainfall (mm) from (2002 to 2011)

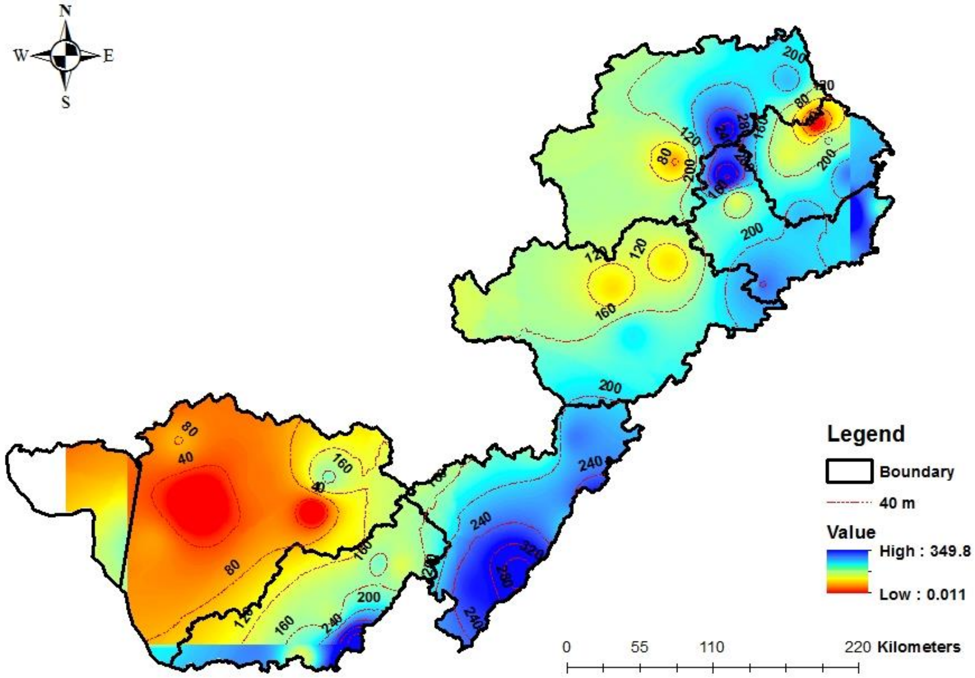


Figure 13: Rainfall distribution (2002)

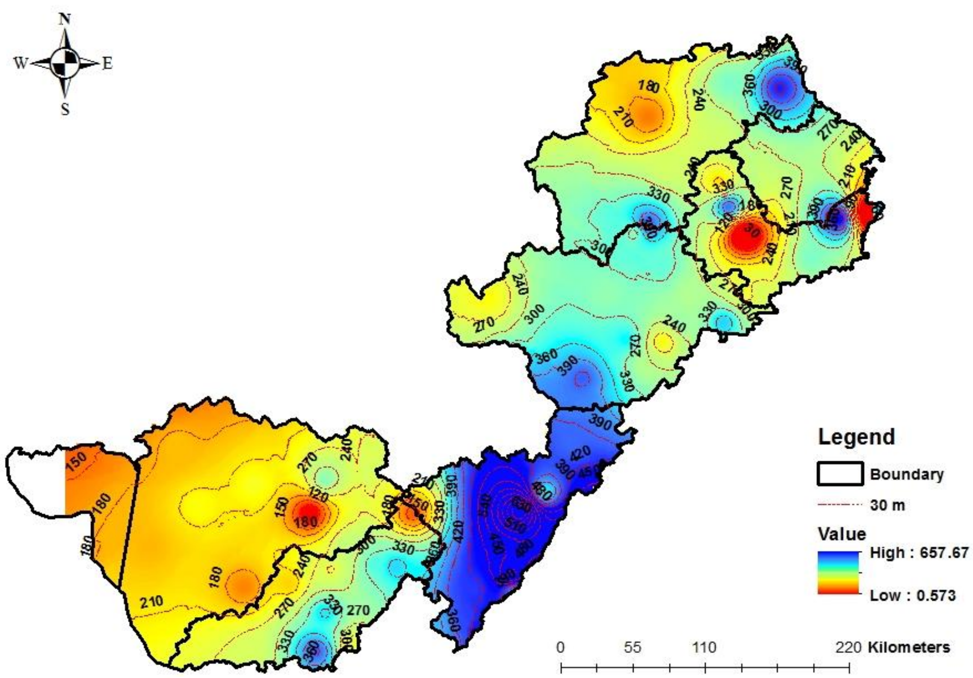


Figure 14: Rainfall distribution (2004)

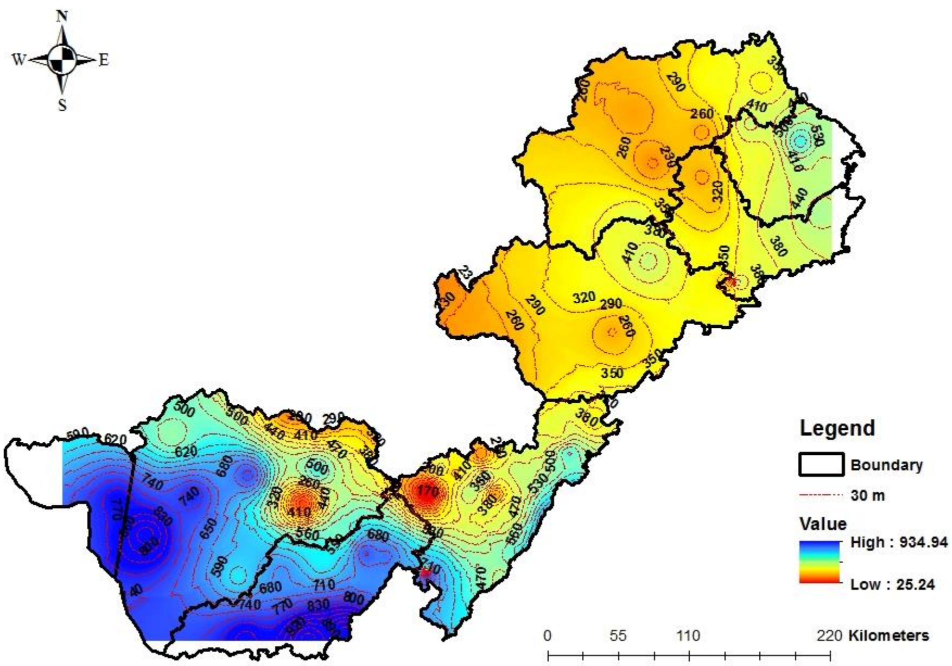


Figure 15: Rainfall distribution (2006)

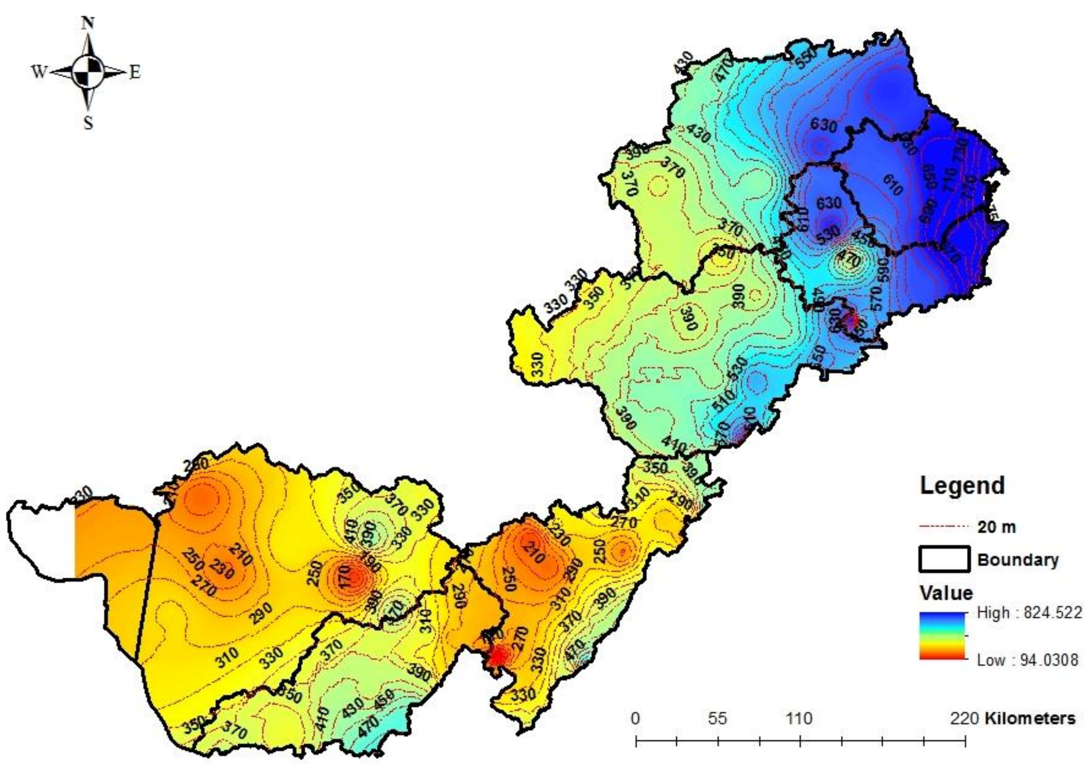


Figure 16: Rainfall distribution (2008)

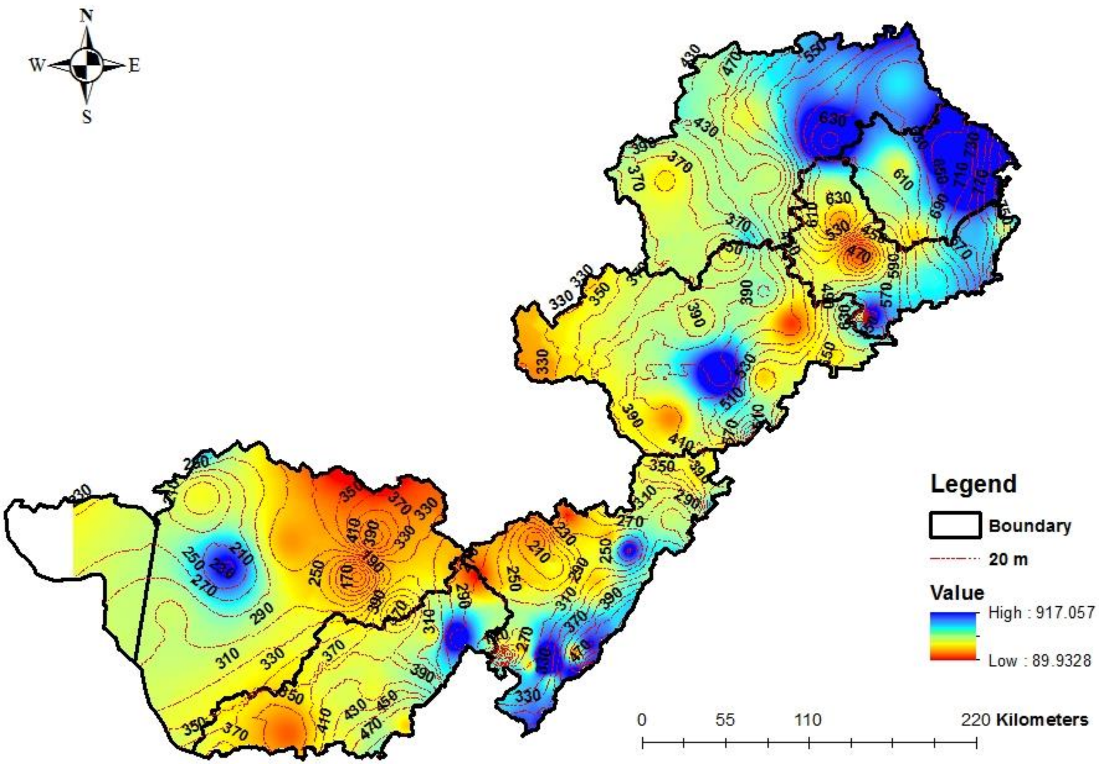


Figure 17: Rainfall distribution (2010)

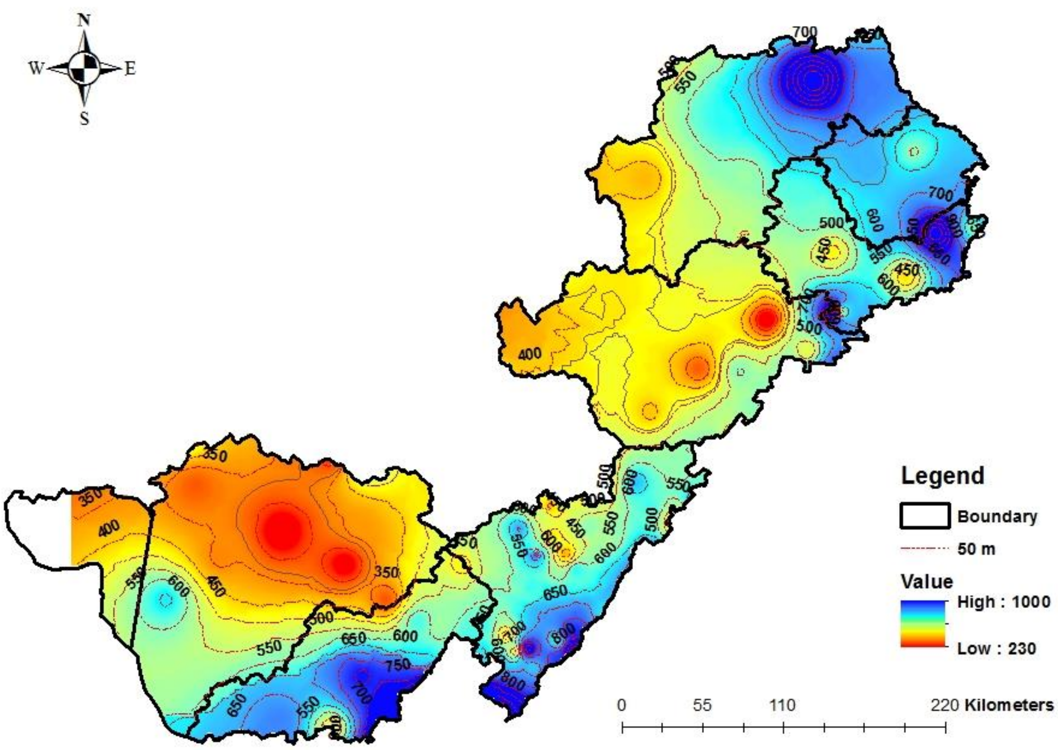


Figure 18: Rainfall distribution (2011)

The district Barmer experiences arid type of climate. Mean annual rainfall between 1971 to 2005 is 281.8 mm whereas normal rainfall (1901-1971) is lower than average rainfall and placed at 277.5 mm. Almost 90% of the total annual rainfall is received during the southwest monsoon, which enters the district in the first week of July and withdraws in the mid of September. As the district lies in the desert area, extreme of heat in summer and cold in winter is the characteristic of the desert. Both day and night temperature increases gradually and reaches their maximum values in May and June. The temperature varies from 48 degree in summer to 2 degree in winter. Atmosphere is generally dry except during the monsoon period. The humidity is highest in August with mean daily relative humidity is 43%. The annual maximum potential evapotranspiration in the district is 1850 mm and it is highest (260 mm) in the month of May and lowest (77 mm) in the month of December.

Mean annual rainfall (1971-2011) of the Sikar district is 463.0 mm whereas normal rainfall for the period 1901 to 1970 is lower than average rainfall and placed at 459.8. Almost 95% of the total annual rainfall is received during the southwest monsoon, which enters the district in the last week of June and withdraws in the middle of September. The mean annual rainfall is highest (536.6 mm) at Neem Ka Thana, which is located in the south eastern part of the district. It is lowest at Fatehpur (407.8 mm), which lies near north western boundary of the district. Climate is generally dry except during the monsoon period. Humidity is the highest in August with mean daily relative humidity of 80%.

Churu is a district with enchanting topography amidst the Thar Desert. It is encircled by large shifting sand dunes with scanty vegetation. The region records temperature ranging from below freezing point in winters to over 55^{o} C in hot summer afternoons. There is a great variation in minimum and maximum temperatures of the district.

Climatic conditions of Pali district are slightly different from the typically arid western Rajasthan. Basically, summer season raises the temperature up to 47^{o}C during peak months (May-June).n A large variation is seen in temperature due to adjoining green and hilly areas. Winters are moderately cool during December and January. And the monsoon during the months of July to October has average rainfall of 450.7 mm.

The Nagaur district experiences arid to semi-arid type of climate. Mean annual rainfall for 1971 to 2005 of the district is 410mm, whereas normal rainfall (1901-1970) is lower than average rainfall and placed at 363.1 mm. It is obvious that there is significant increase in rainfall during the last 30 years. The rainy days are limited to maximum 15 in a year. Almost 80% of the total annual rainfall is received during the southwest monsoon. The probability of occurrence of mean annual rainfall is 38%. Based on agriculture criteria indicates that the district is prone to mild and normal type of droughts. Occurrence of severe and very severe type of drought is very rare. There is not much variation in spatial distribution of rainfall. However, the southern part of the district gets slightly more rainfall than northern part. The mean annual rainfall is lowest at Didwana (347.8mm), which lies in northern part of the district, whereas the mean annual rainfall is highest at Degana (471.9mm) which lies in southern of the district.

Seasonal Distribution of rainfall of Nagaur district: The rainfall in the district is highly seasonal. More than 90% of the total annual rainfall is received during the south – west monsoon season. The monsoon enters the district in the first week of July and withdraws by the middle of September. July is followed by August with monthly normal rainfall of 120.8mm. As the district lies in the desert area, extreme of heat in summer and cold in winter is the characteristic of the desert.. Both day and night temperature increases gradually and reaches their maximum values in May and June respectively. The temperature varies from 46 degree in summer to 7 degree in winter. The cold season starts by middle of November and lasts till February. January is the coldest month with both mean maximum and minimum temperatures being lowest at 22.5° and 6.7° respectively. The minimum temperature may sometime drop down to below the freezing point of water and frost may occur. The diurnal variation in temperature during winter is as high as 16°C. Both maximum and minimum temperature begins to rise rapidly from February onwards, reaching their respective maximum in late May or early June. The mean daily maximum temperature in May is 40.4°C and the mean daily minimum temperature is 25.7°C. Night temperatures in June are much higher than in May with mean daily minimum temperature of 27.9°C. During the summer month the maximum temperature sometimes exceeds 48°C. There is appreciable drop in temperature with the onset of south – west monsoon by about first week of July. After the withdrawal of monsoon by middle of September, the day temperatures register slight increase and a secondary maxima is observed in October. The night temperature, however, continue to fall gradually Atmosphere is generally dry except during the monsoon period. The humidity is highest in August with mean daily relative humidity is 80%. The annual maximum potential evapotranspiration in the district is quite high and it is highest (255.1 mm) in the month of May and lowest (76.5 mm) in the month of December.

6. Groundwater Analysis

Changes in Pre-Monsoon Water Level (m)

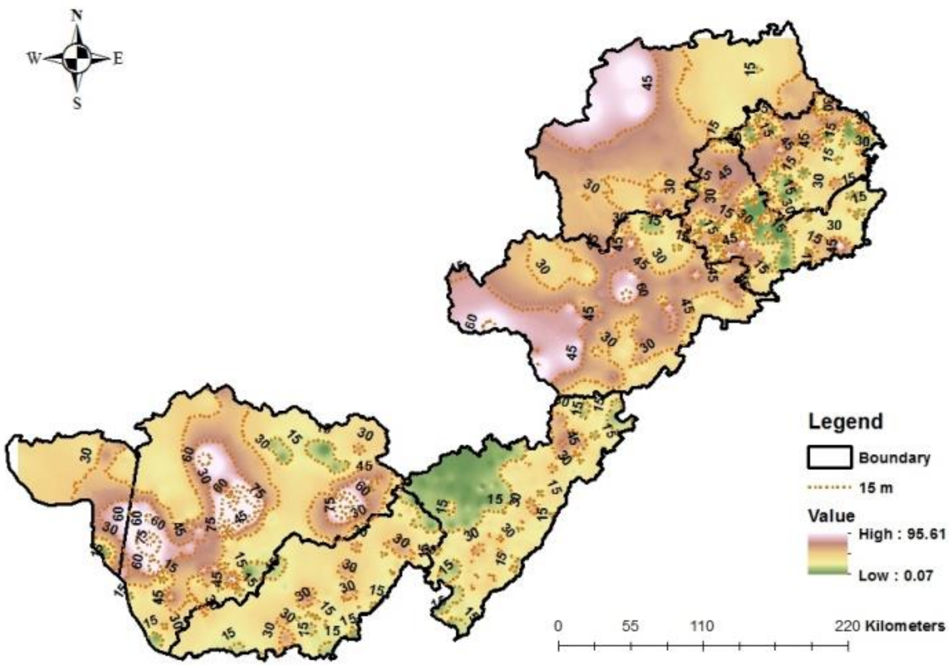


Figure 19: Pre-monsoon water level (2002)

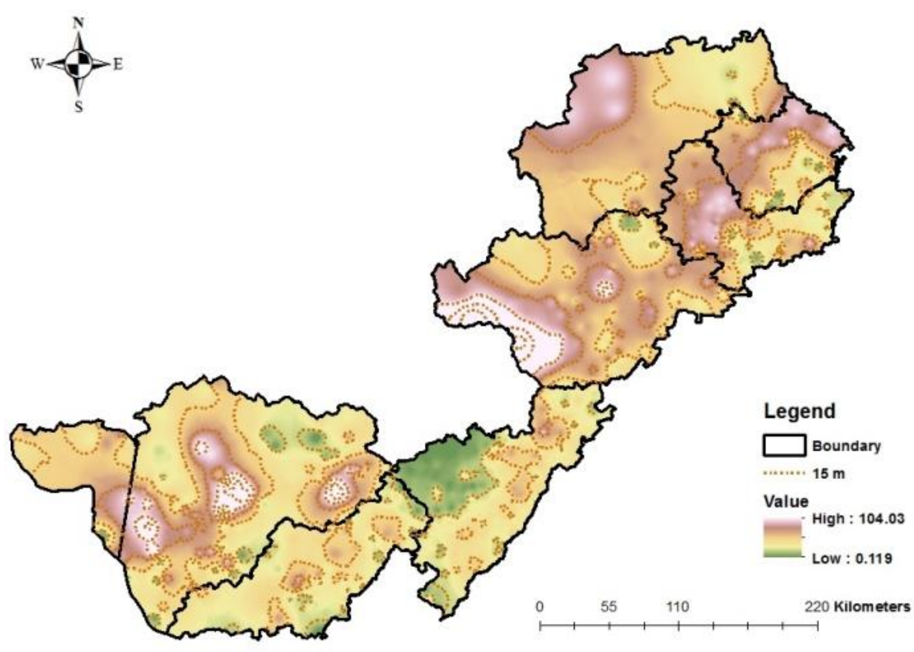


Figure 20: Pre-monsoon water level (2004)

In 2002 high groundwater level can be clearly observed in the western part of Churu, north-western part of Sikar & Jhunjhunun districts, NE to SW diagonal area of Nagaur, and at some parts of Barmer district. And also in the year 2004 the similar pattern of high groundwater distribution is seen.

While in Pali district the groundwater spread is clearly divided into two zones one in green colour shows low groundwater level which is because it is the active runoff zone of the currently flowing rivers originating from Aravalli hills and the other part is the parallel zone of Aravalli and thus there is more ground water in this region as compare to the other one.

In Jalore the pattern indicates moderate to high distribution of depth to groundwater level in both the years which means the ground water scenario does not change much between these two years in this region. Similarly, south western region of Nagaur district again shows the high depth to groundwater level which is because of presence of old inland drainage or due to association of palaeochannels.

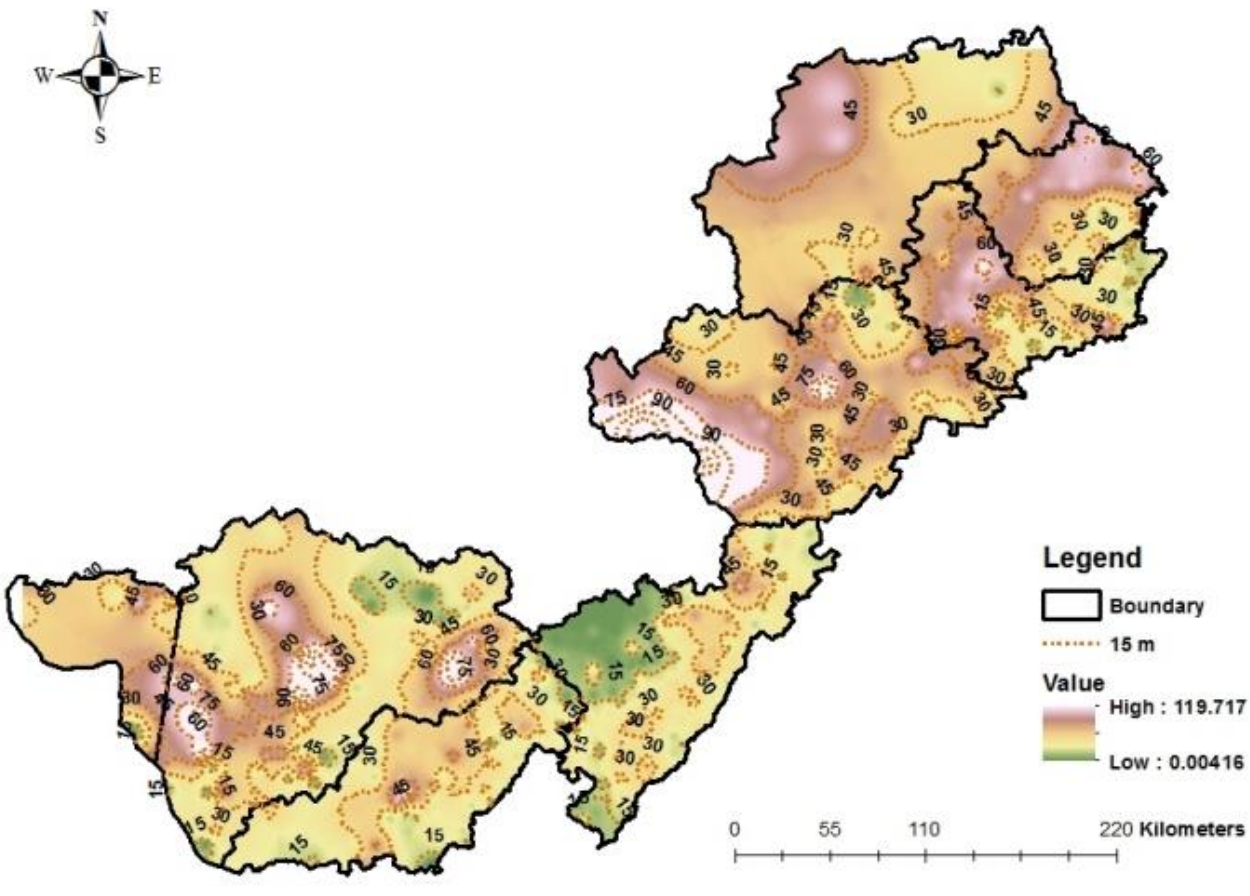


Figure 21: Pre-monsoon water level (2006)

In the year 2006 depth to water level is increased in Jalore district in the middle part and between the Jalore-Barmer boundaries. Increase in groundwater is also visible in western part of Sikar district and distribution in the rest part of the study area remains same as in 2002 to 2004.

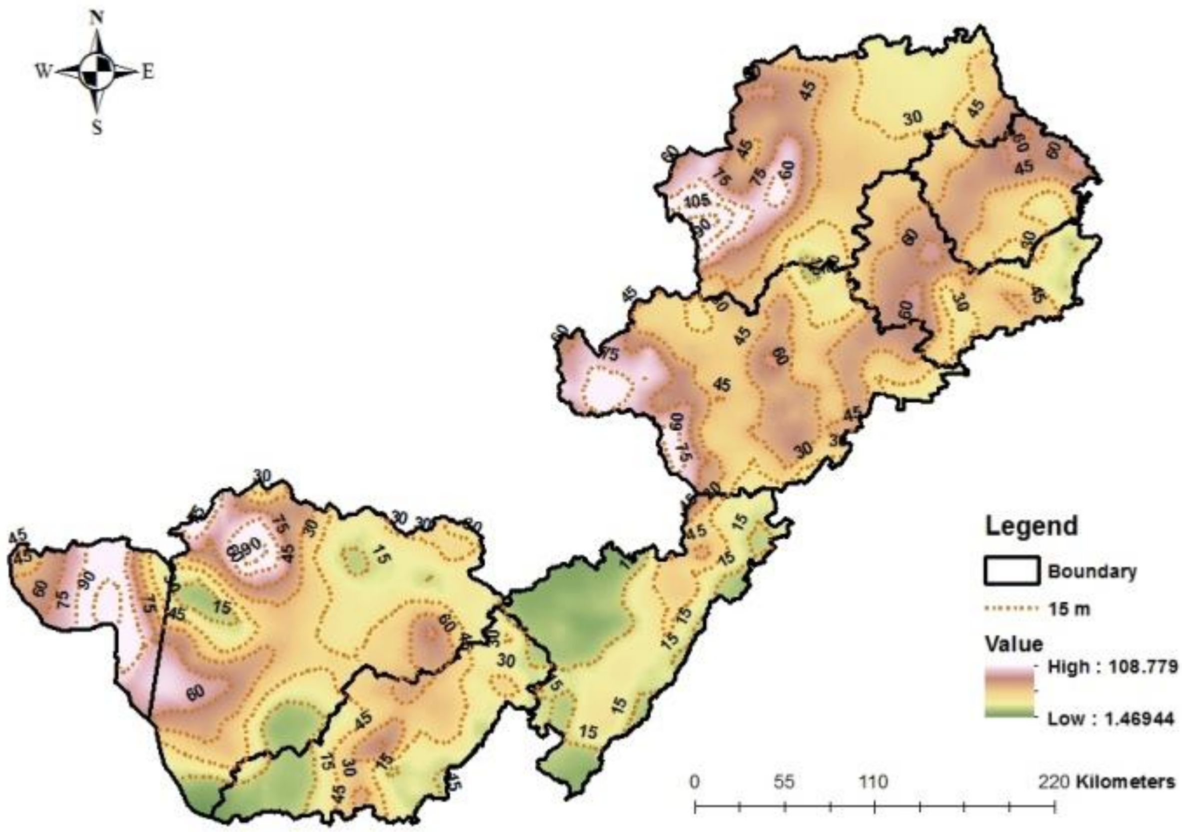


Figure 22: Pre-monsoon water level (2008)

In 2008 the groundwater level increases in western and southern region of Barmer district and southern as well as middle portion of Nagaur. Slight decrement in groundwater level is observed in some parts of Nagaur district as compare to previous years under study. While the rest of the study shows less to no change in ground water level.

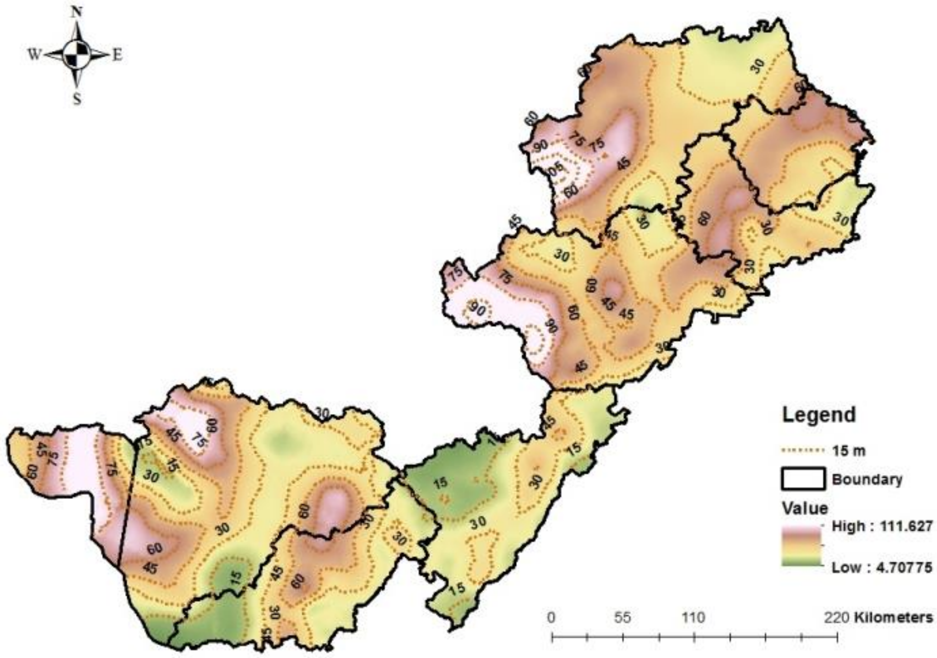


Figure 23:Pre-monsoon water level (2010)

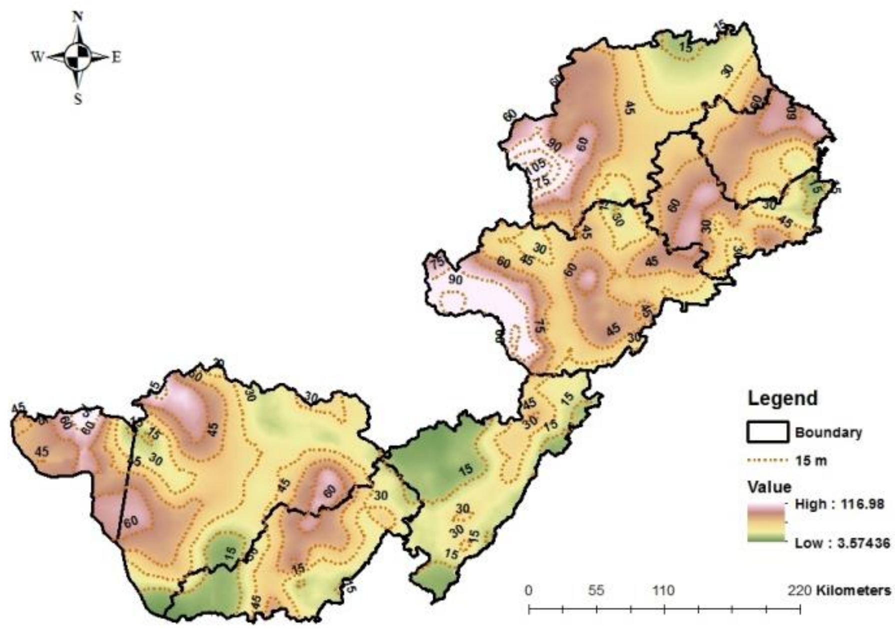


Figure 24:Pre-monsoon water level (2011)

In 2010 and 2011, the southwest part of Barmer, the NW part of Pali and also the belt in Pali which is parallel to Aravalli, the NEE & N of Sikar and Churu districts respectively shows low groundwater level than the previous years and the rest shows the same distribution as in the previous years under study.

Changes in Post-Monsoon Water Level (m)

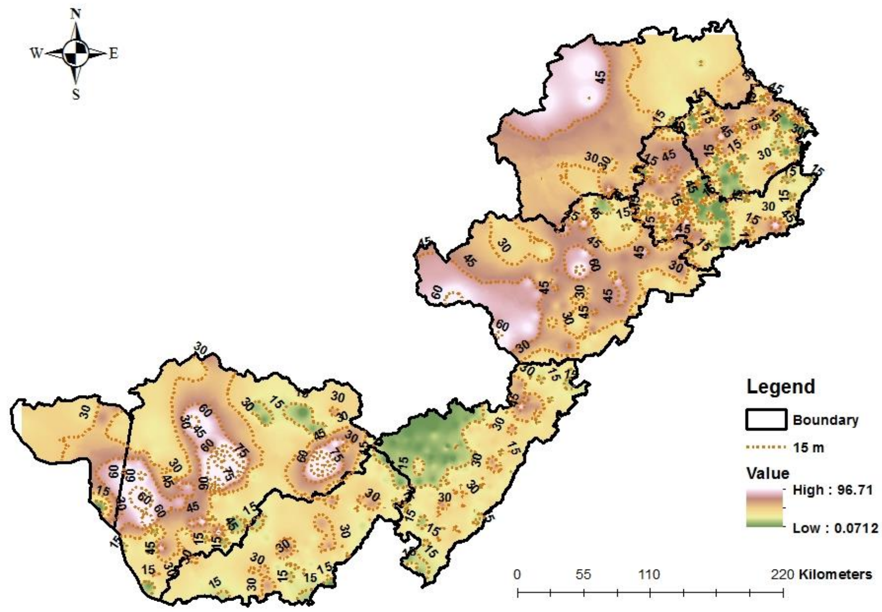


Figure 25: Post-monsoon water level (2002)

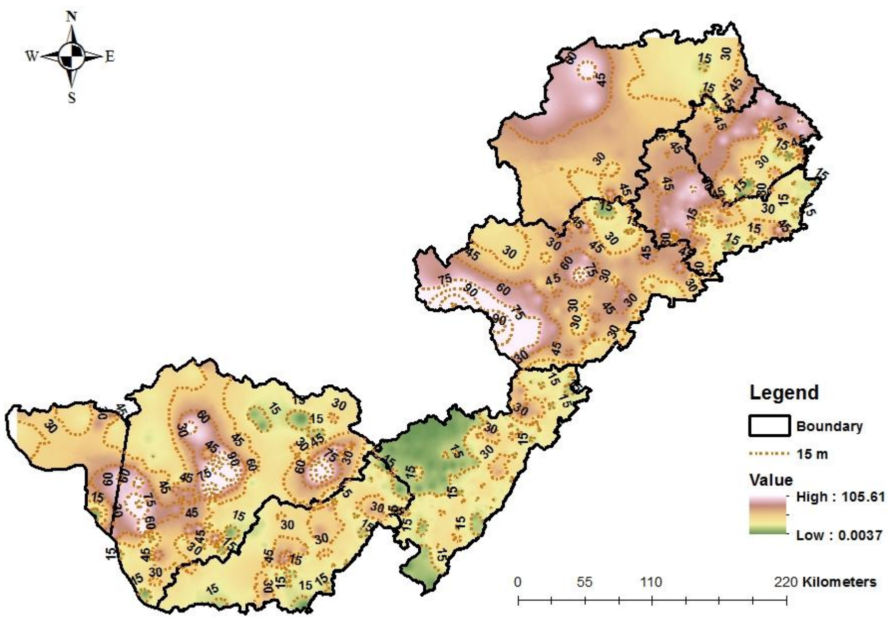


Figure 26:Post-monsoon water level (2004)

In 2002-2011 it can be observed that besides having decrease in water level after monsoon as in the water level fluctuation in some areas such as in NW of Churu, SW of Nagaur, and eastern and south eastern parts of Barmer there seems no changes in depth to water level.There is no change in Pali district besides of having increment in water level fluctuation in 2002 & 2004.

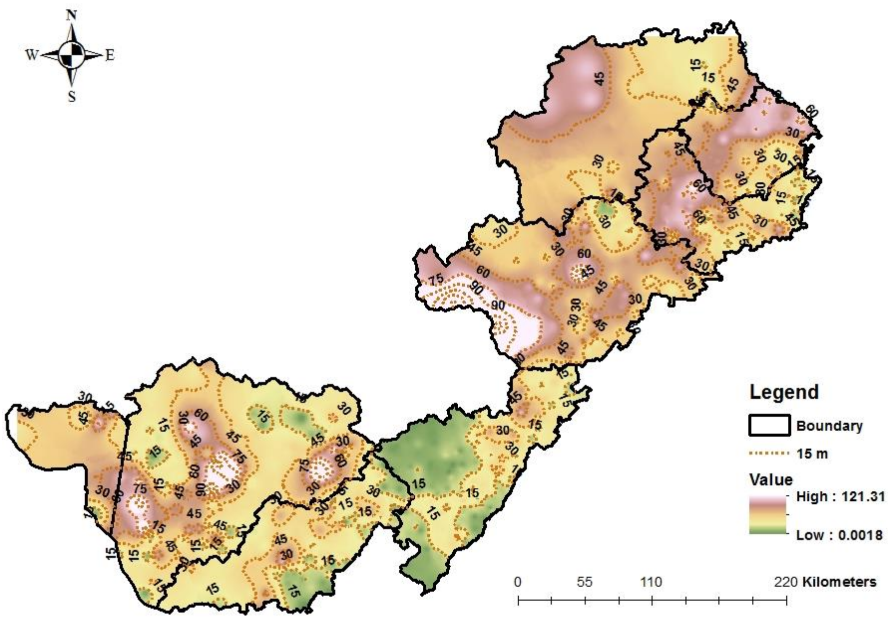


Figure 27:Post-monsoon water level (2006)

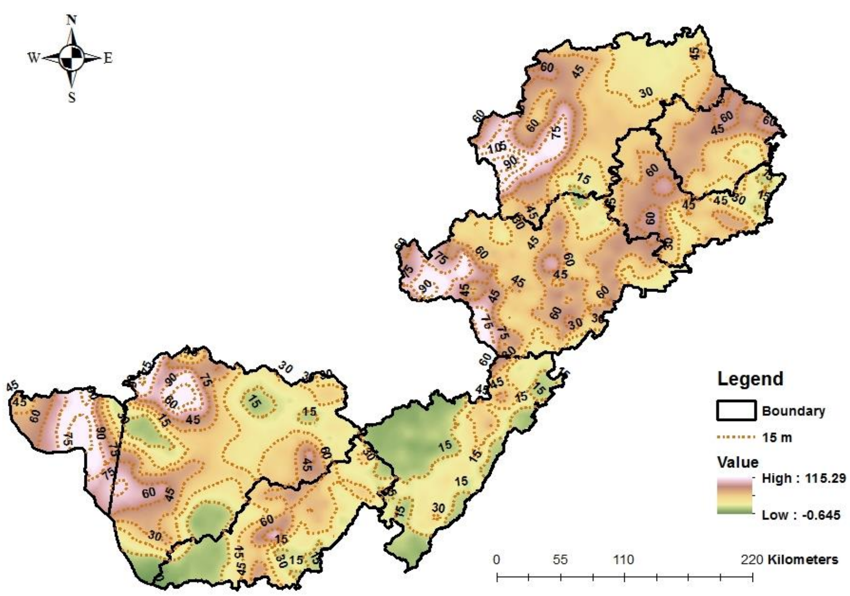


Figure 28: Post-monsoon water level (2008)

In Jhunjhunun, and Sikar districts the overall post monsoon conditions remains same in the studied period and thus less changes has been observed in both pre-monsoon and post-monsoon conditions.

At few places besides of having drought conditions in 2005 and 2011 the depth to ground water level remained constant. These places have been identified and discussed in the case study of the year 2009 and in the yield map of the study area.

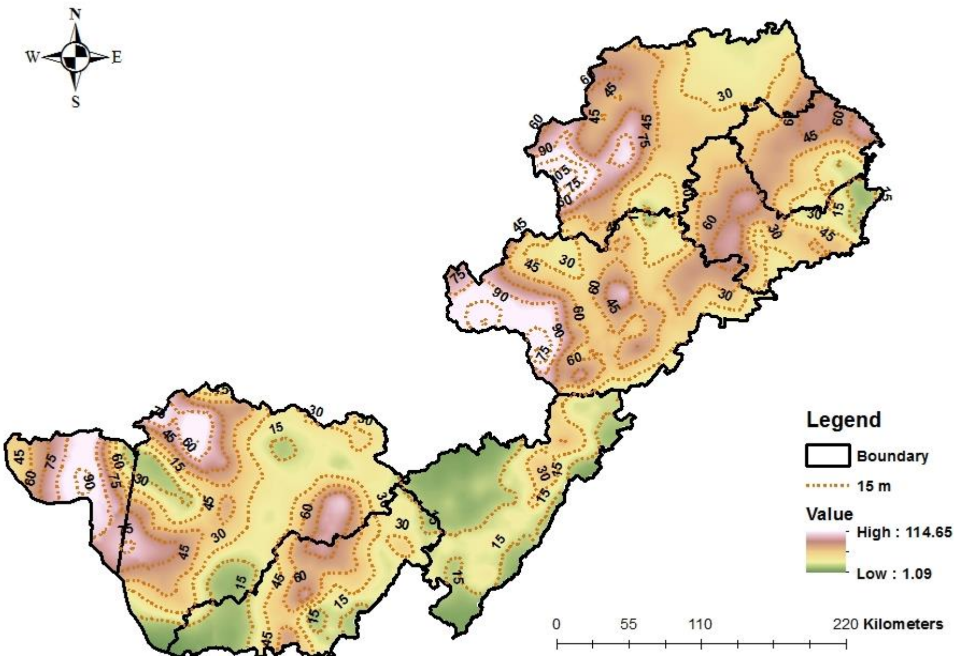


Figure 29:Post-monsoon water level (2010)

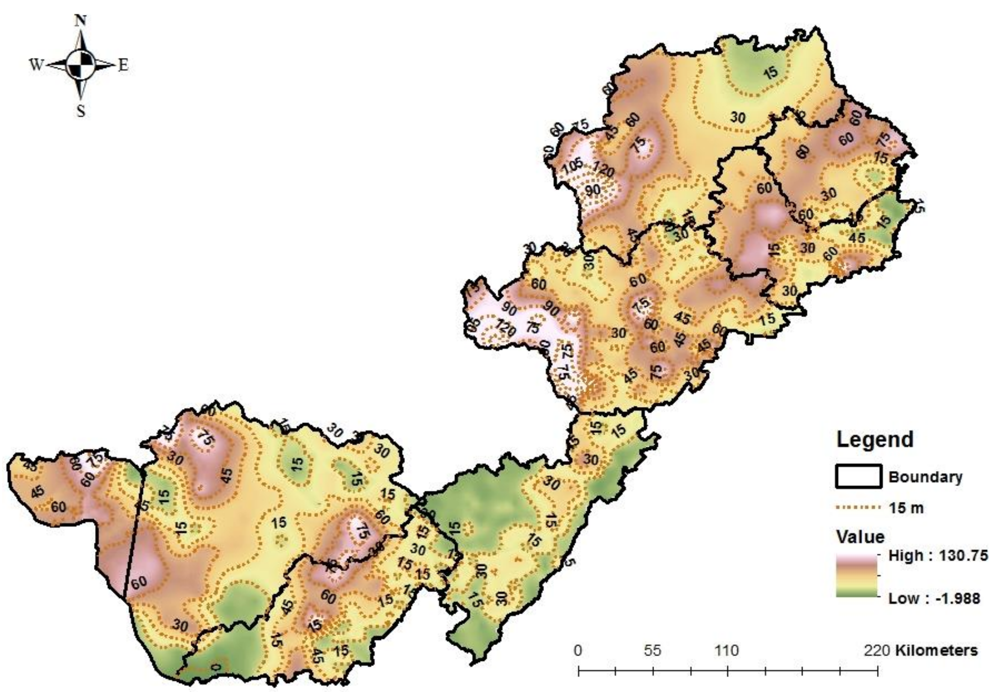


Figure 30: Post-monsoon water level (2011)

Fluctuation in Water Level (m)

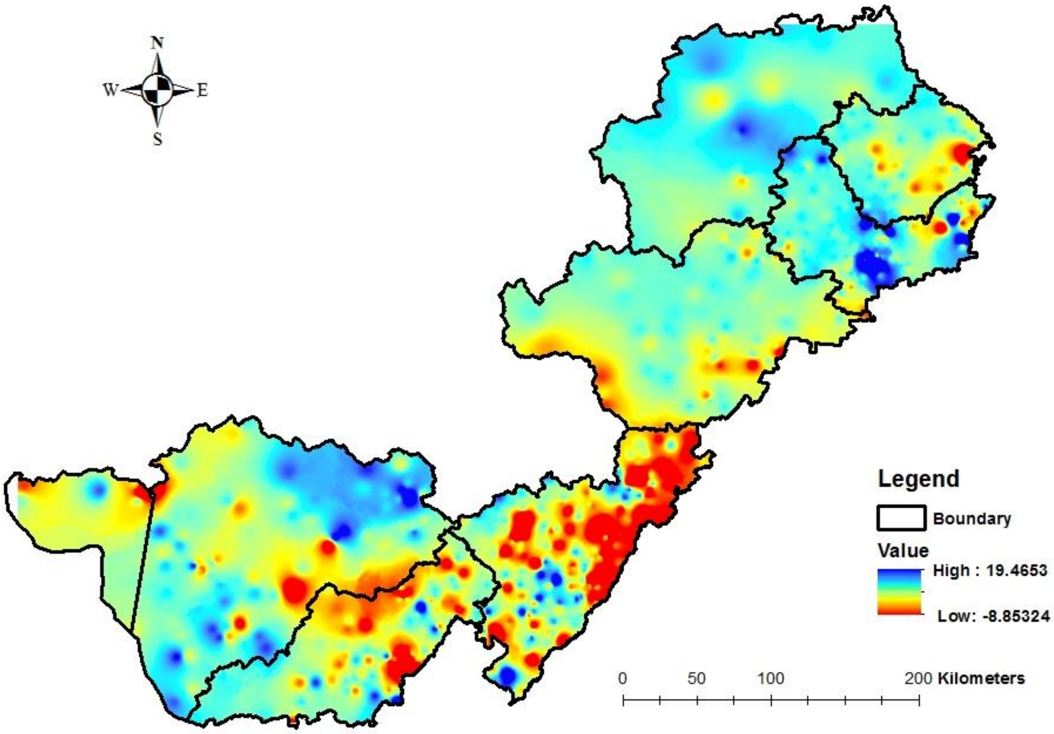


Figure 31: Ground water fluctuations in 2002

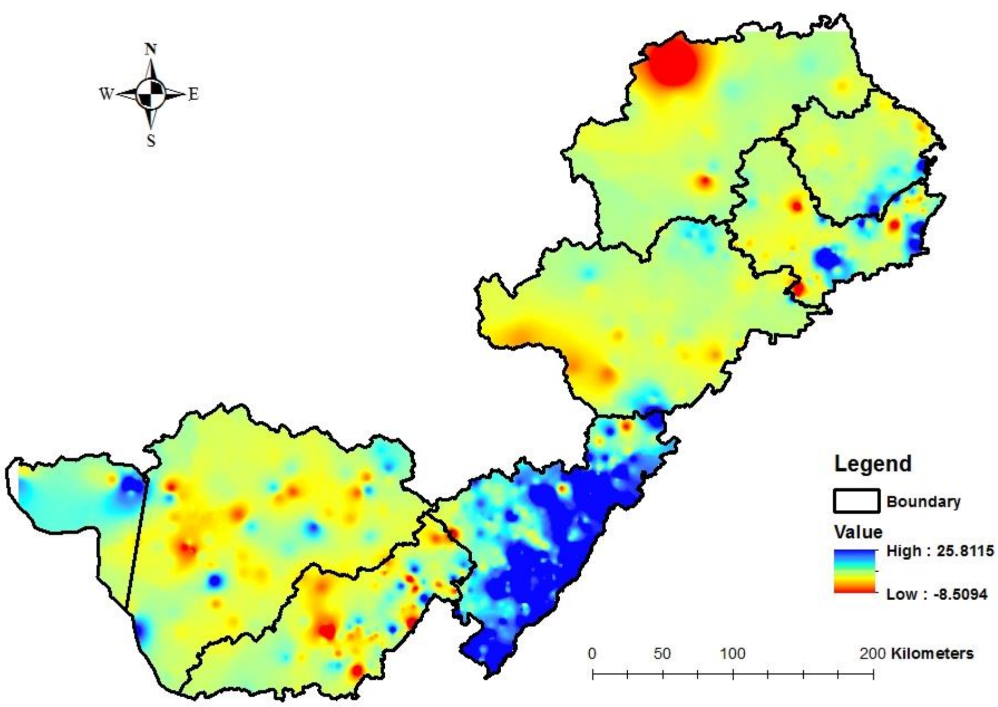


Figure 32: Ground water fluctuations in 2004

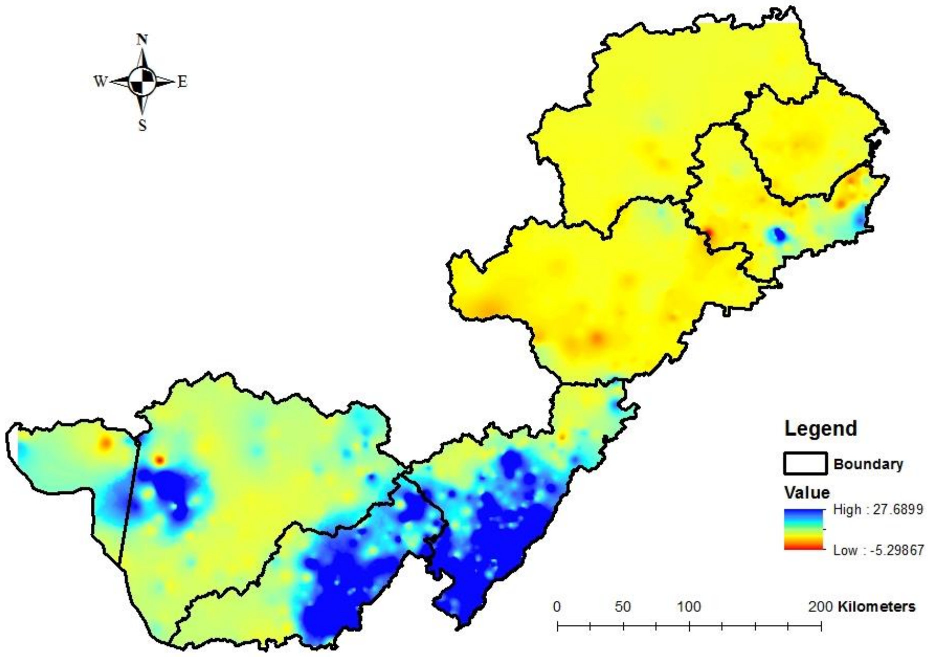


Figure 33: Ground water fluctuations in 2006

2006 has been the different case in the scenario as because the only increase in the water level is seen in southern and south-eastern parts of the study area including Pali, Jalore and parts of Barmer districts which includes the Luni basin which currently flows in this region.

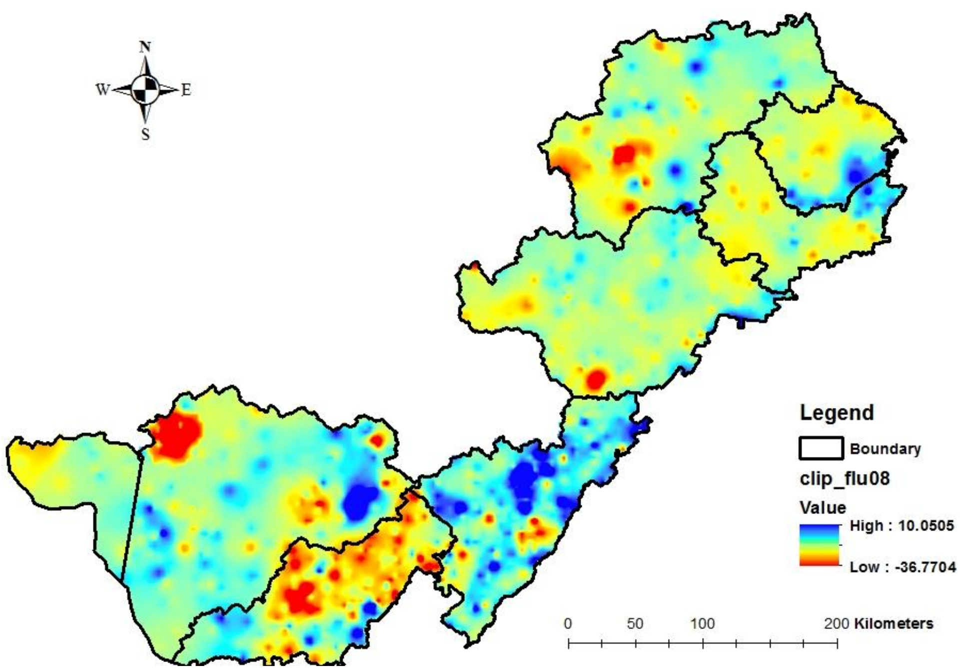


Figure 34: Ground water fluctuations in 2008

The only increment in the fluctuation is seen in Pali district and at some parts of Jalore and Nagaur district. The arid region of Barmer and Churu district including Sikar and Jhunjhunu faces depletion in the water level during 2010. But the scenario changes in 2011 with the increase in water level in Barmer, some parts of Sikar and Jhunjhunu districts.

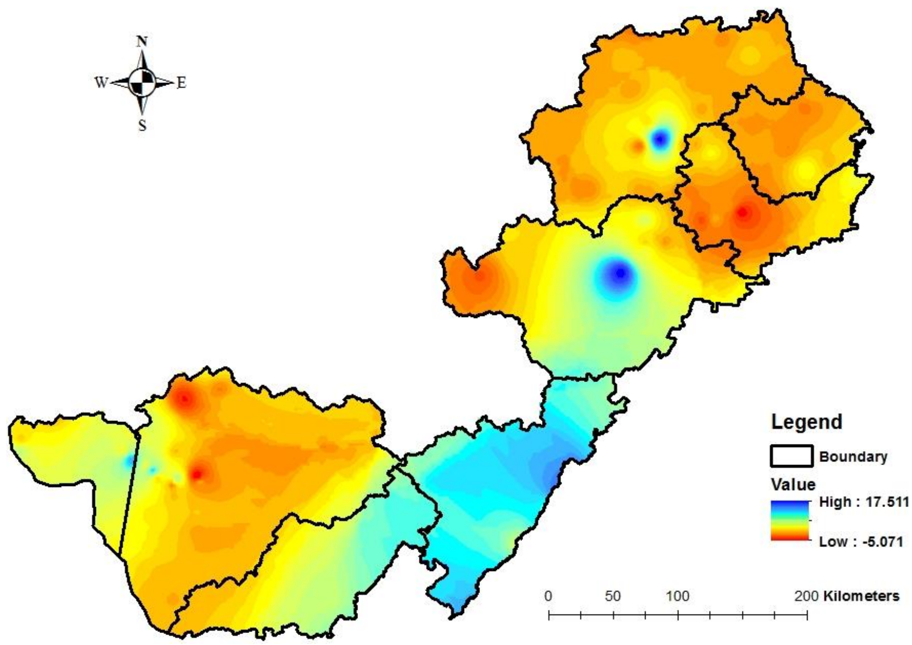


Figure 35: Ground water fluctuations in 2010

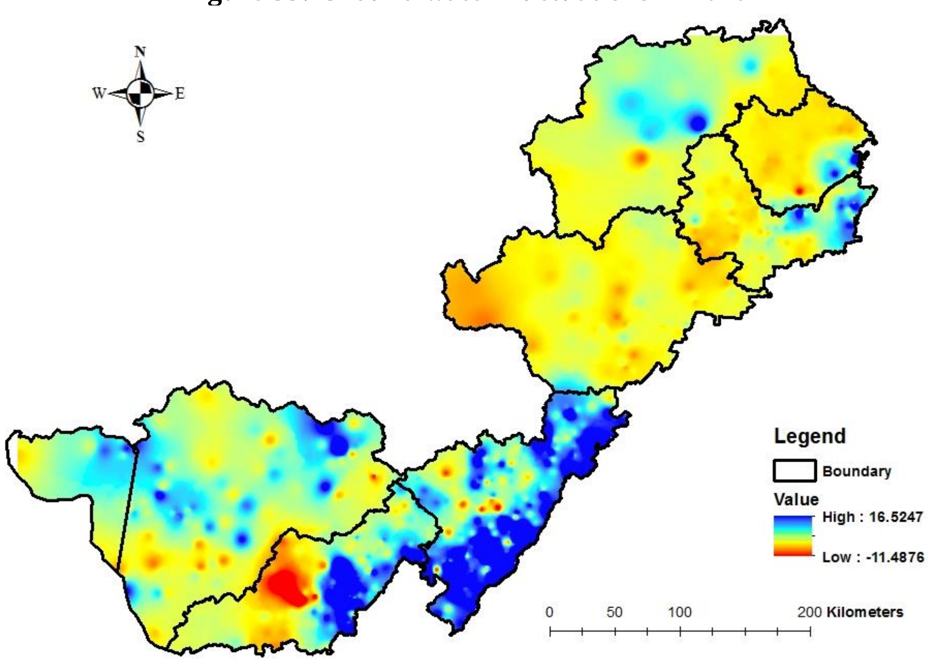


Figure 36: Ground water fluctuations in 2011

The red to blue colour in the fluctuation map represents the changes in depth to water level from decrement to increment in the water level for the years 2002 to 2011 in the study area and the rainfall distribution of the period under study has already been shown in the previous section which is the climate characteristics of the study area. The fluctuation map supports the consequent increment or decrement of the water level in each district under study which has been mentioned in pre-monsoon and post-monsoon water level analysis.

By analyzing the spatial distribution of depth to water level from 2002 to 2011 different in the study area has been identified where there is significant changes in the water level of the area and which supports the interpreted palaeo drainages in the study. This distribution and the reason behind the changes has been discussed in the following ground water analysis of the year 2009 as the case study.

Water level Fluctuation in the year 2009

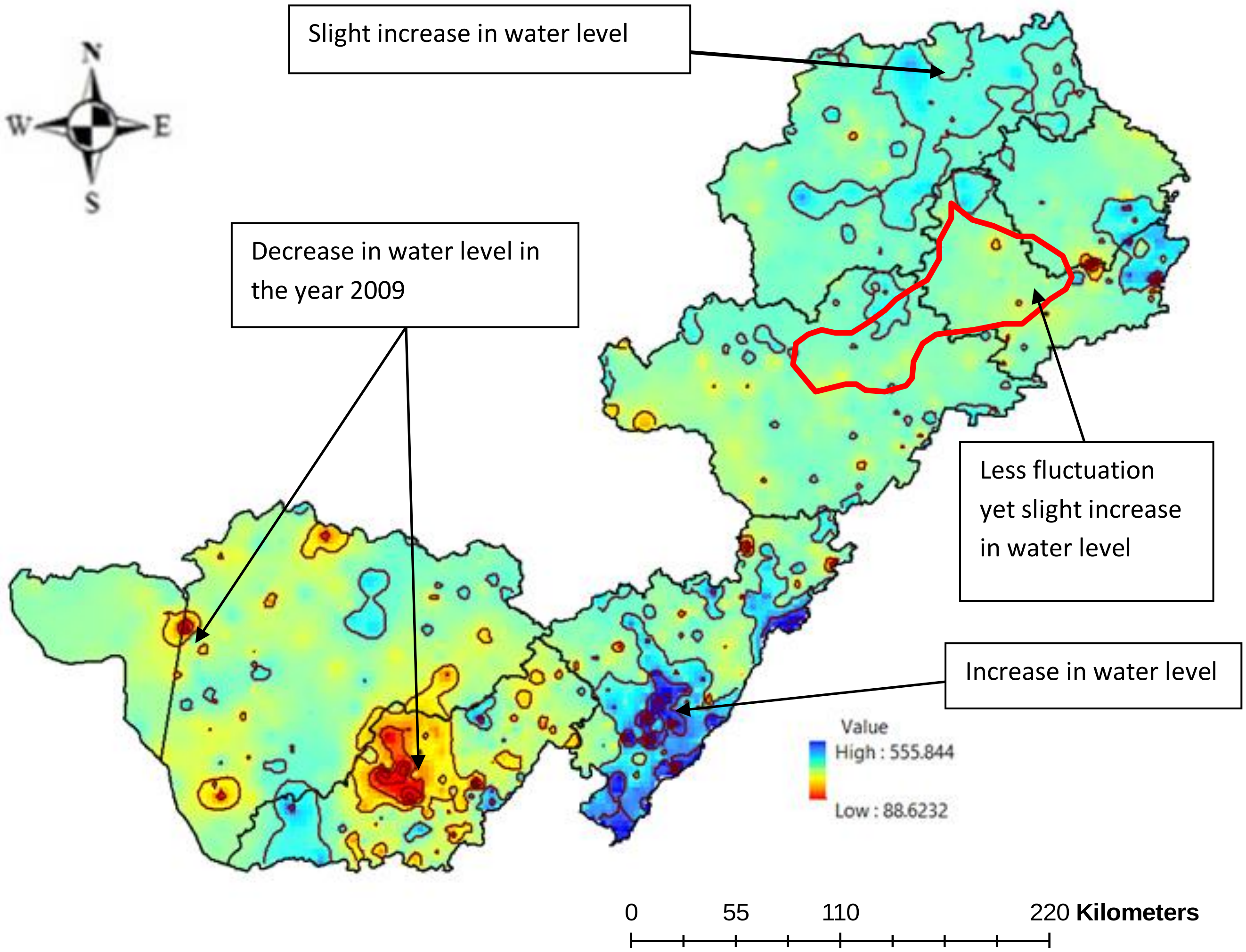


Figure 37: Water level Fluctuation map (2009)

Rainfall Distribution of the year 2009

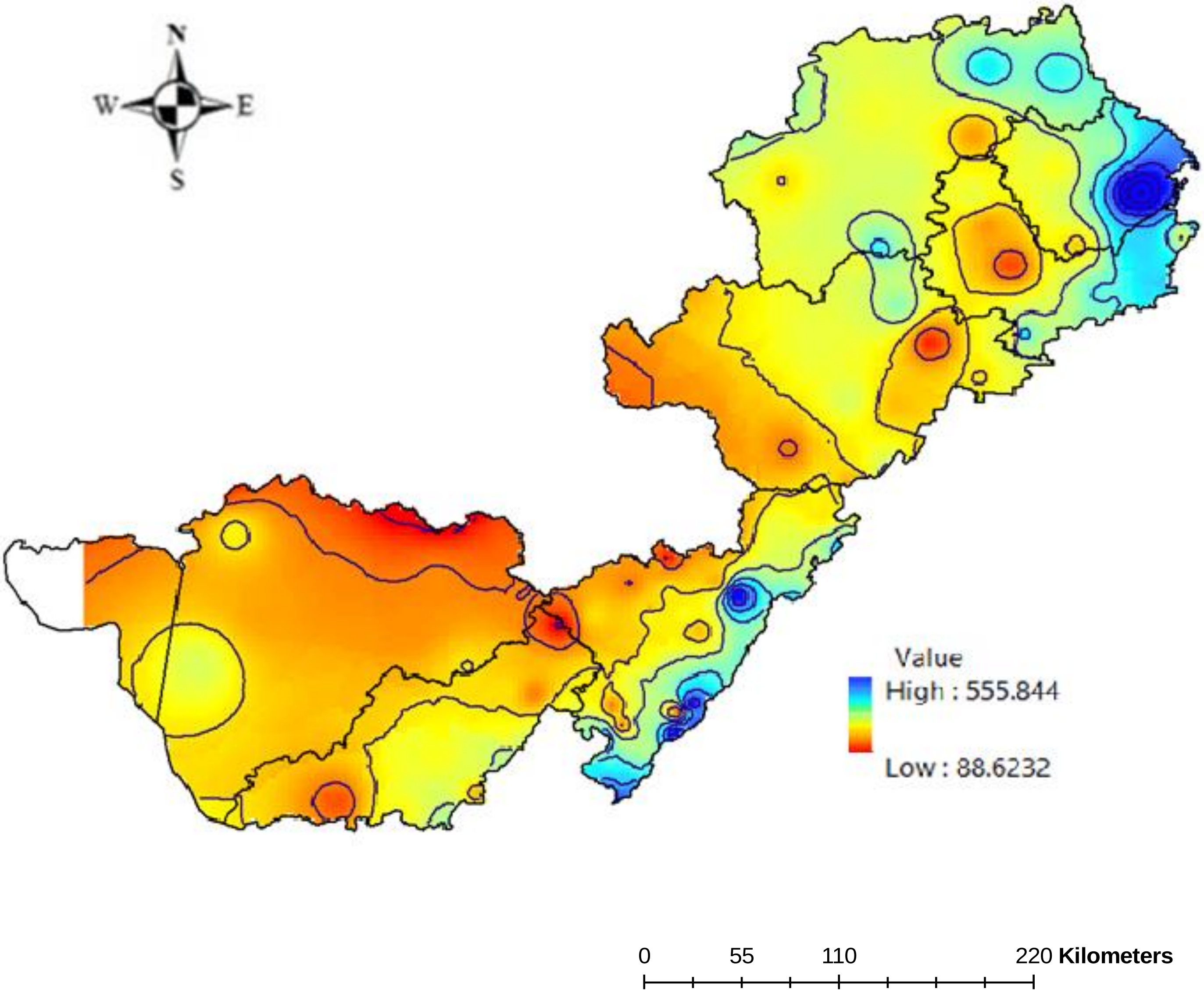


Figure 38: Rainfall Distribution (2009)

Ground Water Yield Analysis

It shows the same flow pattern from NE to W as depicted from pre monsoon, post monsoon and Fluctuation data.

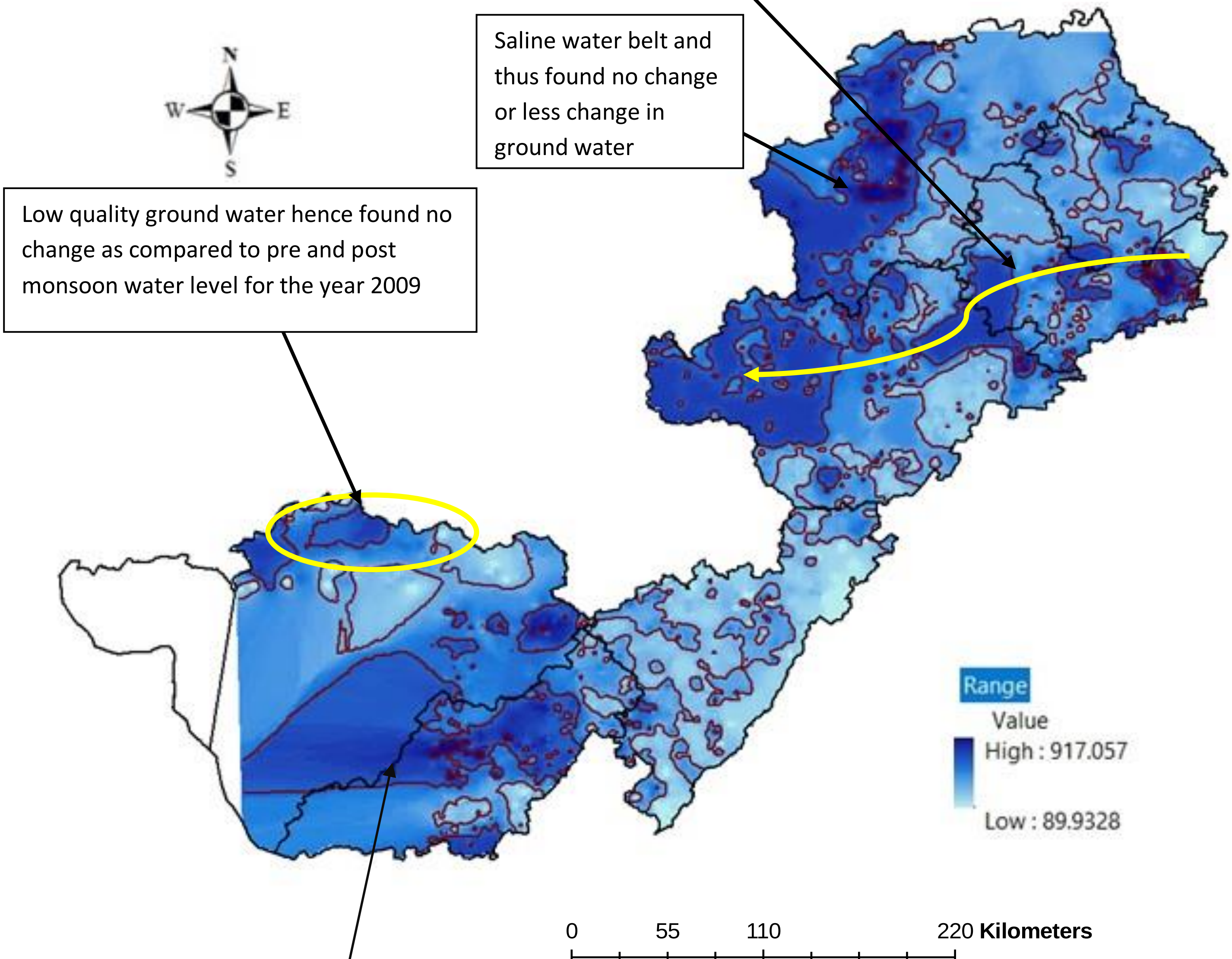


Figure 39: Groundwater yield map

This is linear band of currently flowing Sukri - Bandi river system originating from Aravalli ranges and thus there could not be any palaeo channels instead there could be dried channels of the river system.

Light to dark blue color shows the low to high yield of groundwater from wells. Around 4000 wells were taken into consideration for the study.

Pre-monsoon water level map of the year 2009

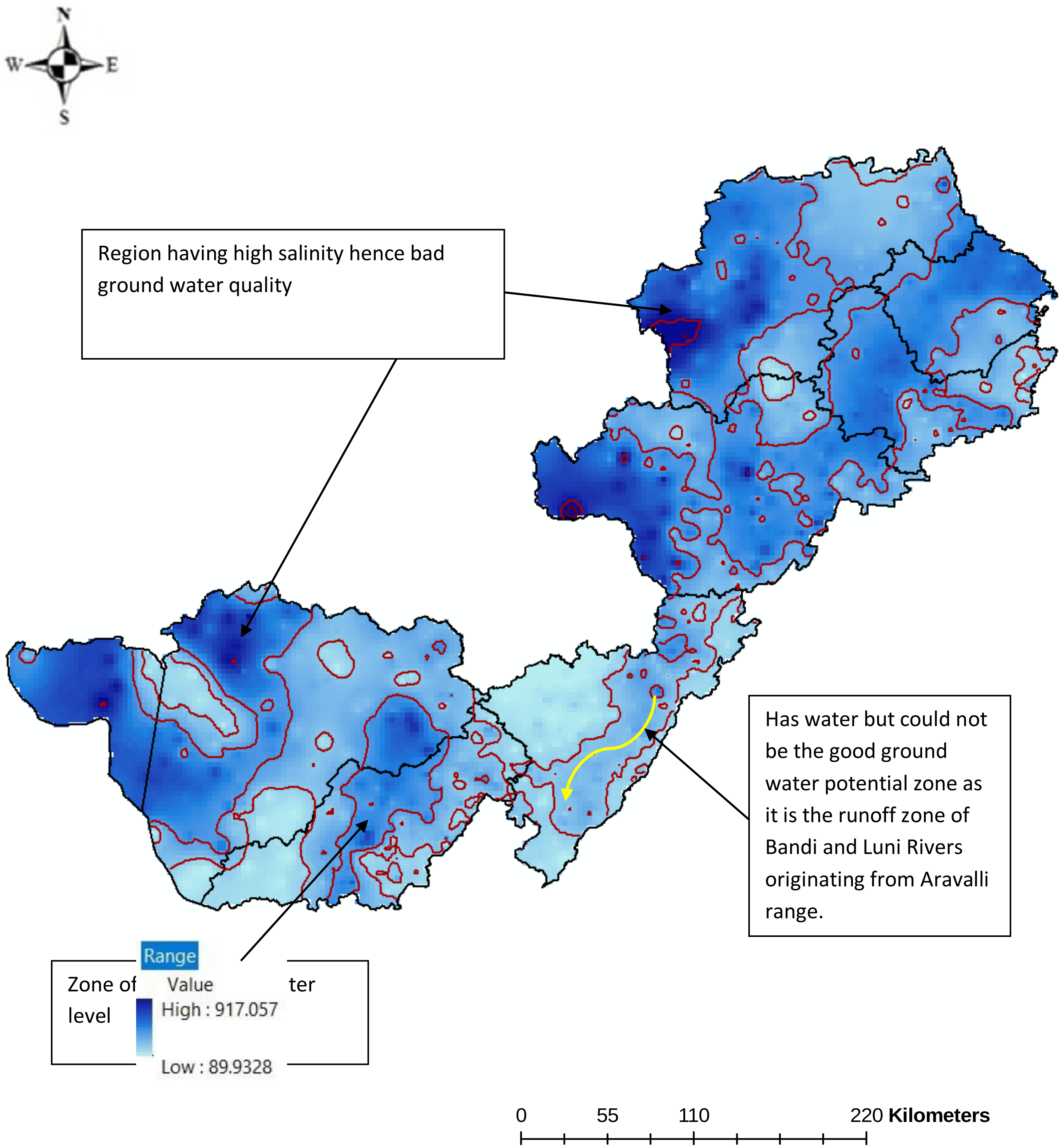


Figure 40: Pre-monsoon water level map (2009)

Post-monsoon water level map of the year 2009

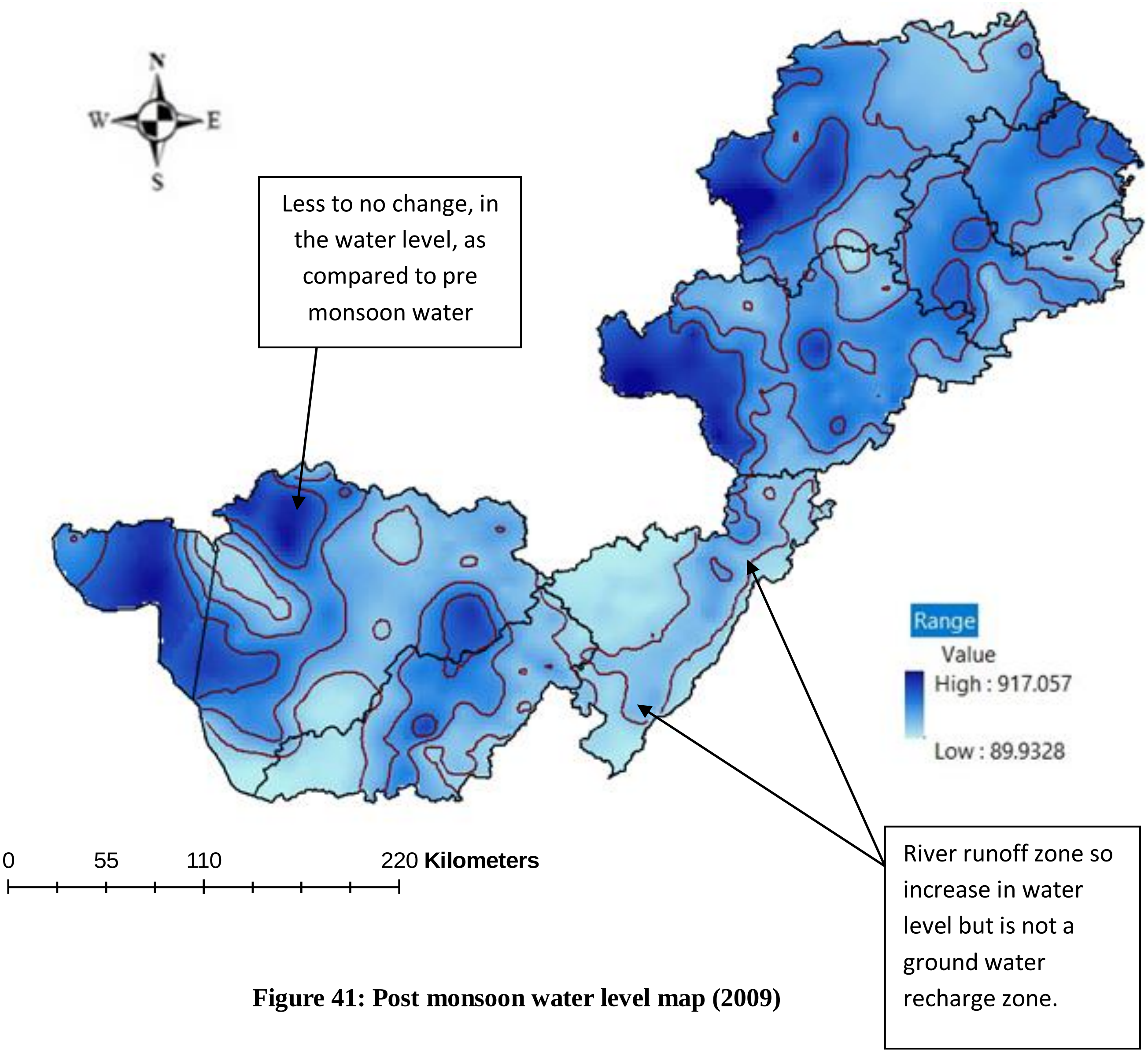


Figure 41: Post monsoon water level map (2009)

The palaeochannels are the potential source of groundwater and mineral deposits. Thus groundwater in the study area has been investigated through number of wells. Total of 4078 wells has been investigated out of which 69 are bore/tube wells with hand pump and 1457 are bore/tube wells with power pump, 1186 wells are Dug cum bore/tube wells and rest 1366 are open dug/ring wells. From all these data hydrogeology of the area under investigation have been assessed for the year 2009.

7. Vegetation Pattern Analysis

Using Remote Sensing data we have extracted and modeled various vegetation biophysical variables. Vegetation indices are dimensionless, radiometric measures that indicate relative abundance and activity of green vegetation, including leaf area index, percentage green cover, chlorophyll content, green biomass, and absorb photosynthetically content, green biomass, and absorbed photosynthetically active radiation. A vegetation index should

1. Maximize sensitivity to plant biophysical parameters, preferably with a linear response in order that sensitivity is available for a wide range of vegetation condition, and to facilitate validation and to facilitate validation and calibration of the index.
2. Normalize or model external effects such as Sun angle, viewing angle, and the atmosphere for consistent spatial and temporal comparisons.
3. Normalize internal effects such as canopy background variation, including topography (slope and aspect), soil variations, and differences in sensed or woody vegetation.
4. Coupled to some specific measurable biophysical parameter such as biomass, LAI or APAR as part of the validation effort and quality control.
5. Used to assess the healthy green vegetation under the target being observed.
6. Identifies the photosynthetic affinity or “greenness” through the reflective properties of chlorophyll and mesophyll layers within the plants.
7. Compares the normalized difference of brightness values of near infrared and red band. It might get affected by varying atmospheric conditions, illumination, viewing angles and soil reflectance etc.

Mathematically represented as:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} \quad (1)$$

Where NIR is the near infrared band and R denotes the red band. The resultant NDVI values lie between -1 and 1 which can be classified from very sparse vegetation to very dense vegetation.

Following are some field photographs were good vegetation is observed during field investigation.

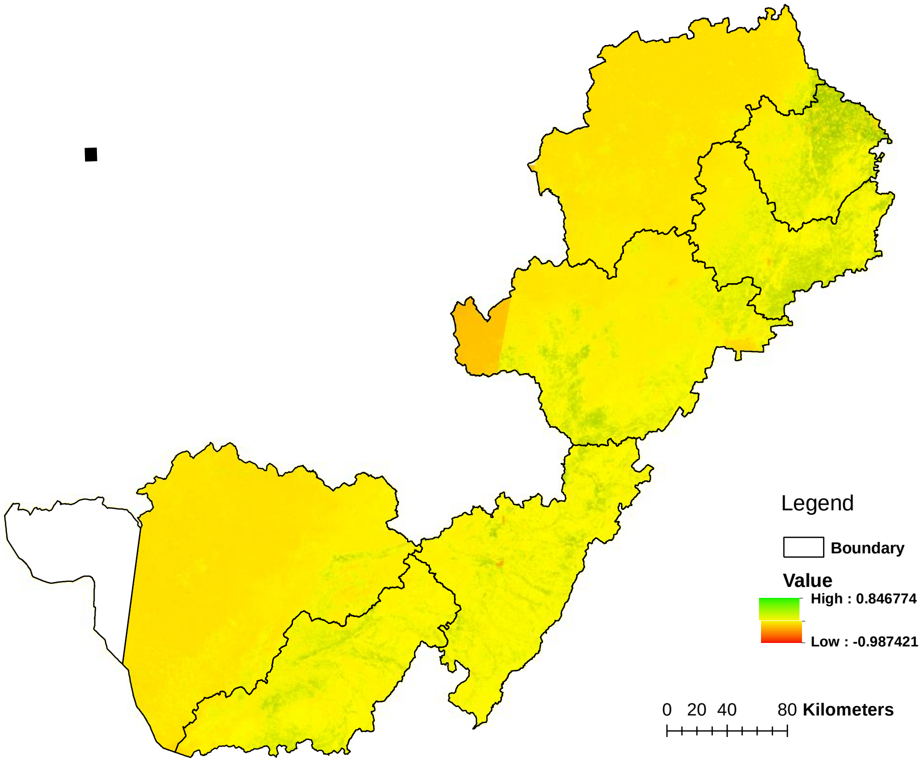


Figure 42: Vegetation pattern for the Rabi season

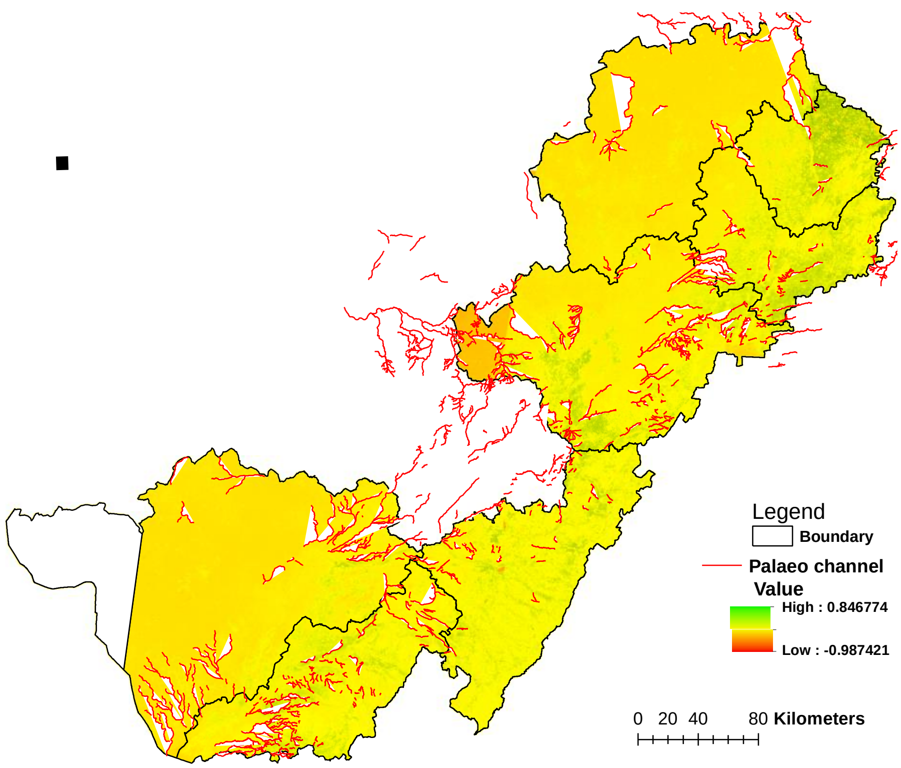


Figure 43: Overlay of Interpreted Palaeo drainage with NDVI

GPS location: 75.41088, 28.66089

Figure 44: Vegetation cover along the road

GPS location:75.41088E,28.66089N

Figure 45: Agriculture on identified palaeo surface

(a)

(b)

(c)

GPS location: 75.08615E, 27.33919N **(d)**

Figure 46: Figures (a), (b), (c), & (d) association of agriculture Along the path of identified palaeochannels

Chapter-5

Remote Sensing of Palaeochannels

Introduction to Remote Sensing

"Remote Sensing is a science by which we can obtain information about an object, areas, Phenomenon through the analysis of data acquired by the device which is not in Physical contact with the object".

Remote sensing is the science of making inferences about objects from measurements, made at a distance, without coming into physical contact with the objects under study. That is Remote sensing refers to any method, which can be used to gather information about an object without actually coming in contact with it. However, currently the term 'Remote Sensing' is used more commonly to denote identification of earth features by detecting the characteristics electromagnetic radiation that is reflected emitted by the earth system.

Remote Sensing means sensing of the earth's surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use, and the protection of the environment.

The basic process involved in remote sensing is the interaction (or emission) of the electromagnetic Radiation with (from) matter. Electromagnetic radiation is made up of electric and magnetic fields and spans a large spectrum of wavelength gamma rays ($^{10-10}$ m) to long radio waves (10^6m). The entire range of the electromagnetic radiation is called electromagnetic spectrum extending from about 0.4 to 0.7 μm wavelengths. While remote sensing may avail of a much broader part of the spectrum in comparison to what is useful for human eyes, the whole of the electromagnetic spectrum is not available for remote sensing for reasons that we may dwell upon at a later stage

It the observation is made based on the electromagnetic radiation from the sun or self-emitted radiance, it is called passive remote sensing. It is also possible to produce electromagnetic radiation of a specific wavelength or band of wavelength to illuminate the object or terrain the interaction of this radiation can then be studied by sensing the scattered radiance from the target, this is called active remote sensing.

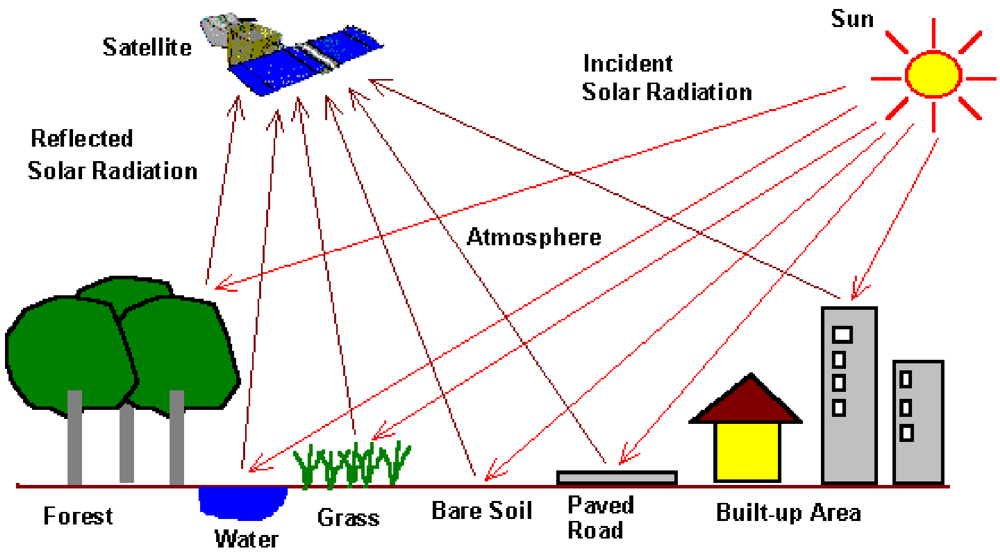


Figure 47: Process of Remote Sensing

Source: https://crisp.nus.edu.sg/~research/tutorial/optical.htm

Stages in remote sensing

- Origin of electromagnetic energy (sun, transmitter carried by the sensor)
- Transmission of energy from the source to the surface of the earth and its interaction with the intervening atmosphere.
- Interaction of energy with the earth's surface (reflection/ absorption/ transmission) or self - emission.
- Transmission of the reflected/ emitted energy to the remote sensor placed on a suitable platform, through the intervening atmosphere.
- Detection of the energy by the sensor, converting it into photographic image or electrical output.
- Transmission/ recording or the sensor output.
- Pre-processing of the data and generation of the data products.
- Collection of information.
- Data analysis and interpretation
- Integration of interpreted images with other data towards deriving management strategies for various them, or other application.

A remote sensing system consists of a sensor to collect radiation and a platform an aircraft, a balloon, rocket satellite or even a ground- based sensor- supporting stand- on which a sensor can be mounted.

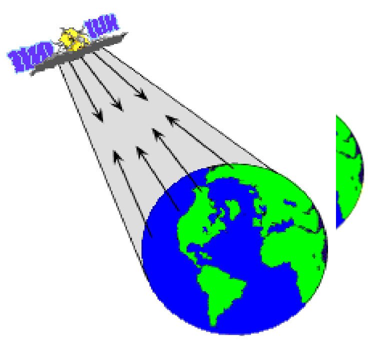
The information received by the sensor suitably manipulated and transported back to the earth- may be telemeter as in the case of unmanned spacecrafts systems, the data are re-formatted and processed on the ground to produce photographs, computer compatible magnetic tapes (CCT) or other digital data storage medium, the photographs/ digital data are interpreted visually digitally to produce thematic maps and other resource information, the interpreted data so generated need to be used along with other data information etc. To arrive at management plan, this is generally carried out using geography Information system (GIS).

Passive Remote Sensing

Remote sensing systems, which measure energy that is naturally available, are called passive sensors. Passive sensors can only be used to detect energy when the naturally occurring energy is available. Examples of former are LANDSAT, SPOT and IRS series of satellites including recent satellite RESOURCESAT (IRS-P6), while that of latter are of ERS, RADARSAT, ASTER.

Active Remote Sensing

Active sensors provide their own energy source for illumination. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season.



(a) Active Remote Sensing **(b) Passive Remote Sensing**

Signature

Electromagnetic Radiation when incident on a surface, gets reflected, absorbed, re-radiated or transmitted through the material depending upon the nature of the objects and the wavelengths of the incident radiation.

Since the nature of interaction of the electromagnetic radiation with on object depends on its cumulative properties, the study of these interactions can lead to an understanding of the objects under observation. In remote sensing, the basic property, which allows identification of an object, is called signature.

In general, the concept of signature in remote sensing is similar to how we identified with signature (or fingerprint) in your transactions. The basic assumption is that each individual has a unique signature or finger print with which can be identified. In general, we can say that any set of observable characteristics, which directly or indirectly leads to the identification of an object and or its condition, is termed as signature. Spectral, spatial, temporal and polarization variations are four major characteristics of the targets, which facilitate discrimination.

Spectral Variations

Spectral Variations are the changes in the reflectance of objects as a function of wavelength colour of objects is a manifestation of spectral variation in reflectance in the visible region.

Spatial variations

Spatial arrangements of terrain features providing attributes, such as shape, size and texture of objects, which lead to their identification, are termed as spatial variations.

Temporal Variations

Temporal variations are the changes in the reflectivity or emissive with time. They can be seasonal. The variation in reflectivity during the growing cycle of a crop helps to distinguish crops which may have similar spectral reflectance but whose growing cycles may not be the same. A plot of spectral reflectance vs. growth stages of a crop provides a phonologic pattern, which is characteristic of a crop, even at the species level. Therefore remote sensing data acquired over the same area at different times can make use of the temporal characteristics to discriminate crops in a better way.

Polarization Variation

Relate to the changes in the polarization of the radiation reflected or emitted by an object, the degree of polarization is a characteristic of the object and hence can help in distinguishing the object. Such observations have been particularly useful in the microwave region.

Table 5: Wavelengths of EMR and their applications

REGIONS	WAVELENGTH (μm)	PRINCIPAL APPLICATION
Blue	0.45 - 0.52	Coastal morphology & Sedimentation study, Soil and Vegetation differentiation, Coniferous & Deciduous vegetation discrimination
Green	0.52 - 0.60	Vigor assessment, Rock & Soil discrimination, Turbidity & bathymetry studies
Red	0.63 - 0.69	Plant species differentiation
Near infrared	0.76 - 0.90	Vegetation vigor, Biomass, Delineation of water features, Landforms / geomorphic studies
Mid infrared	1.55 - 1.75	Vegetation moisture content, soil moisture content, snow & cloud differentiation
Mid infrared	2.08 - 2.35	Differentiation of geological materials & soils
Thermal IR	3.0 - 5.0	For hot targets Viz. Fires and volcanoes
Thermal IR	10.4 - 12.5	Thermal sensing, Vegetation discrimination, Volcanic studies

Importance of Remote Sensing

Satellite remote sensing is used to systematically identify,delineate and reconstruct the Palaeo drainage system due to synoptic, multi- spectral and multi- temporal coverage. It helps in understanding the Palaeo channels in the regional context and narrowing down the area of investigation for ground water targeting, thus reducing the cost and time involved in ground water exploration.

Characteristic of Palaeo Channel on the Satellite Image

The Palaeo channels exhibiting linear, curvilinear and loop-like forms and appearing with typical black ribbon like stripes and loops in black and white products and characteristics reddish stripes and loops in colour coded formats were interpreted. These signatures appear due to moisture enrichment and vegetation along old courses and buried river systems.

Palaeo channels were delineated from satellite image by considering combination of factors like linear/ curvilinear/ meandering courses, channel like shape, high moisture, liner depressions, vegetated regions and association with fluvial landforms. These Palaeo channels were occupied by reworked sand heaped in the form of dunal ridges. Presently signatures of these Palaeo channels have been obliterated from the ground due to levelling/ sand removal for cultivation. Their sinuous shape, high moisture and concentrated vegetation cover helped in the identification from multi- date satellite data.

Satellite data has advantages of synoptic view, multi spectral and multi temporal nature. Useful landforms like palaeo channels in arid regions are sometimes as wide as 6-8 km and their length may be of the order of hundreds of km. It becomes complicated to visualize their presence in field due to agricultural fields, or soil cover e.g., palaeo channel of “lost Saraswati”, observed in the northern parts of Rajasthan and Haryana along the bed of current Gaggar River.

Palaeochannels are large geomorphic units whose curvilinear structure is seen over tens of kilometres. Hence the synoptic viewing is the only way to visualize them. In addition to synoptivity, remote sensing data with the multispectral and multi temporal nature provides enormous information about the Palaeochannels.

Remote Sensing techniques used for interpretation of Palaeochannels

The Advent of Remote Sensing technology could throw much light on the subject. With this technology, it has now become possible to discover, delineate and understand the palaeo channel in a regional context and in an integrated manner.

A remote sensing study of the Indian Thar desert reveals numerous signatures of palaeo channels in the form of curvilinear and meandering courses, which is identified by the tonal variations (Bakliwal et al 1988). Its initial course flowed close to the Aravalli ranges and the successive six stages took west and northwesterly shifts till it coincides with the dry bed of the Ghaggar River.

The rivers migrate for various reasons amongst which tectonic movement is one of the main causes. The study has shown that western Indian show considerable signs of Quaternary tectonic (Landsat photographs on a 1:1000,000 scale) the Palaeo channels were interpreted, as exhibiting linear, curvilinear and loop like features with typical black ribbon like stripes.

The Landsat Imagery studies shows that the Indus river has a very wide flood plain on either side of its courses up to a maximum width of 100-200 km. in the east and south east, to have such a wide flood plains on only one side shows that the Indus river has preferentially migrated towards the north west in the northern parts and towards the west in the central and southern parts. The study of remotely sensed data in the desert tract of Rajasthan shows that there are plenty of Palaeo channels with well sprain up tentacles throughout the desert. On the northern edge of the Thar Great Indian Desert at the Ganganagar-Anupgarh plains, a well-developed set of Palaeo channels is clearly discernible in satellite photographs. The present study shows clearly that the Saraswati river once flowed close to the Aravalli hill ranges and met the Arabian sea the Rann of Kachchh, that it has migrated towards the west, the northwest and the north and has ultimately got lost in the Anupgarh plains.

Interpretation of aerial photographs and satellite imagery covering the North West India has been carried out by numerous investigators to identify and map Palaeo channels as well trace the migratory evolution.

Palaeochannels are large geomorphic units whose curvilinear structure is seen over tens of kilometres. Hence the synoptic viewing is the only way to visualize them. In addition to synoptivity, remote sensing data with the multispectral and multi temporal nature provides enormous information about the Palaeochannels.

The research includes LISS 3 and Landsat data of all the three seasons i.e. Rabi, Kharif and Zaid. False color composite provides good information regarding the Palaeochannels in the image. Further application of various image processing techniques gives much more channels which were not visible in normal or FCC image.

The river core is non vegetated and lighter in the image but the palaeo where there is sand buried under the alluvial deposits and have good vegetation cover. It is because sand bodies are good aquifer zones, which provides water to the surface vegetation and alluvial sediments are good source of nutrients. Therefore they seem to be linear and mostly are found parallel to the present day river courses.

Palaeochannels are distinguished by its sinusoidal pattern on dry ground with high reflection seen in the satellite image, which is characterized by presence of moisture content or even stagnant water patches often known as playas at certain stretches formed by disjointed parts of channels like oxbow lakes or meanders. This physical characteristic of Palaeochannels clearly separates them from its surrounding environment or other active river channels.

Below are the physical characteristics of Palaeochannels that are useful for their identification in the satellite imagery (Nandini, 2014).

1. Palaeochannels have low values in IR bands due to presence of water content.
2. They appear in distinct Sinusoidal pattern.
3. They are associated with water bodies (playas) varying in size and distribution.
4. They have characteristics like drainage but they are not present in topographic maps.
5. They may also appear as highly disjointed bodies of channel, giving rise to smaller ponds, meanders and oxbow lake like pattern.
6. Vegetation is present along the buried channels in a curvilinear pattern (or as the same as of the channel).
7. Associated with thick pile of silty sand, medium to coarse sand and gravel.
8. Presence of structural features like faults and lineaments etc.

Due to moisture content in these channels, vegetation growth can also be seen along the flow direction of old river courses. This presence of vegetation along the channels can be identified in images due to higher reflectance in NIR bands.

Palaeochannels are typically characterized by their own surface signatures in satellite images such as their association with geomorphological features, structural features like lineaments, presence of sand, moisture, vegetation, etc.

These signatures can be highlighted in the remotely sensed data using various remote sensing techniques and indices and thus palaeo channels can be accurately mapped by adopting suitable Digital Image Processing methods and by analyzing the Digital Elevation Model.

The description of these DIP techniques is given in the following section:

Digital Image Processing

Raw satellite data may contain many geometric and radiometric errors. Hence it is important to rectify it before using it in any application. This typically involves the pre processing of the raw data by means of correcting radiometric and geometric distortions, noise removal and calibration of the data. This step or say process is also referred to as image rectification.

The LANDSAT data both TM and ETM contain radiometric errors due to effect of atmosphere, aerosol, sun elevation, moisture, etc. And so these imageries have to be corrected for scene radiometry. However, it was noted the NASA and that US Geological Survey have already performed these radiometric corrections and thus these corrections was not necessary for the images used in the project.

And hence the images used in this project have been directly utilized for further analysis and interpretation.

In the present context of mapping the palaeo channels, the various Image processing techniques used are the image enhancement techniques (Linear Contrast Enhancement, Principal Component Analysis, etc.) and the image fusion techniques such as Intensity Hue Saturation, Wavelet Transformation, etc.

The main objective of the image enhancement is to process an image in order to get a more suitable image for a particular application.

Image Enhancement

Image enhancement techniques have been applied to the multispectral images in order to improve the image quality or to visually interpret the data more effectively. This helps in the better interpretation of palaeochannels in the images and also to segregate one feature from the other.

These techniques involve the use of image manipulation functions as well as various statistical functions provided by the image processing software. Besides these, Image Ratioing (NDVI, NDWI), Principal Component Analysis, and Image Fusion techniques were also applied to the precise interpretation of the palaeo channels.

Various enhancement techniques have been applied to IRS data by Saifuddin and Iqbaluddin(1999) for the reconstruction of the old river courses. Suitable contrast enhancement technique enhanced the impression of palaeo channels in the arid region. This was because of the presence of the moisture in it.

In another study, Rajesh Kumar et al (2005) applied the enhancement, band ratioing, histogram equalization and edge enhancement to LISS 3 image of IRS 1D for the identification of palaeo channels of Thar desert. Philip et al (1991) commented that ratioing and linear contrast stretching are the two powerful image enhancement techniques for the identification and mapping of fluvial palaeo-features.

Contrast Enhancement

This image enhancement technique is used to modify the brightness and contrast of an image, and also to remove blurriness of the image. It also filters out the noise at some level.

Contrast enhancement technique changes the contrast between features and its background by changing the original value of the pixels so that most of the available range is used. Several types of contrast enhancements techniques are there in the image processing software. These can be divided into two types Linear and Non-Linear methods.

Linear contrast stretching uses the lower and upper bound of the histogram (usually minimum and the maximum pixel value of the image respectively). It then applies a transformation function to stretch this range to fill the full range.

The following equation is used in this technique:

$$\mathrm{DN}' = \frac{\mathrm{DN} - \mathrm{Min}}{\mathrm{Max} - \mathrm{Min}} \mathrm{X} 255$$

Where

DN’= digital number to be assigned to the pixel in the output image.

DN= original digital number of the pixel in the input image.

Min = input image’s minimum value.

Max= input image's maximum value.

Thus contrast stretching is the process of reassigning the range of pixel values to another range.

In linear contrast stretching, the contrast in the image with light tones areas appears lighter and dark areas appear darker. This makes a visual interpretation of the feature much easier.

In the project, linear contrast stretching and histogram equalization are used to distinguish between Palaeochannels and current drainage and other associated areas.

Histogram Equalization

Non linear stretching, Histogram equalization very well highlighted certain features in the image this is because the image contains pixels of wet areas, vegetation, dry sandy areas as well as linear features, all of these are distinct from each other but have wide range of DN values. It redistributed the pixel values in such a way that there is approximately the same number of pixels within a given range.

Sediments in the Palaeochannels contains high moisture than the adjacent areas in the image, also there is high vegetation growth associated to Palaeochannels. The DN range of the pixels is limited; contrast stretch alters the narrow range of the grey levels to fit the full length of the image. It gives clear differentiation between palaeo and adjacent areas.

Below shown are the images of parts of Nagaur district (Merta, Nagaur) where these techniques gave significant results in order to discriminate the drainage from vegetation. These figures show the comparison of normal FCC image, with the contrast stretched and Histogram Equalized images. The blue lines show the current flowing drainage in the images. Linear contrast stretching gave better result than normal FCC and histogram equalization in particular areas.

Thus the image enhancement process has brought out more details about Palaeochannels

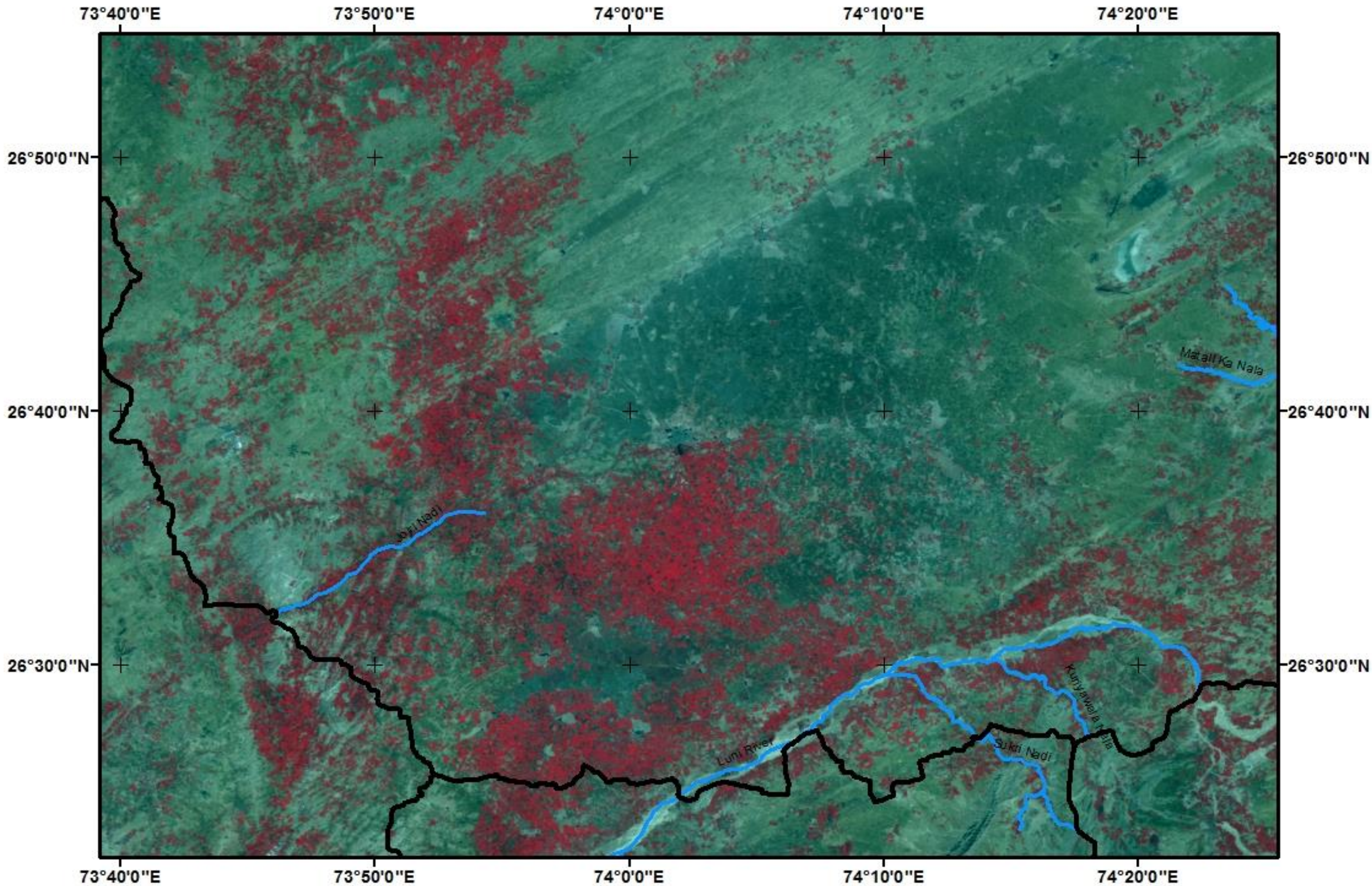


Figure 48: Normal False Colour Composite image

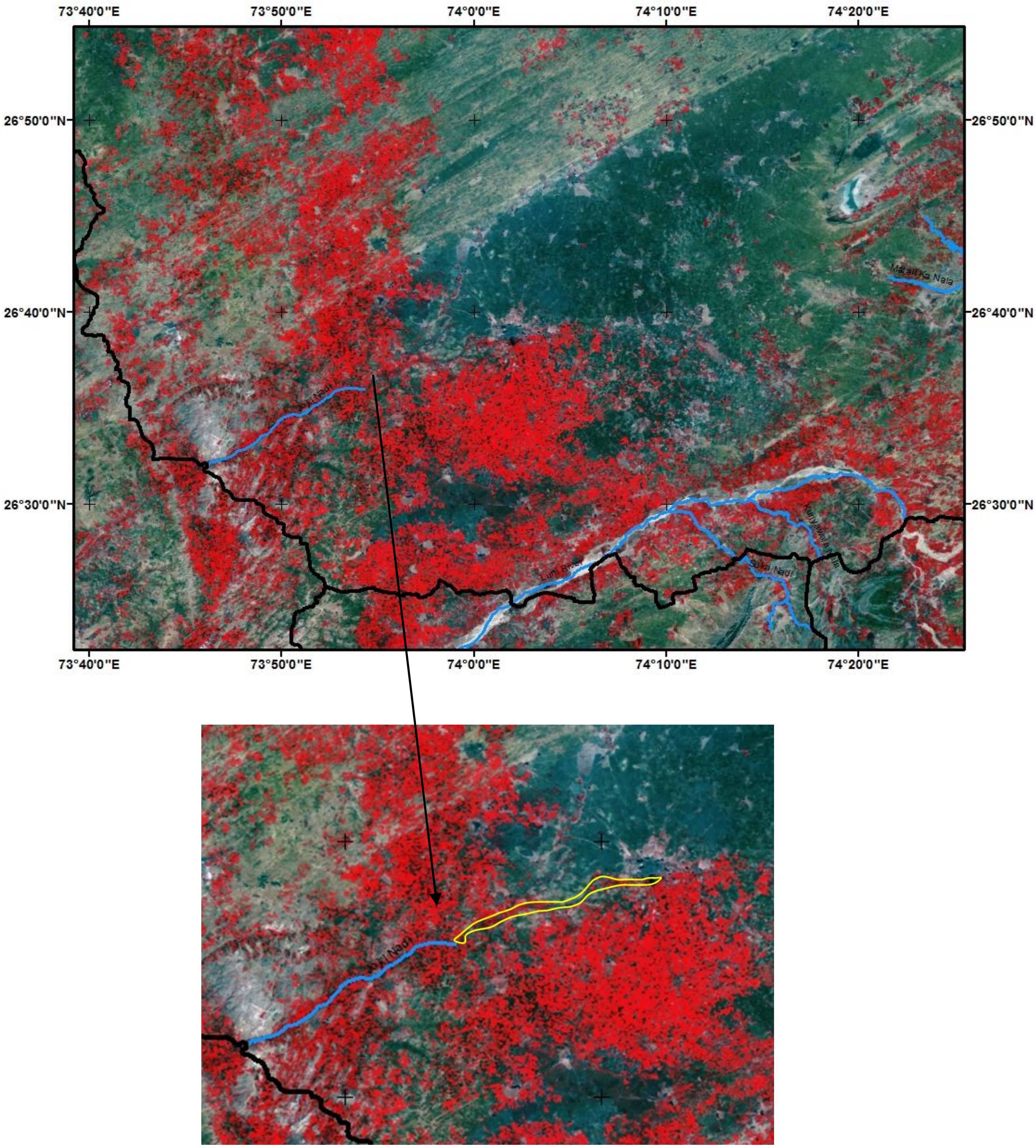


Figure 49: Histogram Equalized Image

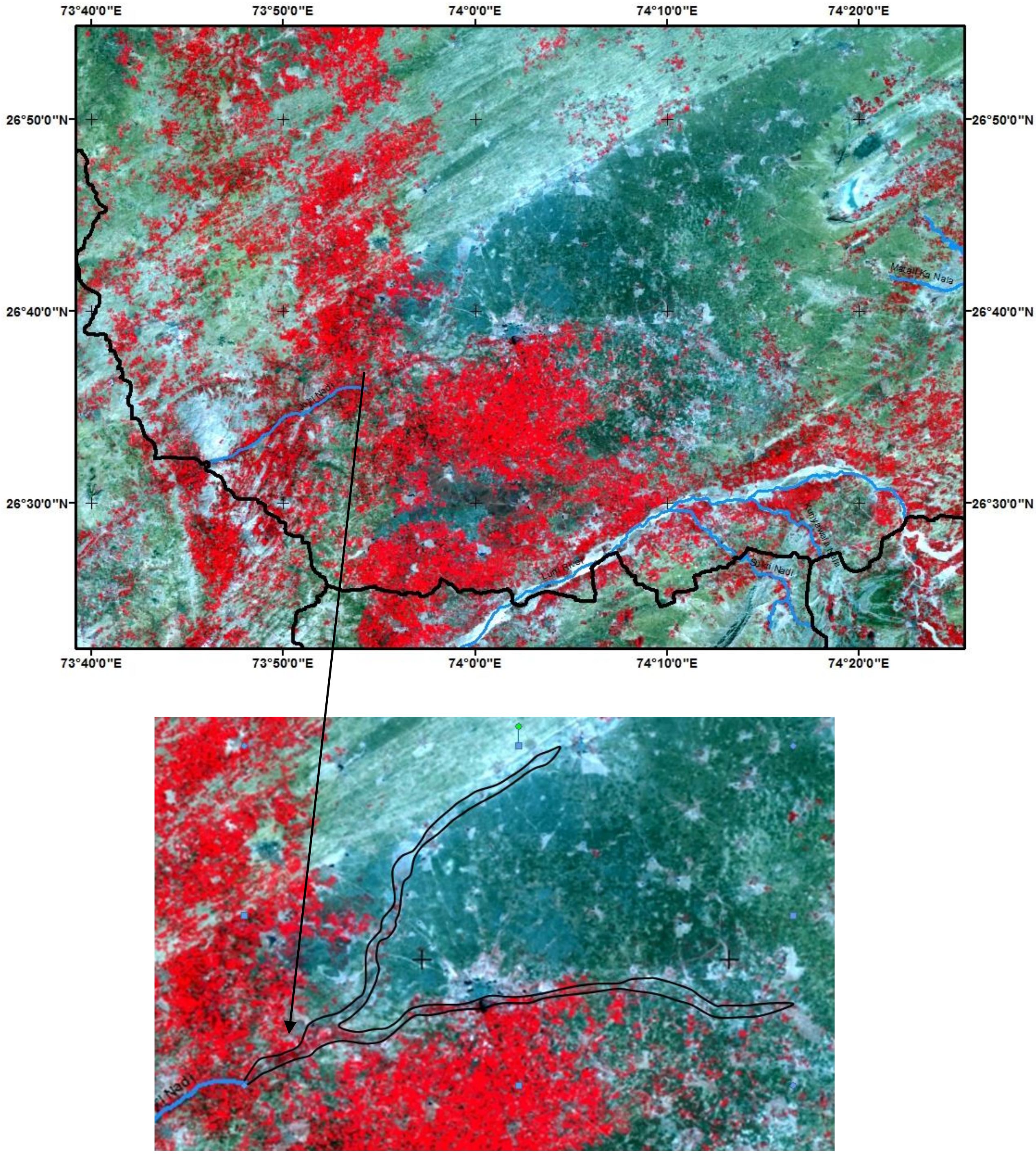


Figure 50: Linear Contrast Stretched Image

Multisensor Image Fusion

Image fusion is generally defined as the combination of two or more different images (may or may not be of the same resolution) to form a new image by using certain algorithm.

Along with the availability of multi resolution, multi temporal, multi sensor and multi frequency remotely sensed data from earth observation satellites; in remote sensing; multi sensor image fusion technique has become a valuable tool for Image evaluation.

Multi sensor Image fusion is used to integrate complementary data to obtain more information than can be derived from a single sensor data (Pohl 1996). Fused images provide more reliable results by combining different images with different characteristics.

Pohl (1996) discussed the various aspects of multispectral image fusion, which includes

1. Improved geometric correction.
2. Sharpened images.
3. Enhancement of certain features not visible or not clearly visible in either of the single data.
4. Use of multi temporal data to identify changes in the image.
5. Substitution of missing information in the image.
6. Replacement of defective data.

All around the world, many scientists used these techniques for better interpretation of remotely sensed data. These include Principal Component Analysis (PCA), Intensity Hue Saturation (HIS) approach, the Brovey method, Wavelet transformation, and the multiplicative method.

Detailed information of these techniques can be found in ERDAS field guide (1999).

Intensity Hue Saturation

This transformation effectively separates the spatial (I) and spectral (H,S) information from the standard RGB image.

Here the intensity (I) refers to the total brightness of the color, Hue (H) refers to the dominant wavelength of the light contributing to the color, Saturation (S) refers to the purity of the color.

Steps involved in the IHS transformation:

The three low resolution bands are first transformed into IHS space, and then IHS transformation separates spatial and spectral information from the image.

Intensity component is replaced by stretched higher resolution image while components of hue and saturation are oversampled to the panchromatic resolution.

Then the image is retransformed into its original space.

It is the standard image analysis procedure that works well for different spatial and spectral resolution data. Also it has become the most effective and controlled visual representation of the data.

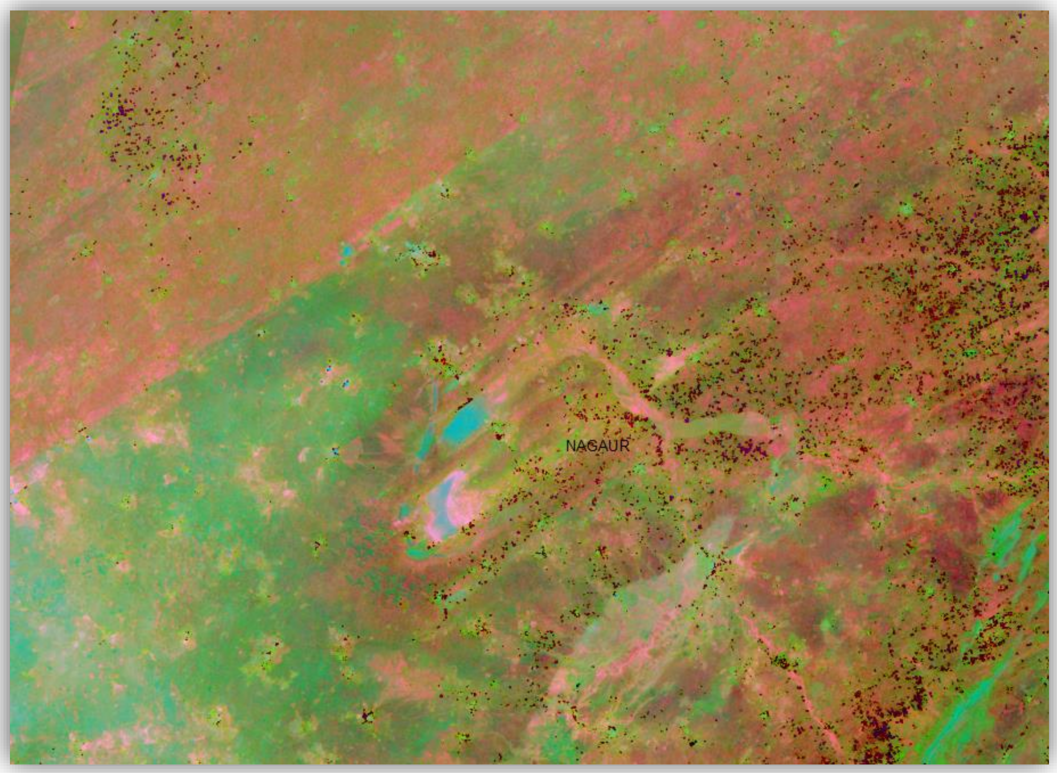


Figure 51: Moisture contained feature highlighted in IHS image

Water is well penetrated by the SWIR bands, and so IHS transformation using this band highlighted the features with good moisture. This helps Palaeochannels to be distinguished from non moisture contents and currently flowing river since river has high moisture than Palaeochannels so they appears brighter than Palaeochannels.

Principal Component Analysis

Principal component analysis is a widely used statistical technique that transforms a multivariate inter-correlated dataset in to a new uncorrelated dataset (Zhang 2002).

Principal component Analysis is the method of compressing redundant data in to fewer bands. Thus it makes the data more interpretable by reducing its dimensionality. The PCA bands are non-correlated and independent and hence are more interpretable than the source data.

It is a powerful statistical technique which is mainly used in the applications such as face recognition and image compression and also is common in finding patterns in high dimensional data. This method is good for visual interpretation and gives clear spectral values of the image making the feature identification easy (Pohl, 1996). PCA technique

PCA improves the image interpretation making the feature clearer that may not be clearly identified using individual data.

It offers dimensionality reduction by minimizing redundant information from multi sources.

The output data range remains same as input multispectral image.

The output obtained by PCA method is found spectrally less distorted as compared to IHS method by Chavez et al. (1991).

The physical signature of existing drainage, palaeo channels (due to moisture content) and vegetation got enhanced and a clear picture of these signatures is visible at few parts of Nagaur district. Comparison of these scenarios has been shown from figure 5 to figure 11.

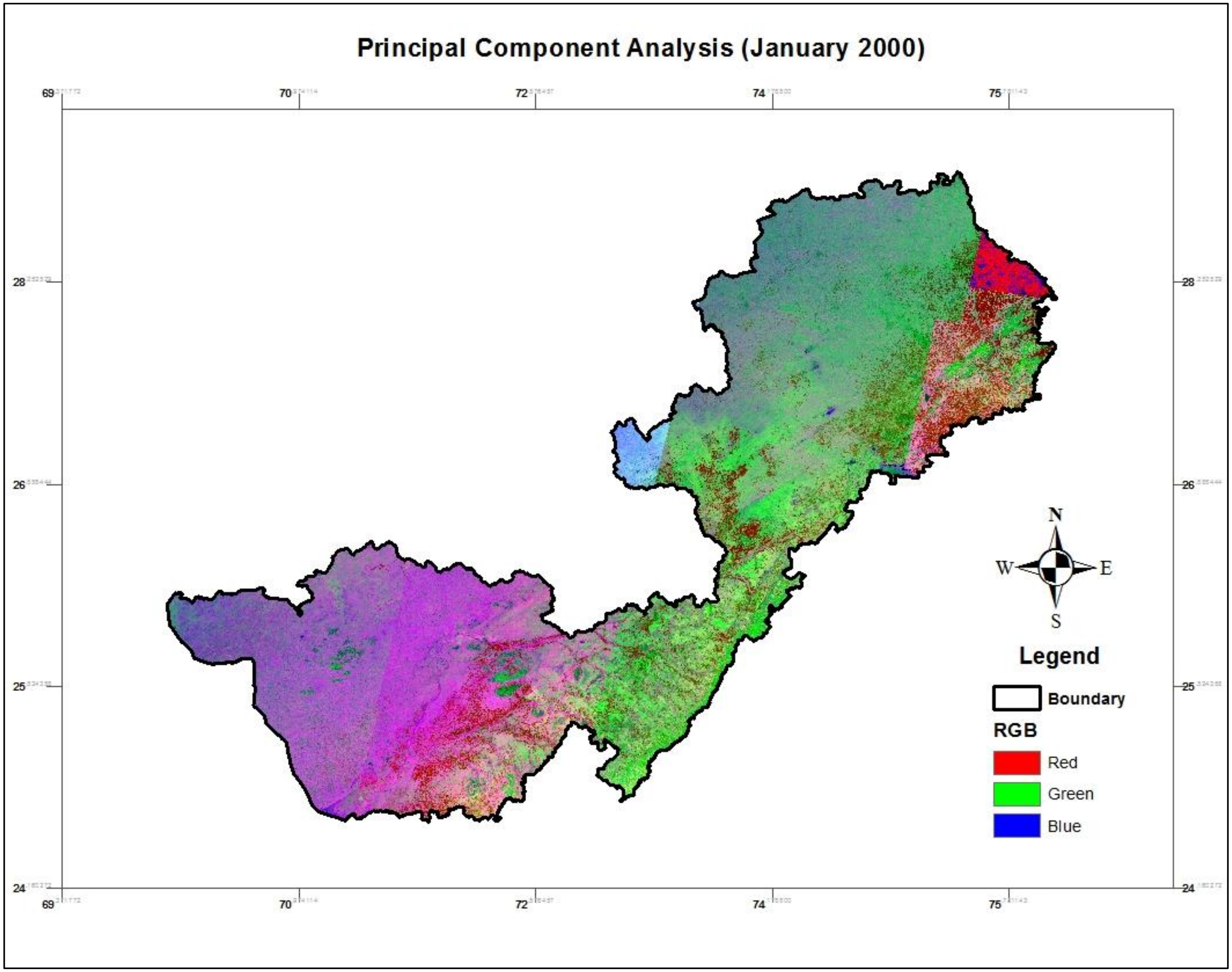


Figure 52: PCA image of January 2000

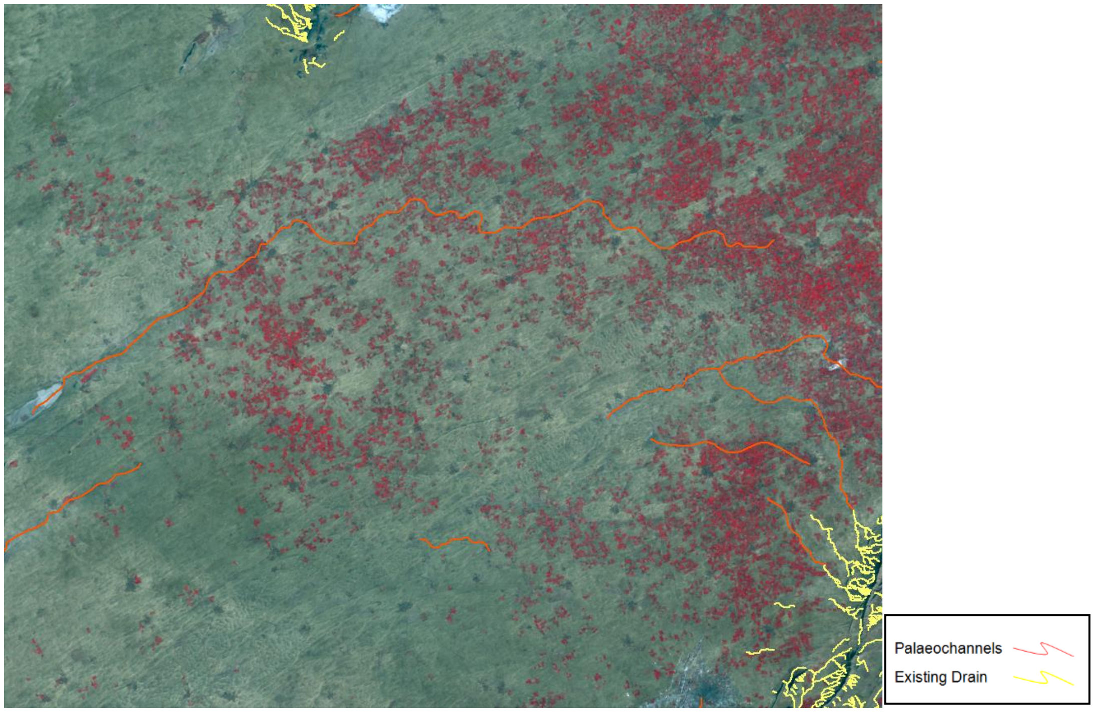


Figure 53: FCC image of Parts of Nagaur district

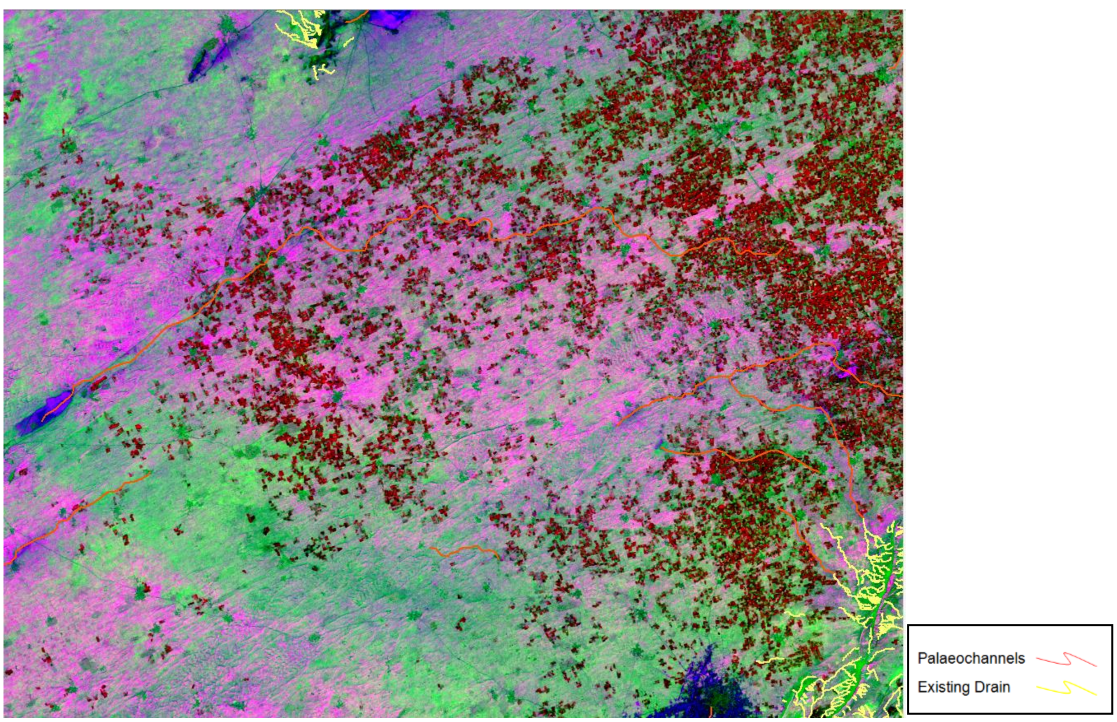


Figure 54: PCA image of Parts of Nagaur district

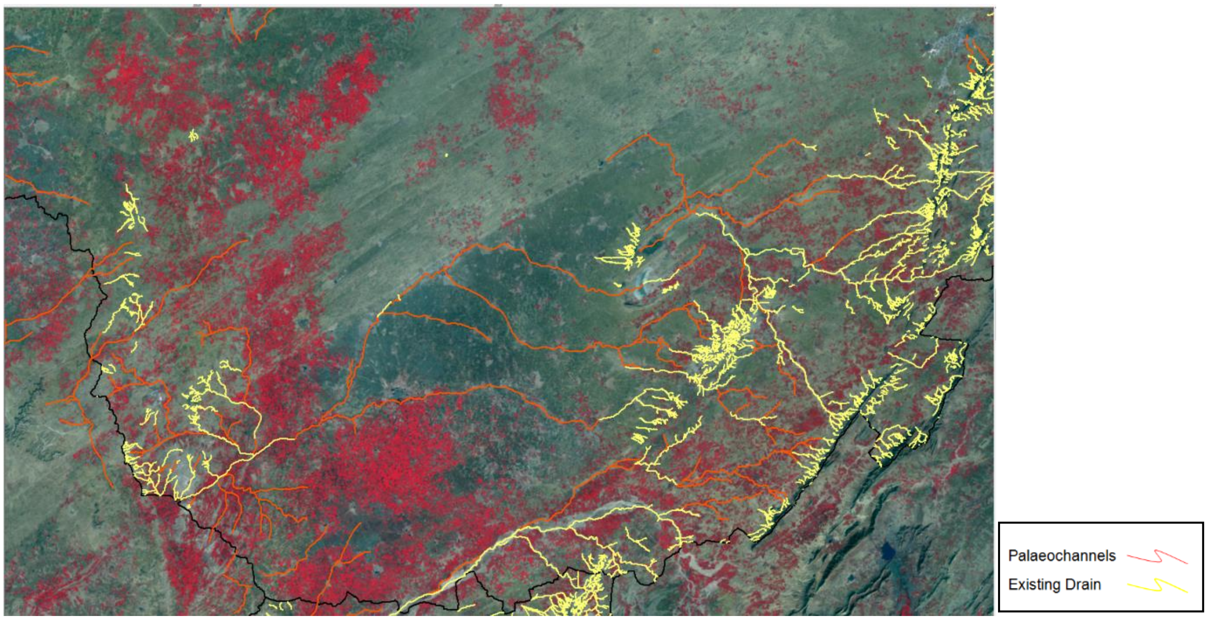


Figure 55: FCC image of Merta, Nagaur

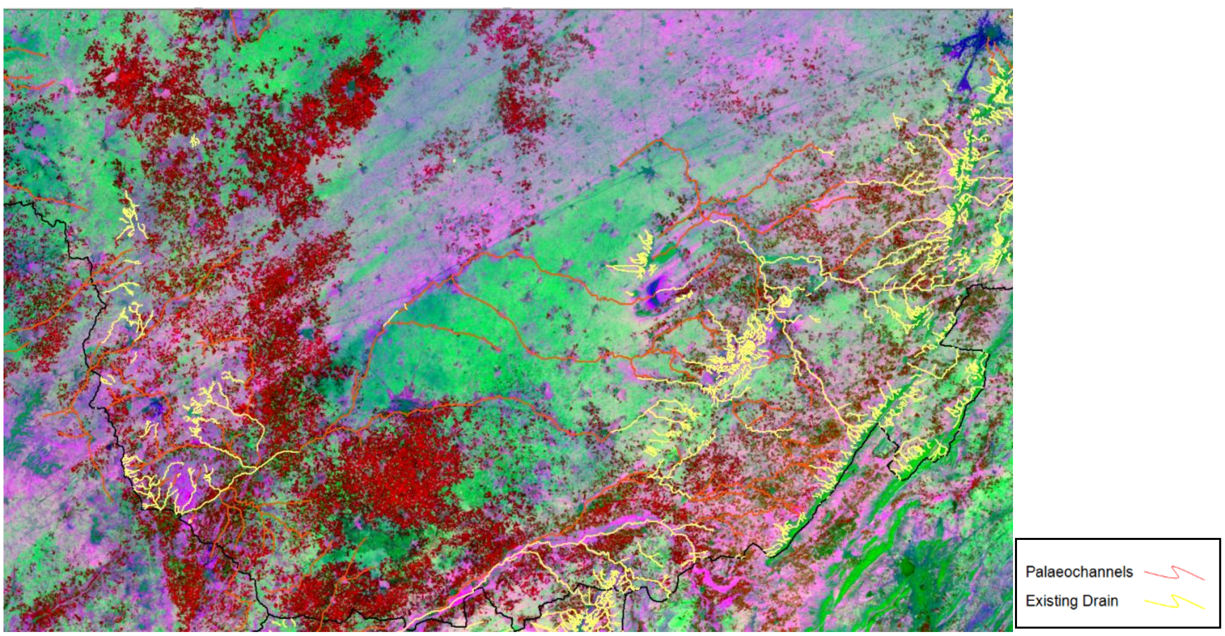


Figure 56: PCA image of Merta, Nagaur

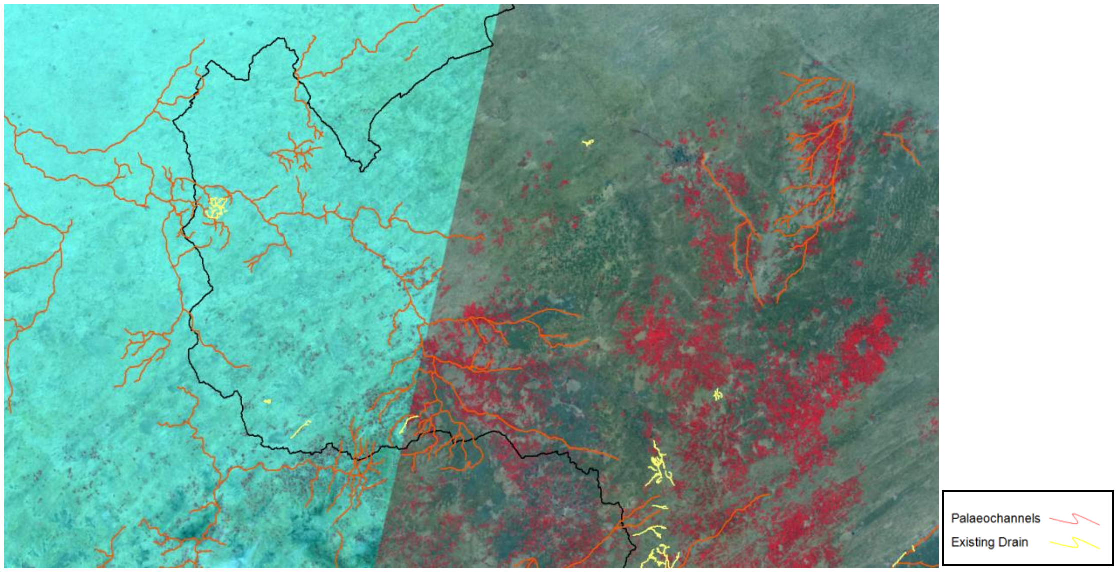


Figure 57: FCC of Parts of Nagaur District

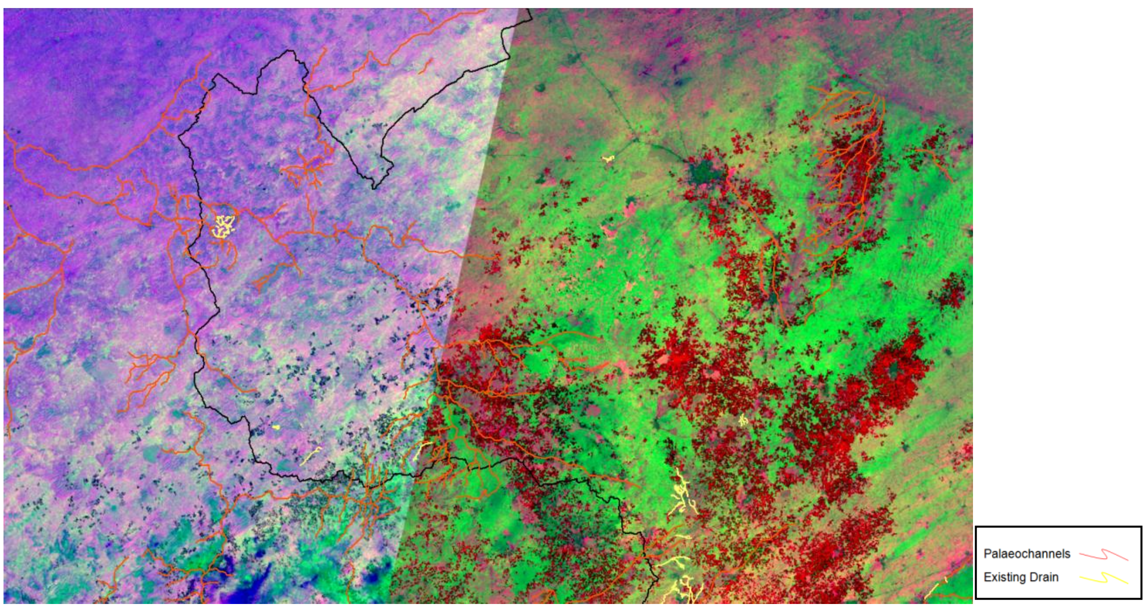


Figure 58: Principal Component Analysis

Chapter-6

Field Observation of Palaeochannels

This chapter deals with the process of verifying the accuracy of the palaeochannels map prepared by applying image processing and interpretation techniques. Such verification is referred here as 'validation' which was accomplished by using information derived from satellite imageries and by ground truthing.

Ground truth in remote sensing refers to the information collected on particular location. It allows the image data to relate with the ground real features. The collection of ground truth data enables calibration of remote sensing data, and aids in the interpretation and analysis of what is being sensed. In the present context, the ground truth verification was performed at some selected sites for validation of identified palaeochannels by field visits. All the findings at these sites are described in detail.

It is obvious that palaeochannels are the old river courses which were once a regular drainage system also had a well-defined valley. However, after losing their status as a drainage channel, perhaps due to river piracy and tectonism, the valley gets filled by sediments gradually. In the present study, palaeochannels are seen as low-lying linear sinous depressions. Field visits have indicated that wherever palaeochannels are present, at some places either water logging is observed or relatively lower elevation is observed along the palaeochannels compared to the adjacent sides. These channels consist of unconsolidated alluvium and at some places clay & silty soil is also observed. There were also loose sand deposits that are mainly filled by the streams and rivers in the depressions. Besides this there were many brick kiln industries which confirms the presence of alluvium soils which are deposited by streams and rivers. In False Color Composite image, a palaeochannels is visualized by crop marks, soil marks, enhanced moisture content and excessive natural vegetation. However, the depressions along the palaeochannels cannot be visualized in FCC for this DEM has been studied and the low depression areas have been identified and such areas have been chosen for the field survey.

The early Harappan has been involved in the minerals and metal economy. It has been noticed that sixteen furnaces were discovered at Mound F of Harappa. About 2000 metal artifacts were excavated in Mohenjo-Daro and over 1000 at Harappa. The metals were copper-bronze, gold, silver, lead and more rarely electrum. Besides this some belts and necklaces contain thousands of metal beads. Few metal tools were points, knives, chisels, and needles. Tin-Bronze alloying was used for the preparation of knives, axes, and chisels, whereas other metal additives such as points, razors and fish hooks were not used as tools. Thus the civilization is significantly a metal economy.

In 1977, R.C Agrawala made a remarkable discovery, the 60 flat copper Celts of 20 to 25 cms were found from a ‘hoard’ in “Neem ka Thana” in Sikar district of Rajasthan. Examination of these copper Celts suggested that they were associated with the Indus Valley Complex. The place Neem ka Thana is about 15 kms from Ganeshwar and the copper axes found here had been made more than 4000 years ago. This site is about 250 kms from Kalibangan and 160 kms from Bhadra.

River Kantli is one of the major rivers of pre-Harappan period. Flowing towards east and across Jhunjhunu town, it now dries up near Rajgarh in the Churu district. It used to join the Drishadvati River in the past somewhere between Nohar and Bhadra in the North from where Kalibanga is hardly 50 kms, and so it was easy to move towards Kalibanga from here. At some places Kantli River (2-3 kms wide) must have made possible movement from Ganeshwar to Kalibangan and Indus centers of the west. Interpretations from Landsat imagery suggests two streams of the river Kantli from Rajgarh, one flowing towards Nohar Bhadra and other towards Hissar. Both these routes are now marked by the railway tracks. One of the important sites of the pre -Harappan period is found at Ganeshwar situated on the source of one of the streams of Kantli River. In 1979, explorations and excavations at Ganeshwar and its surroundings yielded to rich collection of copper objects, which is about 1000 in numbers. These include 60 flat Celts, more than 400 arrow heads, 50 fish hooks, dozens of blades, spear heads, nails, bangles, chisels, etc. all of these belong to the Indus context and not a single specimen is of the copper Hoard type of the Ganga-Yamuna doab. Kurada Celts with four marks is likely to be prepared in the Ganeshwar region. Kurada was situated on a trade route which runs towards south west across Ganeshwar along the path Kurada-Pokharan-Phalodi-Jaisalmer-KotDiji, etc.

Following are the findings of the field investigation

Initially entire area under investigation is divided into two major zones. One is NW flowing part of the area consisting of drainages related to Kantli River basin which started from Aravalli hills in Sikar district and flowing towards NW across Sikar, Jhunjhunun and Churu districts. During field investigations there was a surface drainage found up to Sulkhania of Jhunjhunun district near Rajgarh were it seems that river streamed over a wide area and the flowing water absorbed within this flat and alluvial soils. The river water sometimes reached near this place i.e. Sulkhania even now, beyond this surface signatures are very weak and sometimes difficult to understand the course of drainage but distribution of clay and silty soil in the direction towards the Ghaggar belt across the Hanumangarh district gives a fairly good idea about the extension of Kantli river up to Ghaggar belt. In this area the fluvial deposits of clay and silt are being excavated at numerous locations for making bricks which is a major occupation of the local people of the area. The idea is further extended by the fact that best quality of bricks are being prepared in the area between Sulkhania to Ghaggar belt specifically around Rajgarh, Bhadra, Nohar and so on. The alignment of brick producing zone is extended towards SE to NW direction along the stipulated course of palaeo drainage of Kantli River (Figure 59 a, b, c, d). Apart from kilns there are numerous culverts, bridges, road spill over's location of very old villages (more than 250 years) were also observed along the entire river course available on surface and also beyond that (evidences in the form of photographs attached as annexure and the GPS locations of the individual observations are shown in figure 1). During field investigation there are many such areas having the properties of fluvial deposits and series of scattered evidences in the form of surface drainage, old fluvial silts and clay deposits series of wells and series of ponds are also found at numerous locations around Pilani, Rajgarh, Chirawa area which seems to be the tributaries of the large network of drainage associated to Kantli river. Discussion with the local people were also done during field investigations in villages who also confirms that they heard about rich drainage in their areas and they also confirmed that there was very shallow water level (10 to 20 m) available in the area which has gone down with the time even now the quality of water is potable. Otherwise in the surrounding areas water quality is not that much good which they observed in the areas of probable drainage. At this point of time these disjointed drainages are in the form of local water flows ending into large ponds or local depressions. The agriculture pattern of the area is not much evident of availability of palaeochannels.

(a)

(b)

(c)

(d)

Figure 59: Figures (a), (b), (c), and (d) depicts the soil coverage favourable to river depositsbeing used to make bricks and so there are many brick kilnindustries along the path of identified palaeochannels on both the sides of roadwith good vegetation cover and having moisture in the soil.

Other promising area found during the field investigation is near Mandawa in Kuharu village from Nawalgarh-Dundlod-Mukungarh-Mandawa-Kuharu. Where some faint evidences of Palaeo drainages are observed in the form of elongated and narrow deep valleys among sand dunes high moisture and high vegetated areas, very old habitations, clay soils under the high dunes which are being used for making bricks, river meander scars near dundlod fort and railway station, etc are observed.

Investigating team interviewed some of the villagers to confirm that these valleys are associated with drainage flowing from Singana near Khetri and one another river started from Udaipurwati hills and flowing through Nawalgarh-Mukundgarh, etc. One of the villagersBanwari Ram during interview said that Kantli river (2-5 kms of width) around 250 years ago used to originate from Singhana village and used to flow near Kuharu village (Figure 60a, b). This river discontinues to flow due to many manmade interventions created by local people to store water for their use. It is also observed that during heavy rain even now water used to flow in the same valleys but in discrete form in sand dunes either in thick alluvium ponds or other kinds of water bodies. Numerous pukka water harvesting structures were also found in identified channels.

(a)

GPS location: 75.14775E, 28.09224N (b)

Figure 60: (a) and (b) shows the River valley at Kuharu near Mandawa village in Churu district

Another villager Vilas Singh, a pujari of Gogaji temple of Mandawa village said that Mandawa village is the only temple between Fatehpur and Jhunjhunun, it has a well which was constructed about 160 years ago during the Vikram Samwat time in 1916, at that time it had 100 feet of water level but at present time the well is dried due to increase in fluoride content and other natural phenomenon. A palaeo channel was identified about five kms from Mandawa Village (Figure 61a, b, c).

(a)

(b)

(c)

GPS location: 75.14775E, 28.09224N

Figure 61: (a), (b), and (c) shows the extension of river valley

GPS location: 75.53718E, 28.2011091N

Figure 62: River bed near Sulkhania Bara village

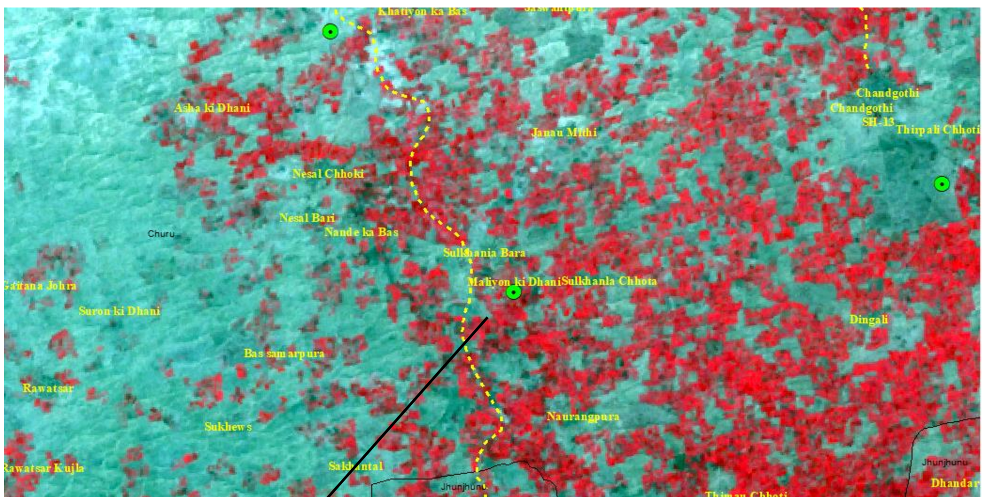


Figure 63: Extension of the river bed near Sulkhania Bara

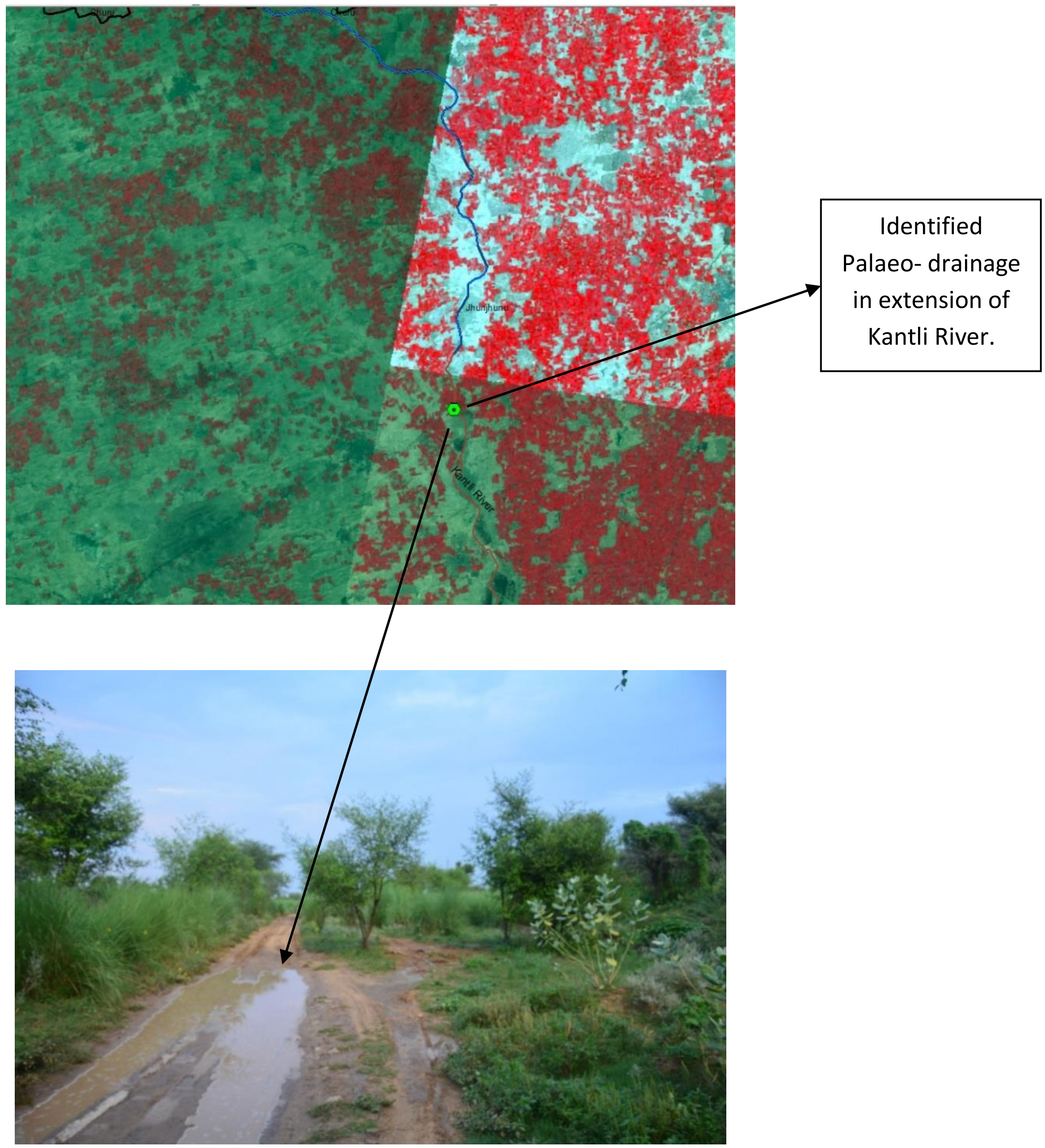
Local people confirmed that this place (Figure 63) near Sulkhania Bara village in Churu is the last point of river Kantli heard by them. There are good crops near the channels of Kantli north of bagar town near Khudana village (Figure 64, 65). There are also dry drainage networks near Baktawarpure village of Jhunjhunu district and water flows in rainy season. (Figure 66, 67)

GPS location: 75.53718, 28.2011091

Figure 64: Good vegetation cover along the road

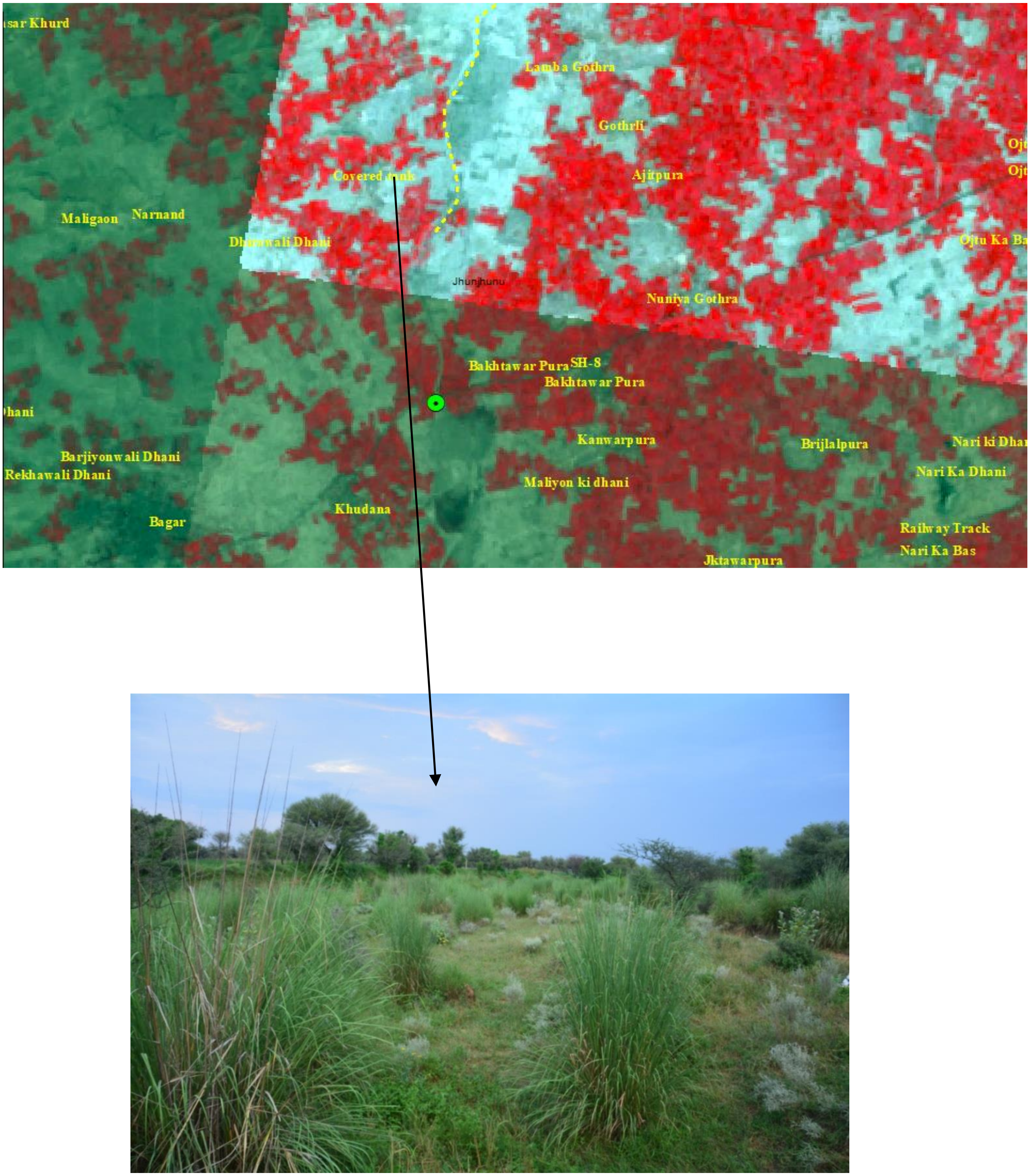
GPS location: 75.53718E, 28.2011091N

Figure 65: Alluvium soil with good vegetation cover



GPS location: 75.53718E, 28.2011091N

Figure 66: Water logging along the old river course associated with good vegetation



GPS location:75.53718E, 28.2011091N

Figure 67: Undulating slope

GPS location:75.52048E, 28.41086N

Figure 68: Mud barrier made by local people in between the drainage path

Figure 69: Unconsolidated soil cover

Figure 70: Loose Sandy soil cover with good natural vegetation

Figure 71: Good Alluvium soil cover that is filled by stream or river migration

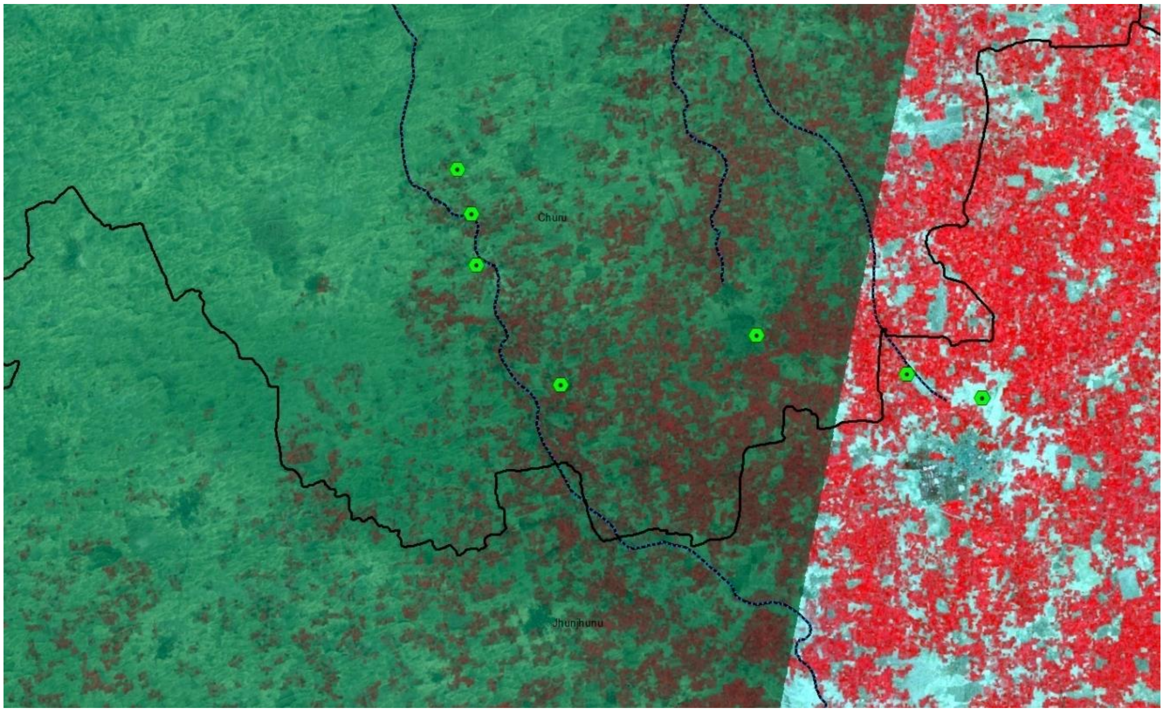


Figure 72: Selected sites for field validation in Jhunjhunu-Churu district

Figure 73: Layers of good soil deposits with water logging along the path of palaeochannels being traced

Figure 74: Extension of waterlogged area shown in figure 13
Having brick kiln industry on the one side
And river bed on the other side

A villager Sardar Mal of the village Jaitpur was interviewed during our field to Sikar district. He was born in 1958. He said that there was water on the surface during his childhood days in 1960 to 1970 where he used to play with his friends in Nala. According to him the surface water lasts up to 1981-82.During this time, there was abundant water to support agriculture and the vegetables like tomatoes, kakdi, etc were grown. There are signatures of drainage in the area and underpass of the roads for flowing of water (Figure 75 and 76 a, b, c) But in present scenario, there is no agriculture due to lack of water. As per the local people, the reason behind the water depletion is the construction of wall boundaries and nearby harvesting activities, which led the flow of water discontinue in between and hence the water got decreased. Another main reason is the decrease in amount of rainfall in last two three decades.

Before 1981, the water level was 5 to 6 feet above the surface which has been depleted to 270 feet below the ground surface. Nowadays, rotary machines are used to drill the drinking water and there left only two sprinklers for other purpose. Here less to no agriculture is now supported by ground water.

Figure 75: The place near Jaitpur where the interview was taken

(a)

GPS location: 75.7287E, 27.14053N (b)

(c)

Figure 76: (a) walls constructed in between the flow of drainage, (b) school in between Nala, (c) Nala below the road for the passage of water

There are good evidences of soil erosion by fluvial activities near village Morija in Jaipur district. It seems that these drainages are associated to palaeo channels of Anokhi river starting from samod hill and finally merge in to salt lake of sambhar in Jaipur district (Figure 77a, b and 78)

(a)

GPS location 75.7566E, 27.15983N (b)

Figure 77: (a) & (b) shows the impressions of old drainage on one side of the elevated area

GPS location: 75.7287, 27.14053

Figure 78: Construction on other side of the elevated area in between the flow of drainage

An intensive network of palaeo drainage is visible on satellite image in discrete forms around Sanchor town of Jalore district. In general these palaeochannels have very few surface signatures due to the fact that the area is under intensive crop and the target areas are covered by vegetation.

Figure 79: Place of interrogation near Hadater village

One more palaeo drainage have been identified in North direction of the above mentioned palaeo near Hadater village which flows through Dhamana village and meet the existing network of Palaeo drainage near village Palri (Figure 79). A villager Vikram Singh of the village Dhamana confirmed that many small drainages originating from nearby hilly areas and travel parallel to earlier palaeo drainages and meet her

Figure 80: Embankment made by local people to stop the flow of water for their use

An embankment for local storage has been found during field observation and the area of the drainage path was sand dominant, all these field evidences are shown in the field photographs. Also intermittent surface ponding has been observed along the path of this palaeo drainage (Figure 80).

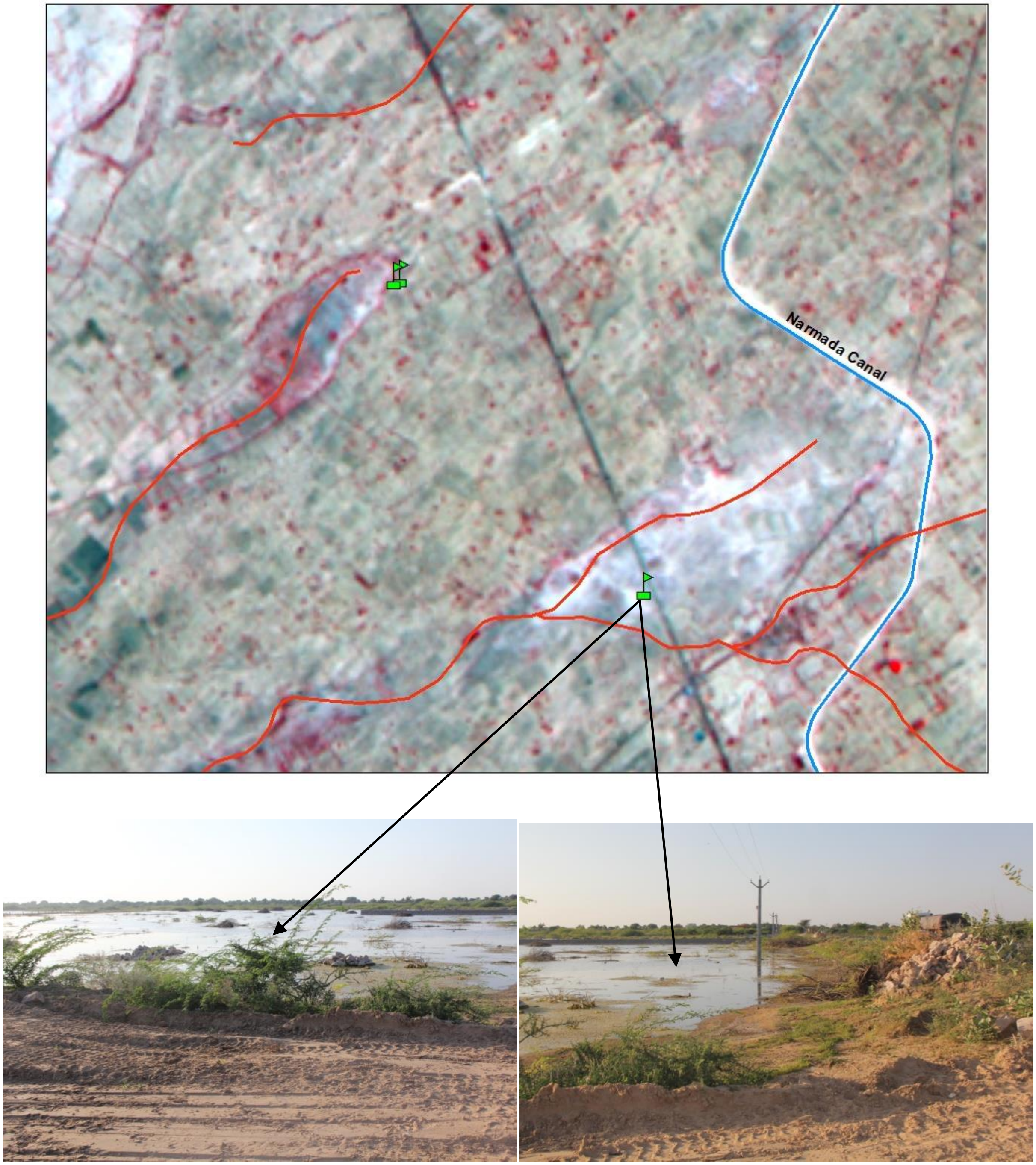


Figure 81: Playa near village Dhamana Village

Big saline playa of approximate 7 to 8 kms of width surrounded by babool and other weeds making it inaccessible has been found during our field observation (Figure 81). A palaeo channel originating from large distance and from East to south west direction flowing through this playa has been identified in the satellite image. Field investigation confirmed that this palaeo meets the existing drainage near Chhitalwara village. Nearby resident tribes said that the area gets seasonal water logging during heavy rainfall (Figure 82).

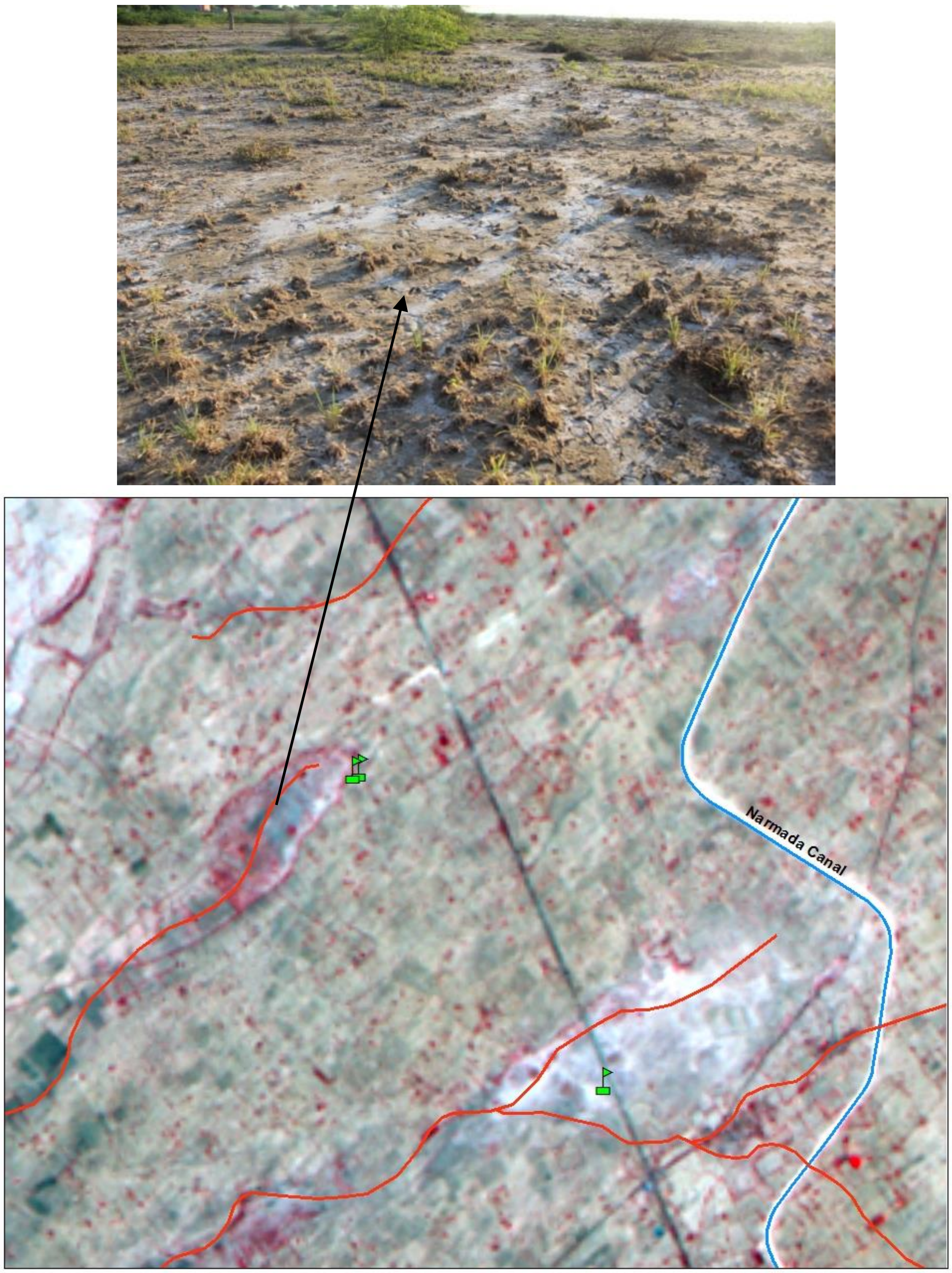


Figure 82: Saline playa surrounded by babool making it inaccessible

There are many places showing small local surface drainage associated with playas, deposition of Calcium carbonate in and around playas, salt present in playas, deposition of clay soil of fluvial origin, in comparable low lying area. At places there are well defined wide and narrow valleys.

Elongated pattern of heavy vegetation and long wide valleys are the evidences of palaeo drainages which was flowing in historical time. This has been shown in the following field photographs (Figure 83).

Figure 83: Saline playa surrounded by vegetation

Figure 84: Calcium Carbonate noodles in the soil

Figure 85: Drainage flowing under the road

Figure 86: Undulating Surface

Figure 87: Physical signature of the drain

Figure 88: Physical signature of the drain

Figure 89: Physical signature of the drain

Figure 90: Lime stone on the surface found in Nagaur district

Limestone contains some marine particles which is only possible if there may be any river or other drain flowing in that place during BCE.

And so the areas where the limestone is found during the field observations can be correlated with the interpretated palaeo drainage and the results supported the existence of Palaeo drainage in association with the lime stone. The associated figures show the places where limestone is seen on the surface somewhere in Nagaur district (Figure 90)

Chapter-7

Integration of Remote Sensing, Thematic and Field Analysis

Zone wise Analysis of the obtained results

The area under study is characterized by wide spectrum of landscapes including pediments, undulating fluvial plains, hillocks, Aeolian sand dunes, palaeochannels, etc. Based on the physical characteristics and field investigations and with respect to the project objectives (identification of palaeochannels), five potential zones were observed and the obtained results were correlated with the structures (lineaments), playas, existing drain and vegetation patterns, etc. Depending on presence of palaeo-channels, ground water availability, playas, vegetation pattern and other parameters these zones were further classified into potential and non potential zones of palaeo channels.

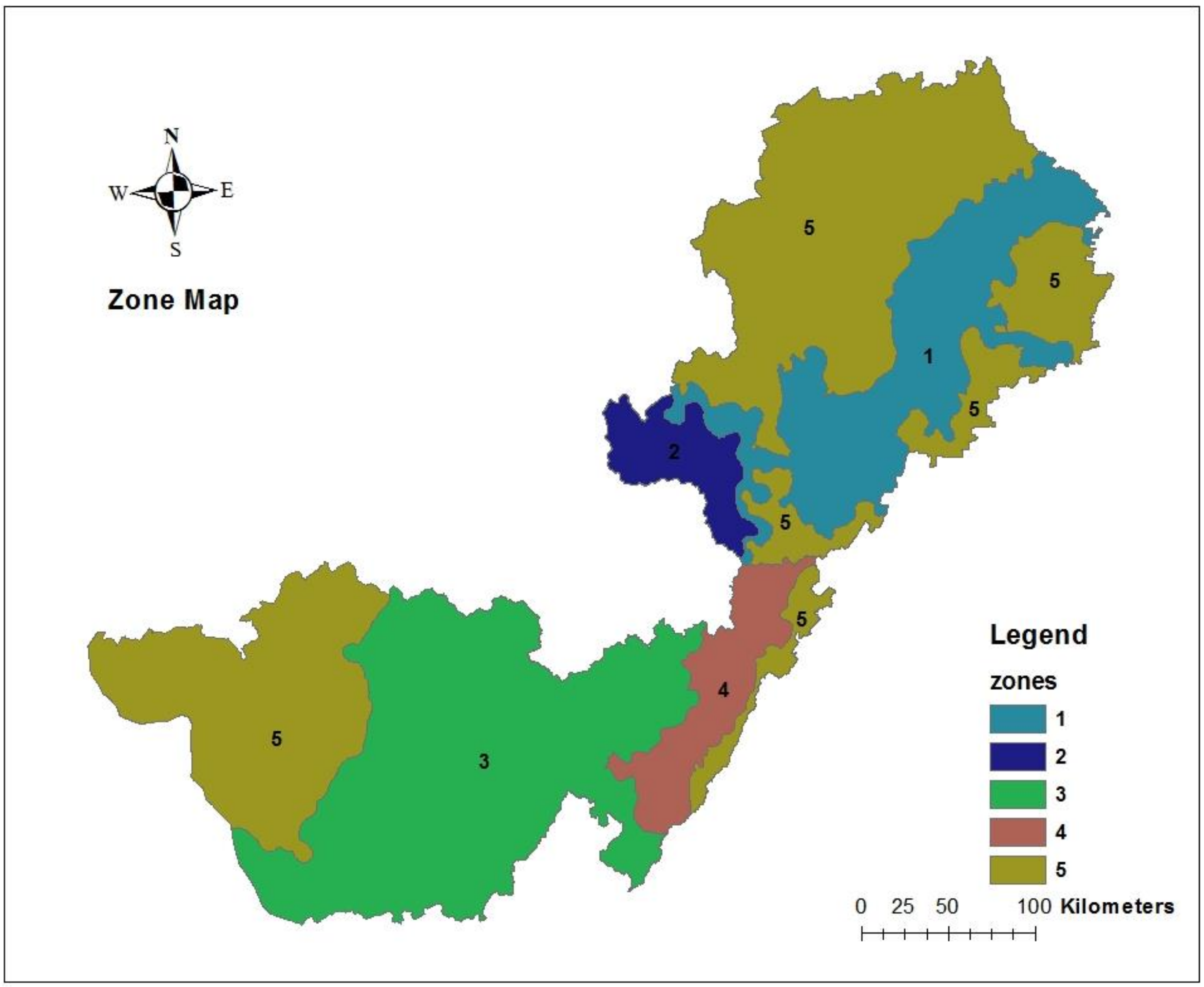


Figure 91: Zone map of the study area

Zone no one, two and three are the potential zones of the study area which includes NE to SW part of Sikar&Nagaur district, Eastern part of Jhunjhunun, south western part of Nagaur district (containing inland drainage). Also this include parts of Barmer, Pali and Jalore districts where palaeo drainages drain into Luni river which meets Rann of Kutch in southern part of the study area. The rest of the study area falls under non potential zone where no significant palaeo drainage signatures are found.

Potential zone of Palaeochannels:

Zone 1:

This zone includes Eastern part of Jhunjhunun - Khetri and Udaipurvati, NE to SW part of Sikar district – Neem Ka Thana, and NE to SW part of Nagaur (Figure 92)

NE part of Nagaurdistrict is mainly composed of denudation hills and older sediments drained by many small rivulets in western and south-western directions. Most of flowing water here is initiated from these Denudational hills, associated pediment and other elevated landform areas. Soil of this area is composed of material from the flowing rivers in the nearby areas, which is mainly silt and clay material flown by the rivers. Recharge conditionsare good as a result water level is good and shows good correlation with rainfall forming continuous belt from north, central and west part of Sikar and central part of Nagaurdistrict have better ground water availability with good water quality. During our field investigations we found that in this zone there are many small rivulets starting from comparatively elevated areas flowing in various directions and generally absorbed in sandy alluvium or aeolian sands. It seems that these rivulets collectively make an extensive system of drainage related to a big and old river network. There are many valleys and flood plain and thick layers of older alluvium which are good evidences of extensive network of palaeo drainage. Satellite images shows that there are good vegetation pattern in this are due to the impact of good ground water availability. This area also shows good correlation between rainfall and water table fluctuation which is also an evidence of presence of old drainage system present in the area.

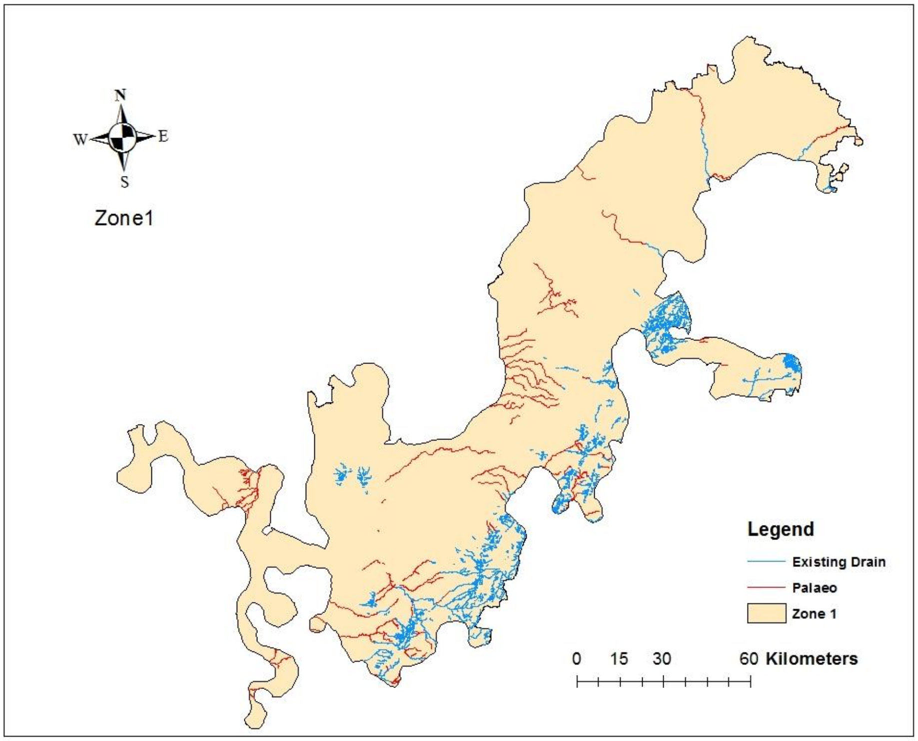


Figure 92: Existing Drainage and Interpreted Palaeochannels / Old dried up drains in Zone 1

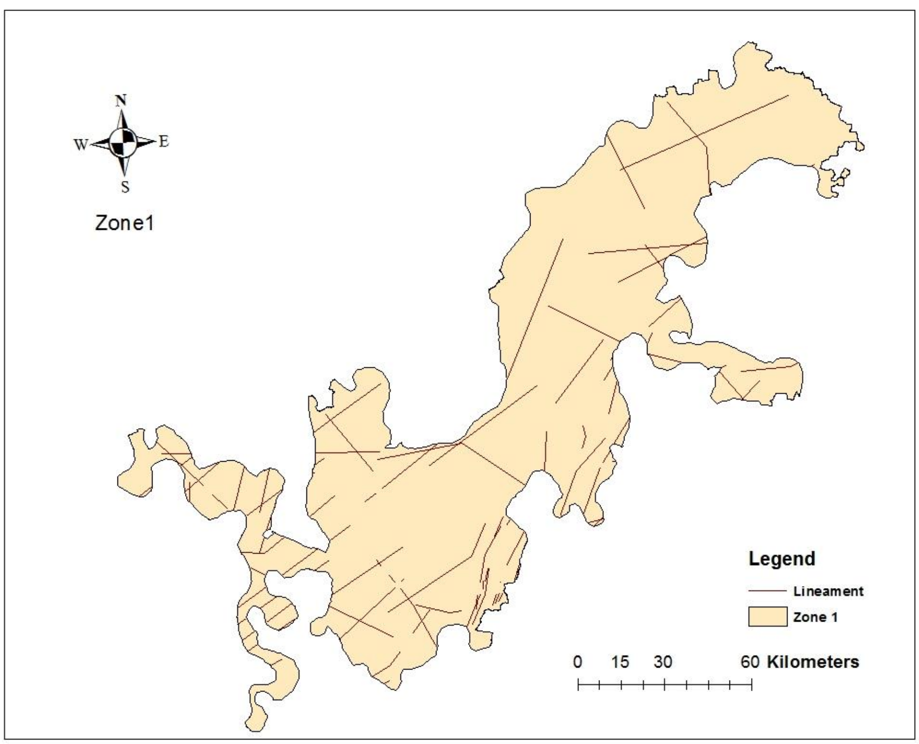


Figure 93: Lineaments in Zone 1

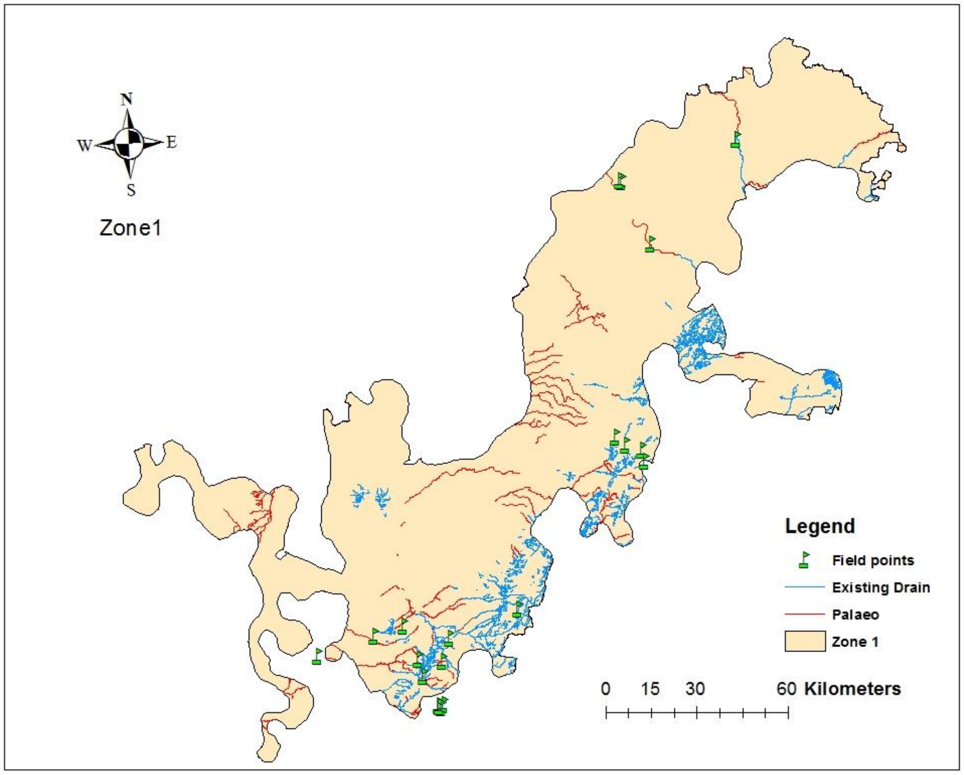


Figure 94: Field points in Zone 1

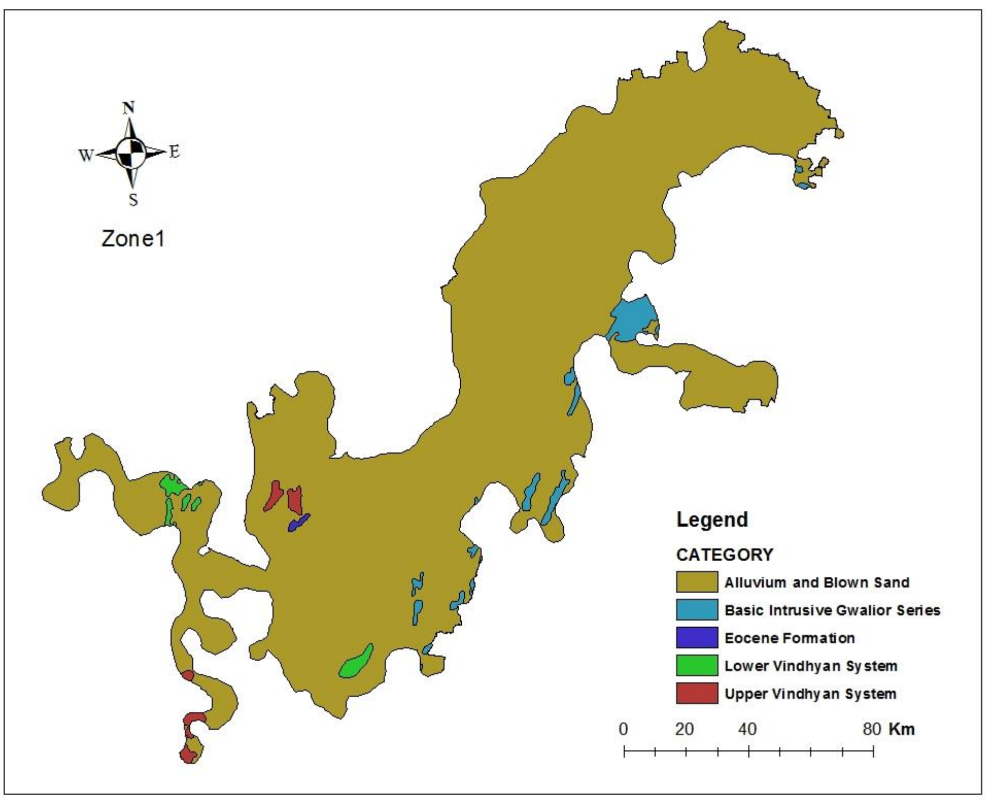


Figure 95: Geology of Zone 1

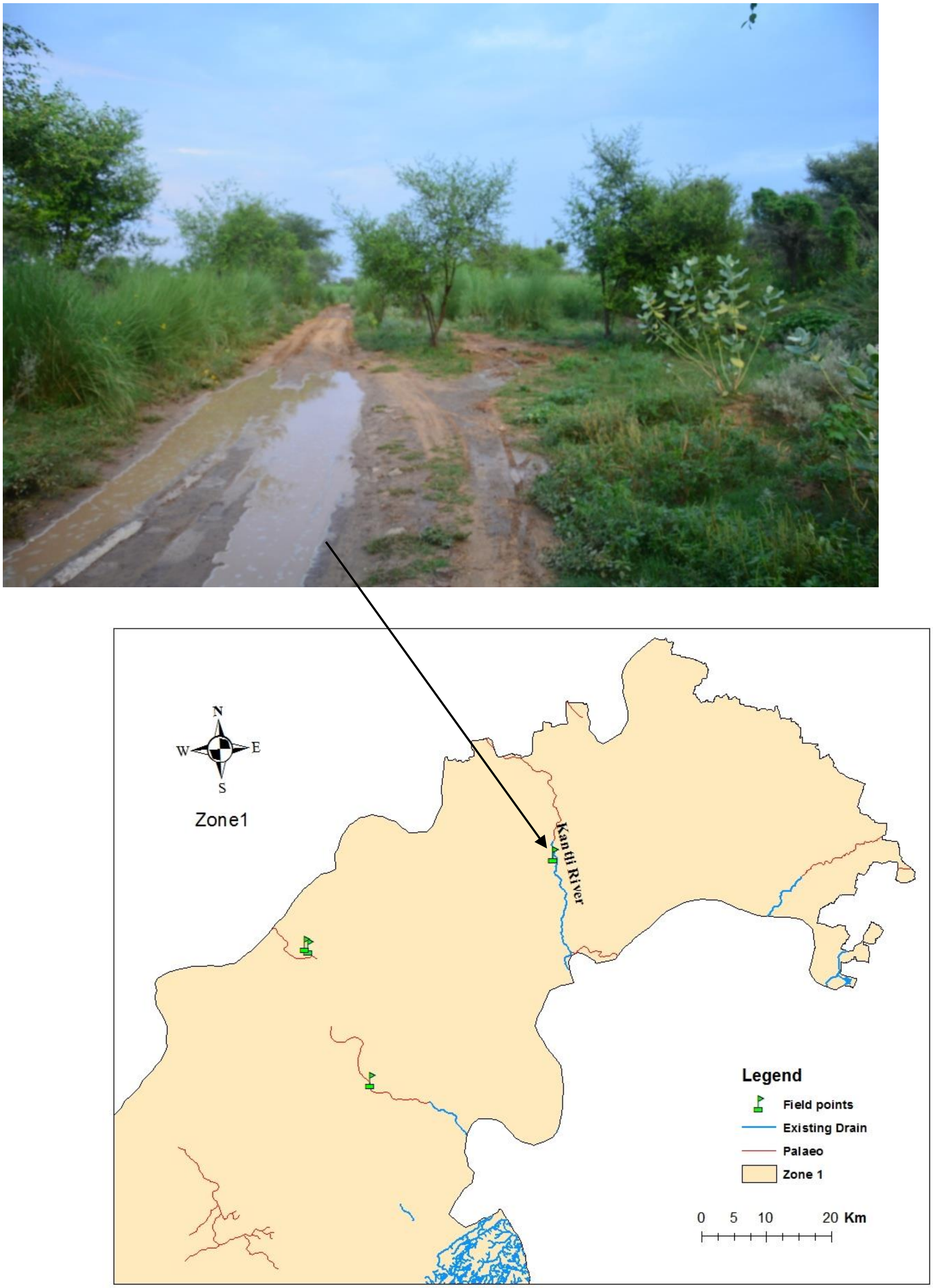


Figure 96: Water logging along the old river course associated with good vegetation

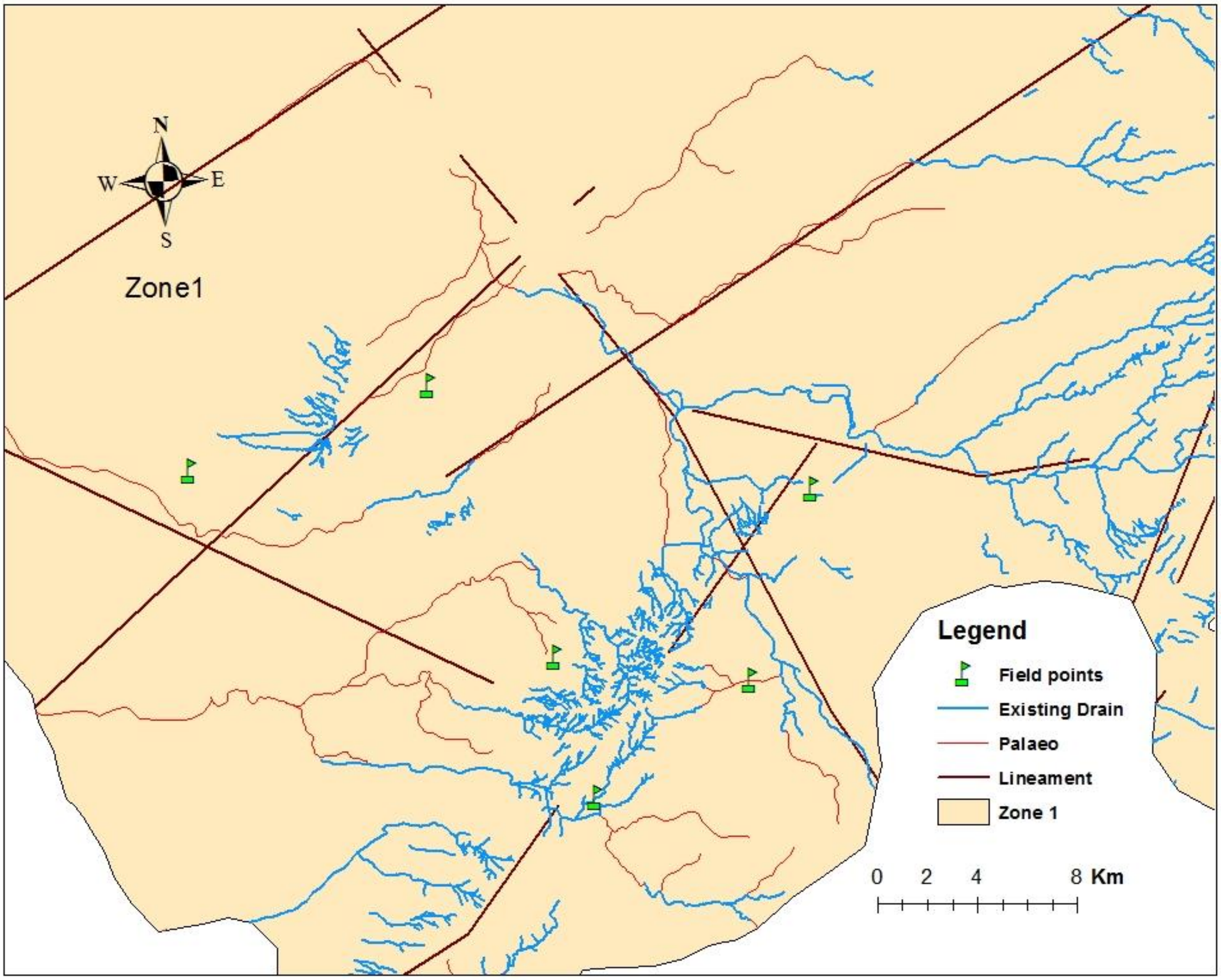


Figure 97: Correlation of Lineaments with identified palaeochannels

Some area of Jhunjhunu district falls mainly in Shekhawati basin while North western part falls outside the basin. The south and east of hill ranges in Khetri area is drained by Dohana River. All the rivers and Nalas are ephemeral in nature and flows in response to heavy precipitation during monsoon. All the rivers, dry nallahs, dry valleys are flowing or seems to be flowing in western and north western directions, forming two river systems one flowing towards west through Nawalgargh, Mukandgarh, mandawa and beyond and another from udaipurwati and khetri area through kintli river which goes up to sulkhaniya village between pilani and Rajgarh towns. there are very clear evidenses of flow in this area. Interview of local people and histories told by their forefathers shows that this river (Kantli) was a big river and used to reach to Ghaghar bed in ancient times. Being Desertic terrain particularly in north eastern and north western part of the district has inland drainage. The area in the south eastern part is drained by Singhana River and a small area in south western corner of the district is drained by Budhi Nala. While North- Central-West part of Jhunjhunu district has good groundwater potential due to nearby network of rivers. There is good association of structural features in Jhunjhunu and Sikar districts (Figure 97)

Generally, Palaeo channels are associated with the structural features like faults and lineaments. (Figure98)The figure clearly indicates the association of palaeo- drainage with the lineaments and the flag points shows the area of field investigations which also confirms the presence of old drainage at these points. The area shown in the figure is the SE part of Nagaur district, it consists of good network of existing drainage and there are two saline playas which are further strengthen the presence of palaeo channels. Earlier these are part of channels but with the extinction of drainages these remains as in depression areas but these playas are elongated with the identified palaeo drainages. (Figure no.98).

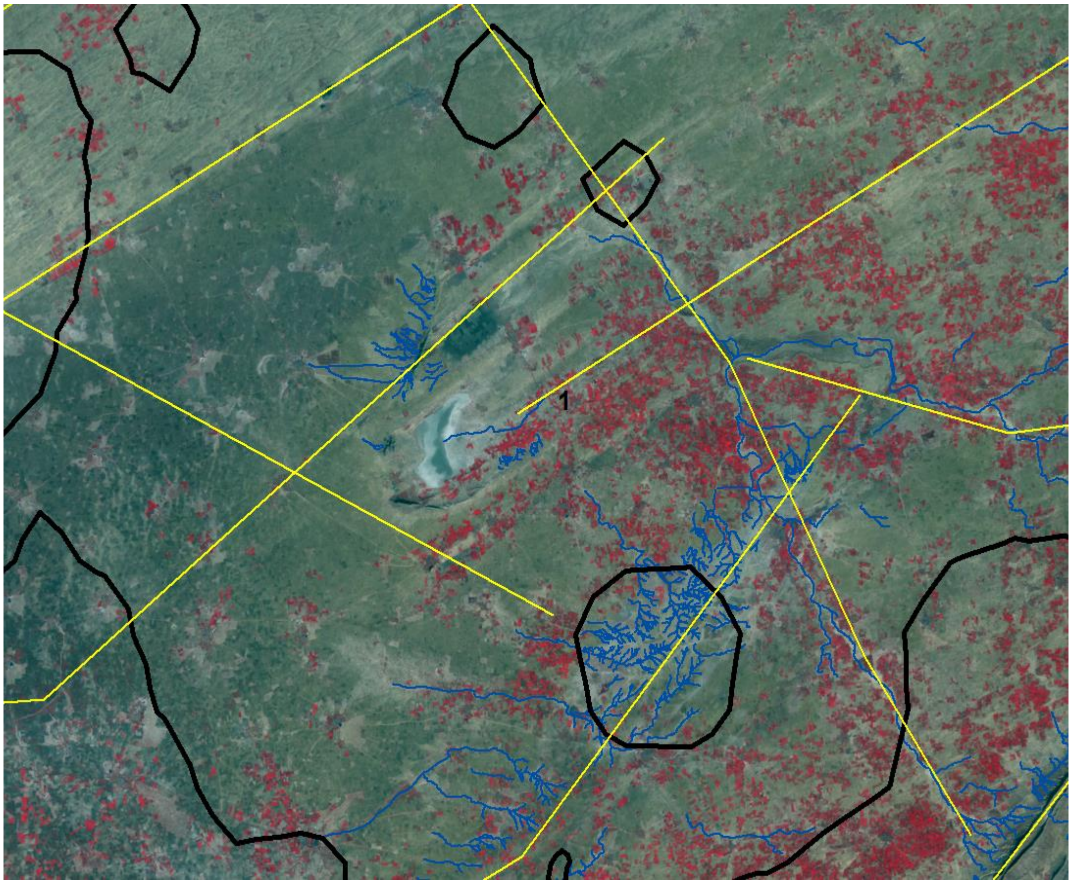


Figure 98: Playas located along the path of palaeo drainage

Zone 2:

This zone includes south-western part of Nagaur district having inland drainage and seems to be approaching towards an identified path of ancient Saraswati River by some of the earlier researchers. (Amal Kar and Rajawat)

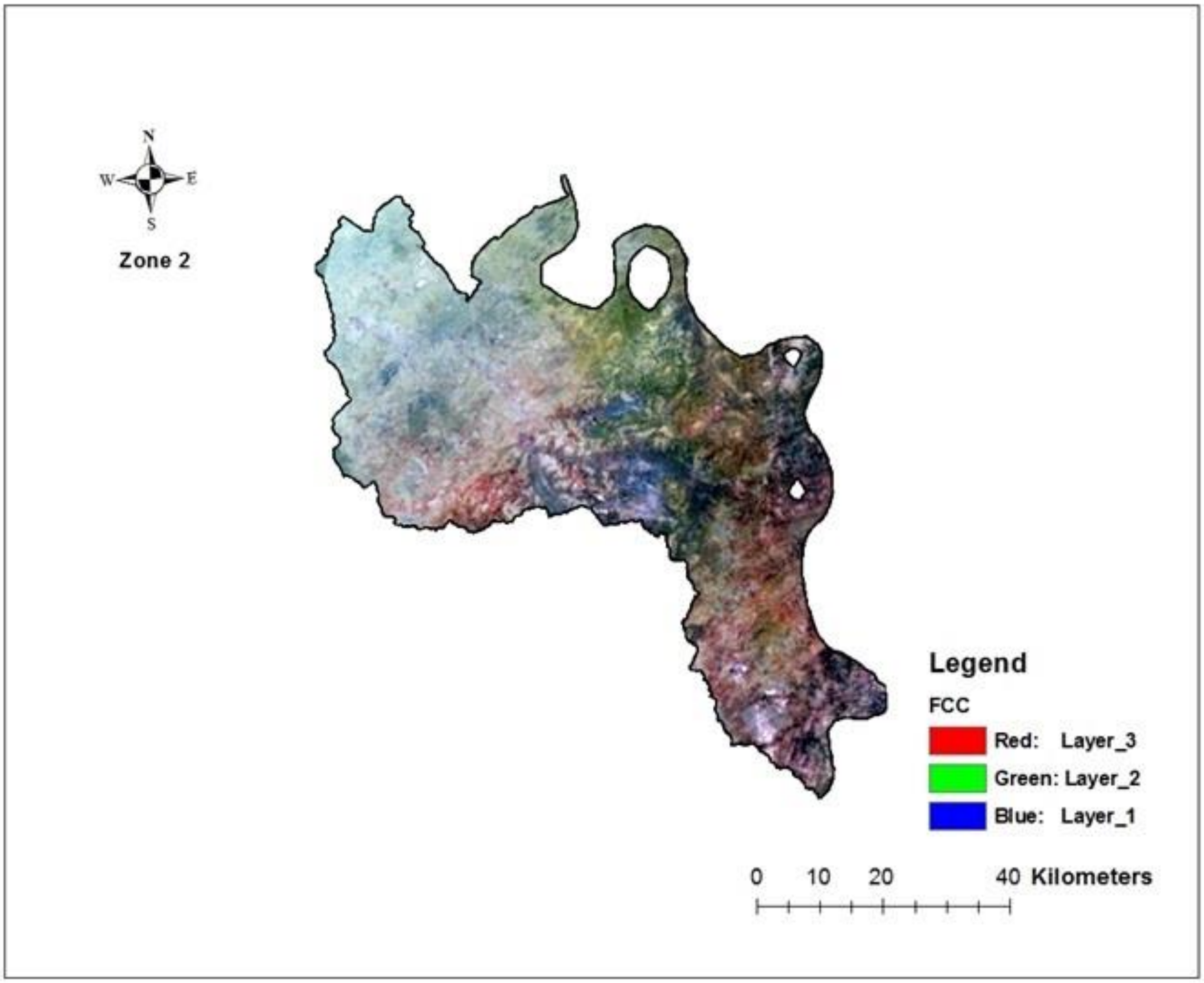


Figure 99: Satellite Image of Zone 4 showing inland drainage

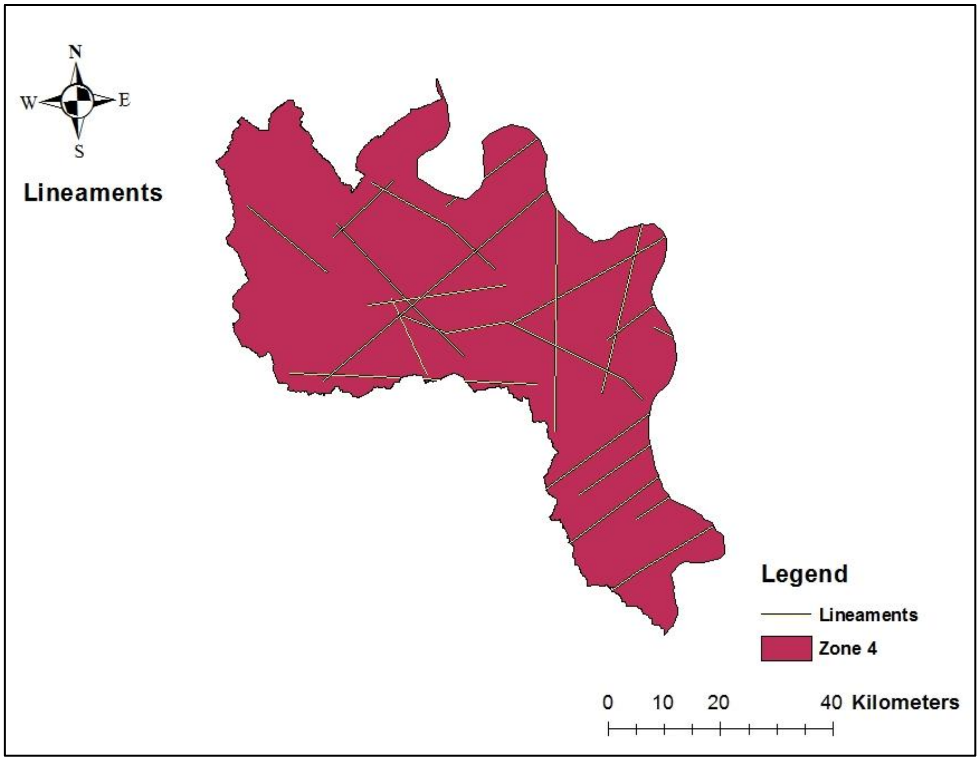


Figure 100: Lineaments in zone 2

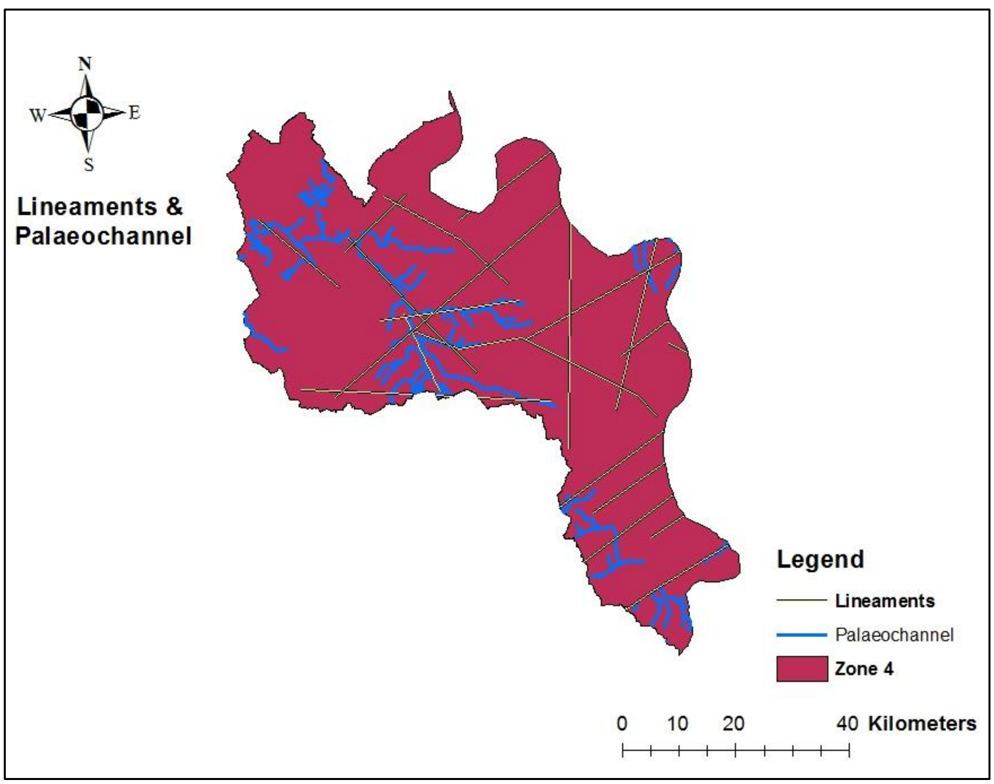


Figure 101: Identified Palaeochannels in zone 2

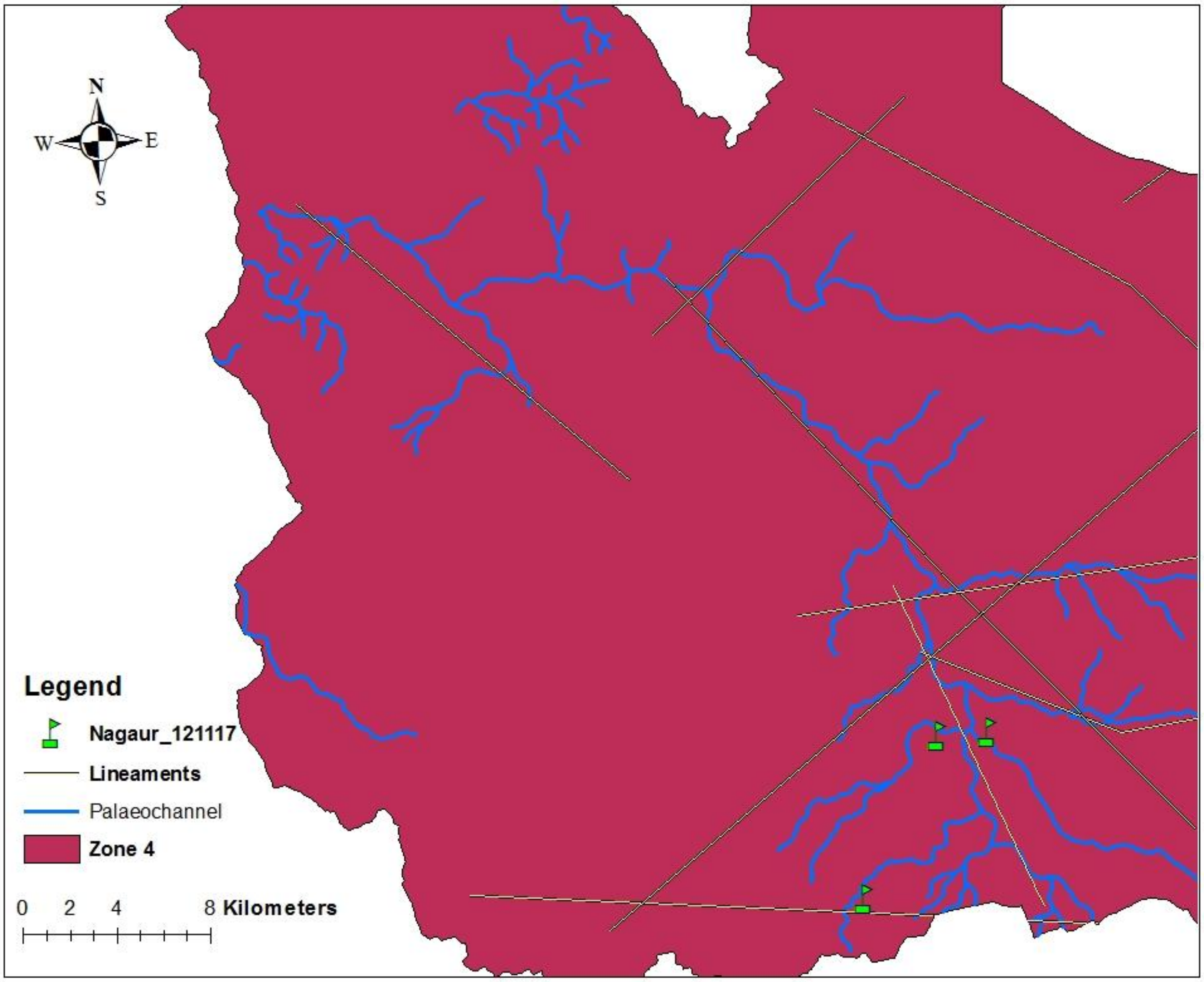


Figure 102: Association of palaeo drainage with lineaments and field investigation sites

The physical signatures of the old drainage/inland drainage/ Palaeo drainage in SW corner of Nagaur district are associated with lineaments (Figure 101 and 102). During field investigations local people confirmed that water used to reach up to the accumulation zone of inland drainage or playas from Kankari and Bhadotra village. Many small drains from different directions meet at Khemsar and accumulated flow goes up to Panchor village and slightly beyond.

Besides this rocks in the area are just 5 to 10 feet below the surface, while soil in the area is deposited by water flown over time and looks like clay soil with good productivity. Local people also confirmed that in past few years some of the farmers near to identified palaeo channel had wells only 50 feet deep but now they are up to 80 feet. In rainy season those well used to fill up to the surface and the area impounded with water. With the increase in depth, water quality also deteriorated. Thus in entire scenario black and clay soil in desert area, traces of water flow, good quality of ground water at shallow depth, association with the lineaments, etcare good evidences of Palaeo drainage (ancient water flow system) in this area.

Zone3:

This zone includes the area near the existing river(Luni) flowing towards Rann of Kutch (i.e. Luni river belt) in the parts of Jalore, Pali and Barmer district.

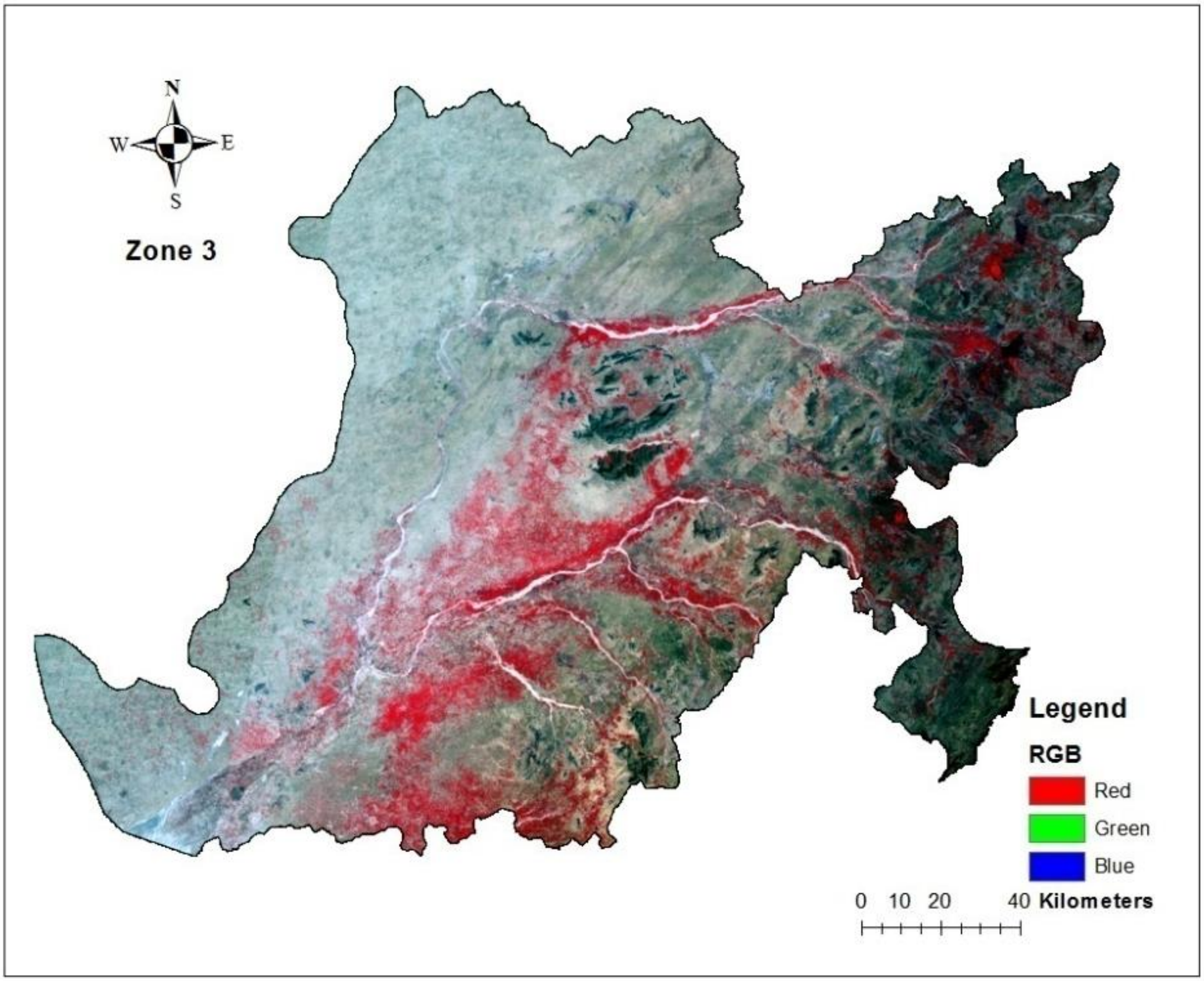


Figure 103: Satellite view of zone 3

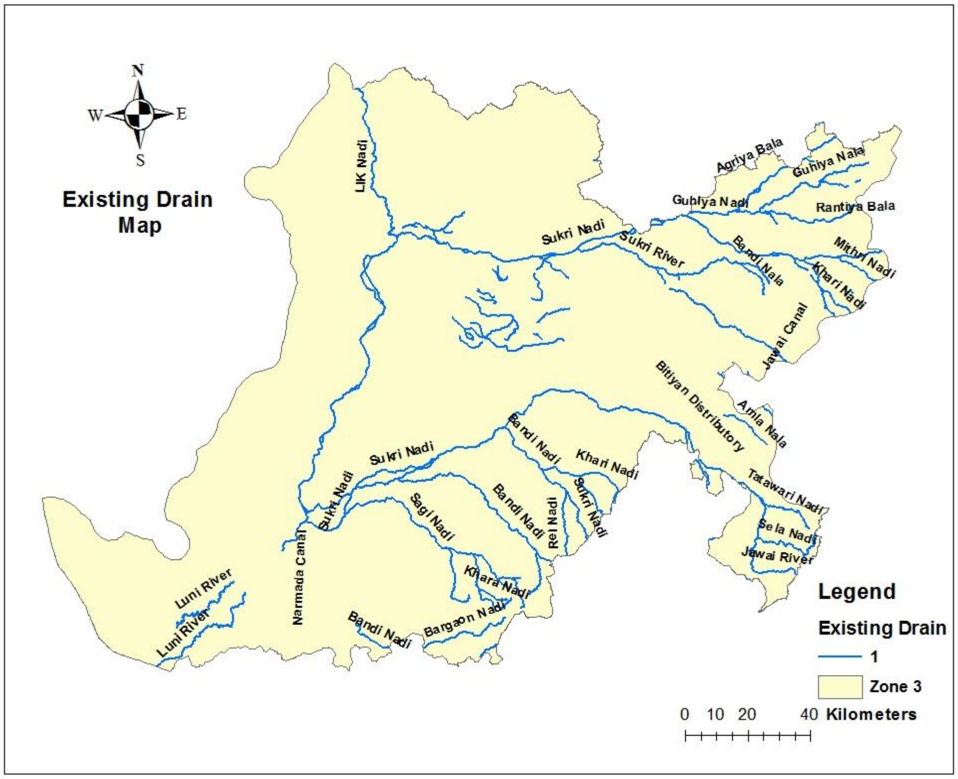


Figure 104: Existing Drain in the zone3

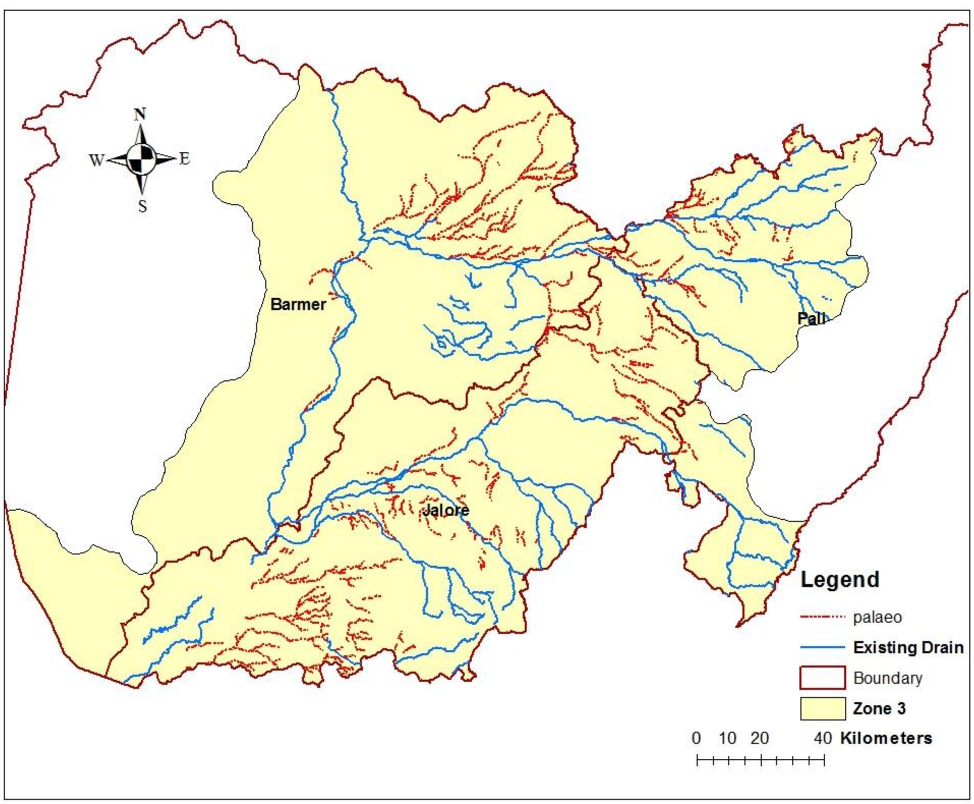


Figure 105: Palaeochannels in the zone

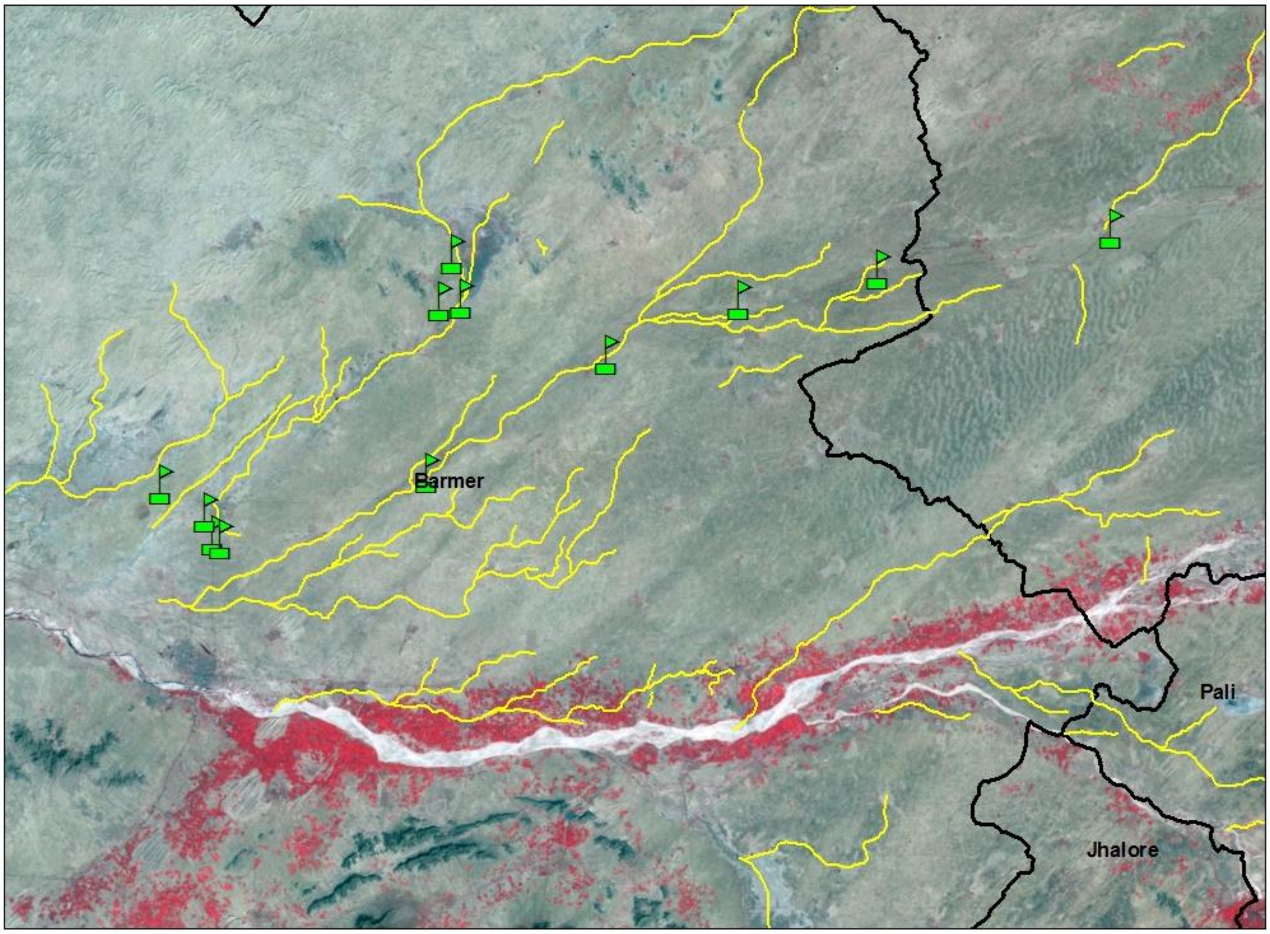


Figure 106: Field investigation points and identified Palaeo drainage in northern part of Luni river in Barmer district

An extensive network of palaeo is identified using satellite images in parts of Nagaur, Pali, Jalore and Barmer district originating from various uplands, joining together in the way at various places and merging into the main Luni area at Balotra. These areas have series of playas at Didwana, Nawa, Degana, Merta, and Pachpadra which are located in NE to SW direction. It seems to be a part of major network ofpalaeo drainages. It seems that Luni River before Balotra was also a tributary of this major network of Palaeo drainage probably associated to the ancient Saraswati River. Distribution of groundwater potential zones, water quality, water table, seasonal water fluctuation also shows the similar pattern of identified area for palaeo drainage

Valley associated with good vegetation on both the sides of the road, going towards Pachpadra from Balotra. Besides this big saline playas were of few kilometers width was found on this route (Figure 107, 108 and 109)

Figure 107: Valley on both sides of the road

Figure 108: Playas along the road

Figure 109: Saline playa of few kilometres on both the sides of road

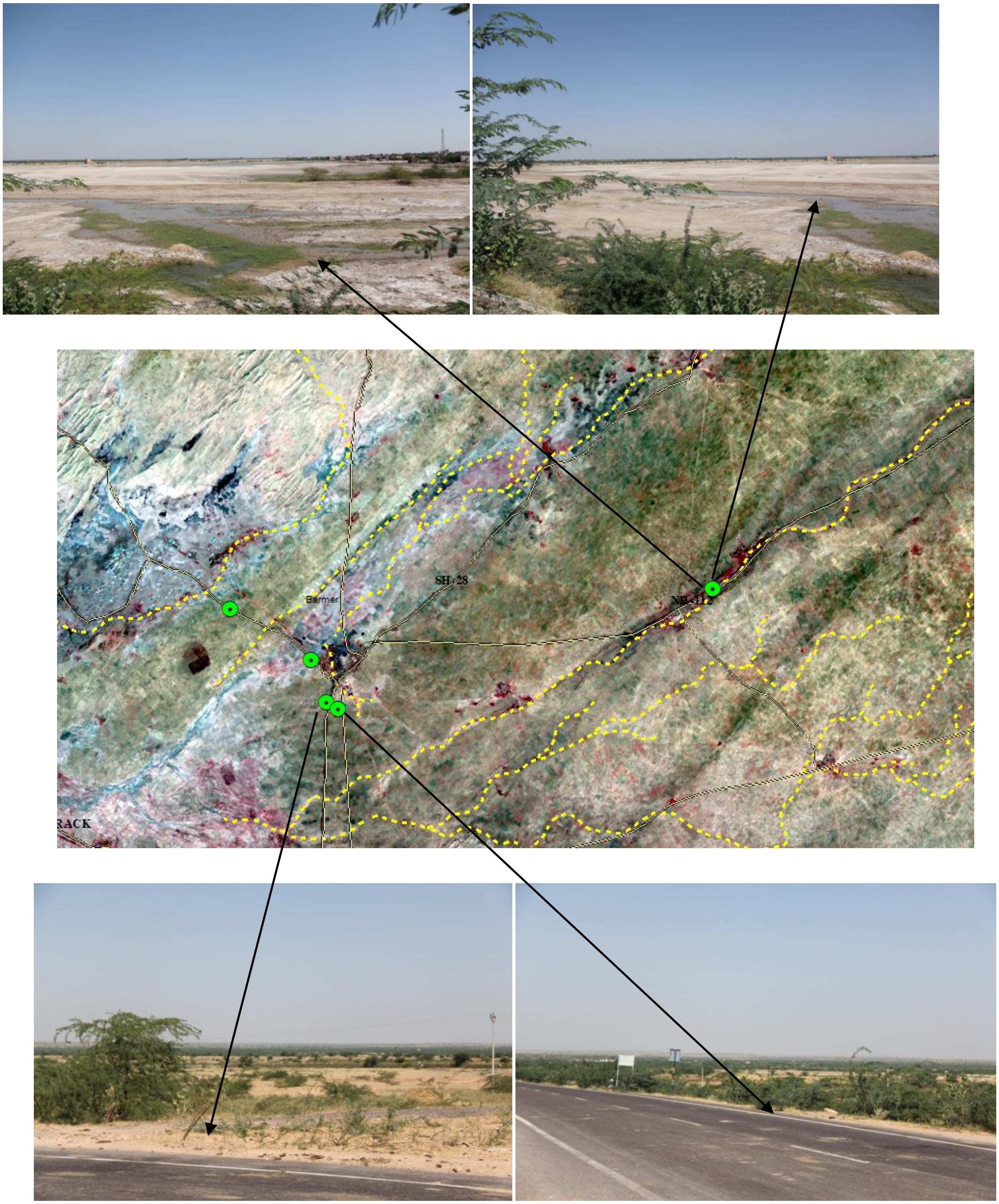


Figure 110: Physical signature of old drainage on both the sides of road

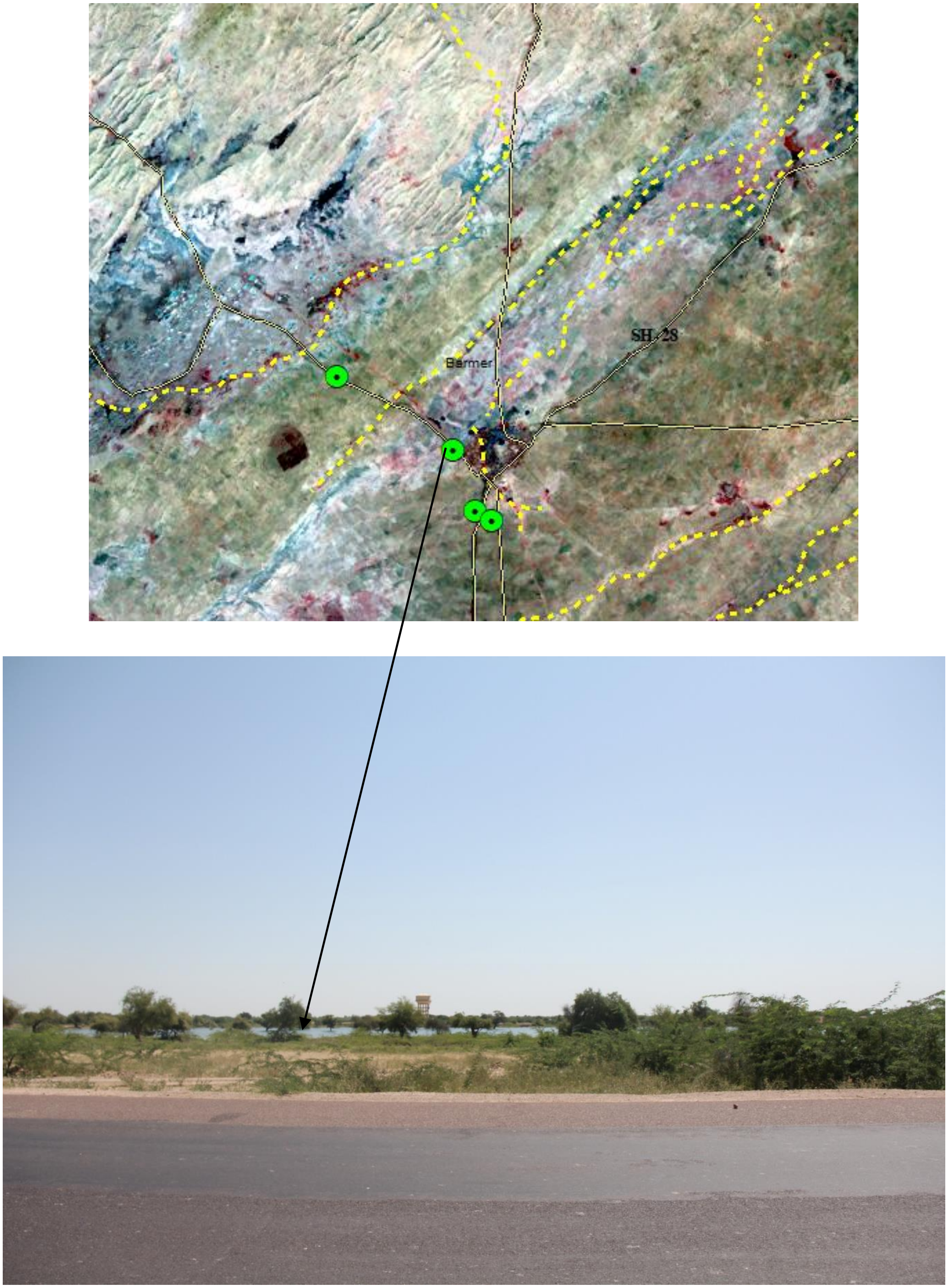


Figure 111: Playas on both the sides of road

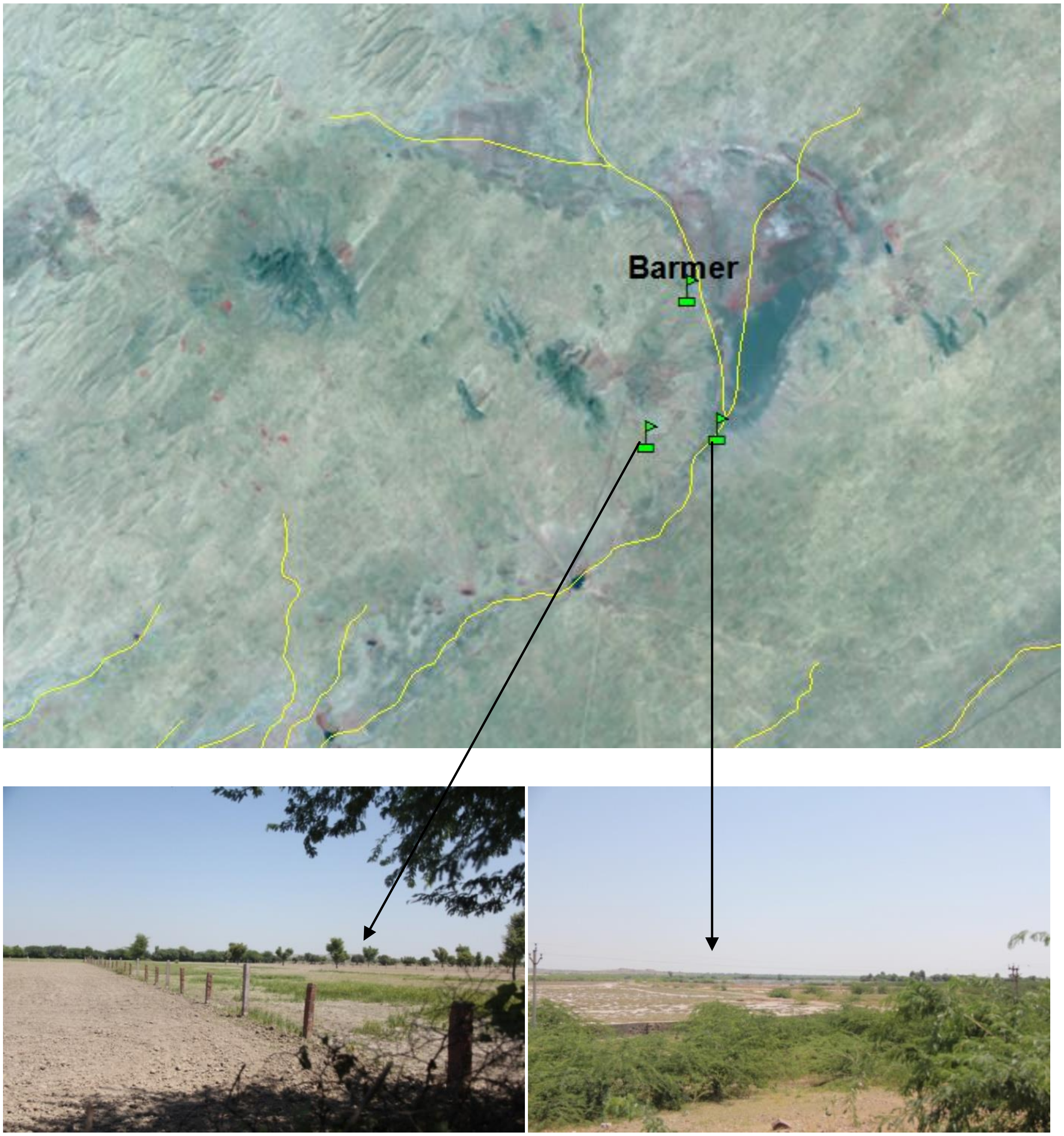


Figure 112: Salinity between agricultural fields

Agriculture and other vegetation was associated with the saline playas in Barmer district in north-eastern part of the currently Luni river. This was found along with the path of palaeochannels which further meets the Luni River as one of its tributary. Its path has been delineated and shown in the above and below given figures (Figure 111, 112 and 113)

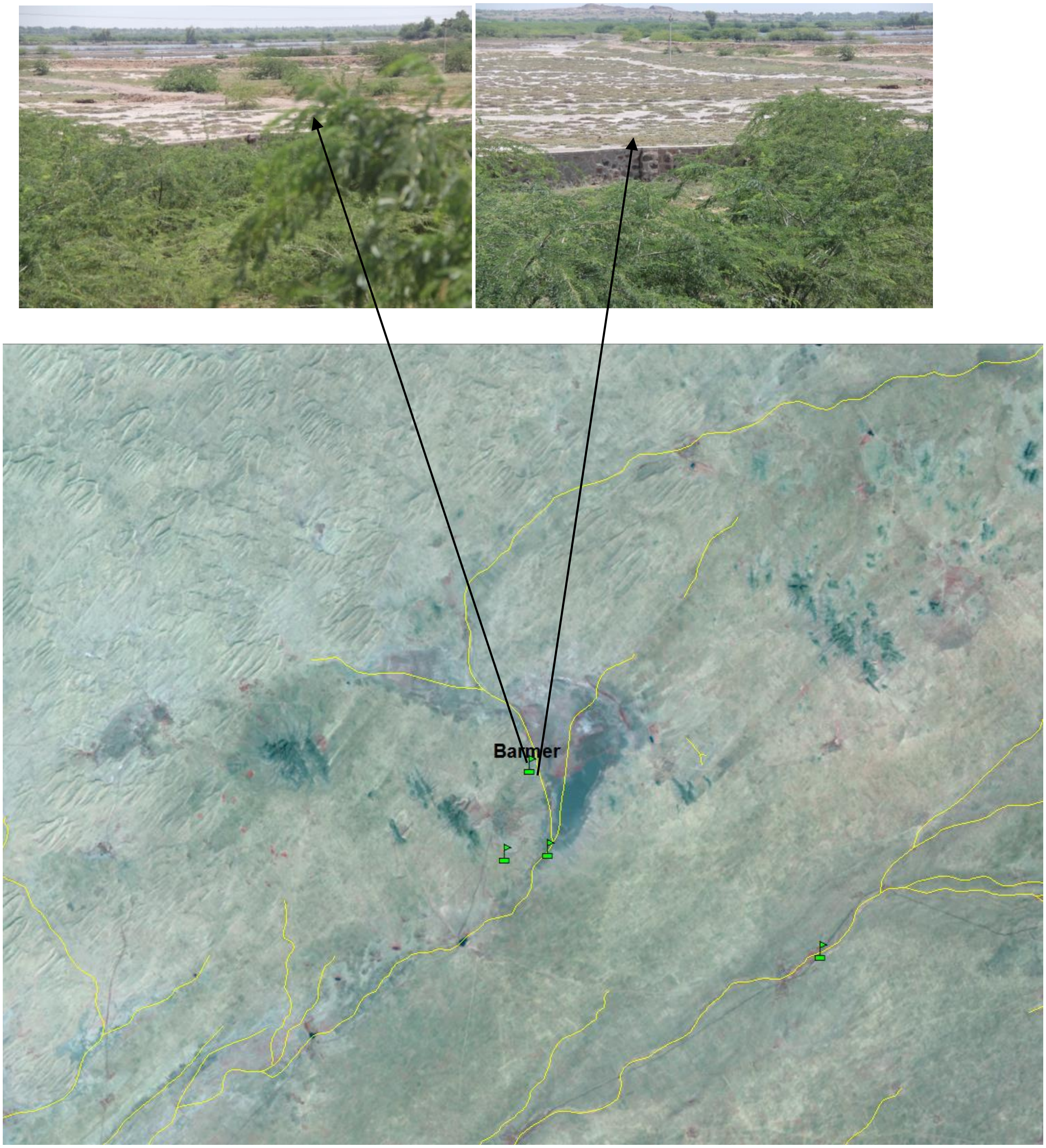


Figure 113: Saline playa found along the delineated path of palaeo drainage towards south west of Barmer District.

Figure 114: Playas of few kilometres width withgood vegetation in background

Moving further big saline playas of few kilometres width and natural vegetation in terms of weeds has been observed. While the physical signatures of old drain along the kaccha road with alluvium soil cover with moisture in it (Figure 114).

Figure 115: playa and physical signature of the dried up drain

The south east area of Luni basin (in Jalore district) has lots of palaeochannels/old drainages that drain in to Luni River. It is known that water follows its old path at the time of excessive rain and so in case of Jalore district where this year due to heavy rain in the district, the water followed its old course along the identified palaeochannels and made its way by damaging the roads, fields and other things coming across its way. Figure 118 to 122shows the damaged roads along the palaeochannels. This confirmed the existence of the palaeochannels in this area.

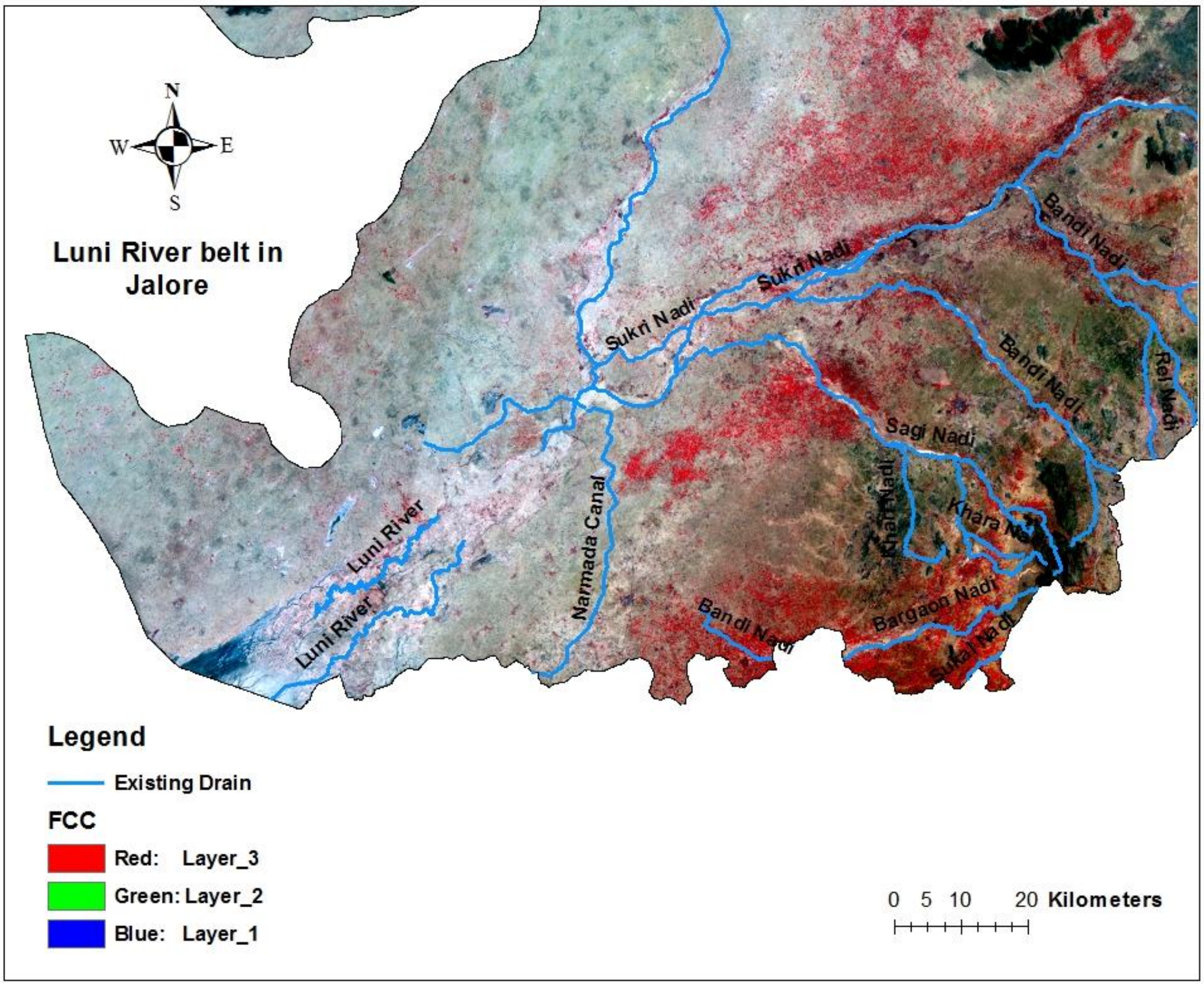


Figure 116: Luni river belt draining into Rann of Kutch through Jalore

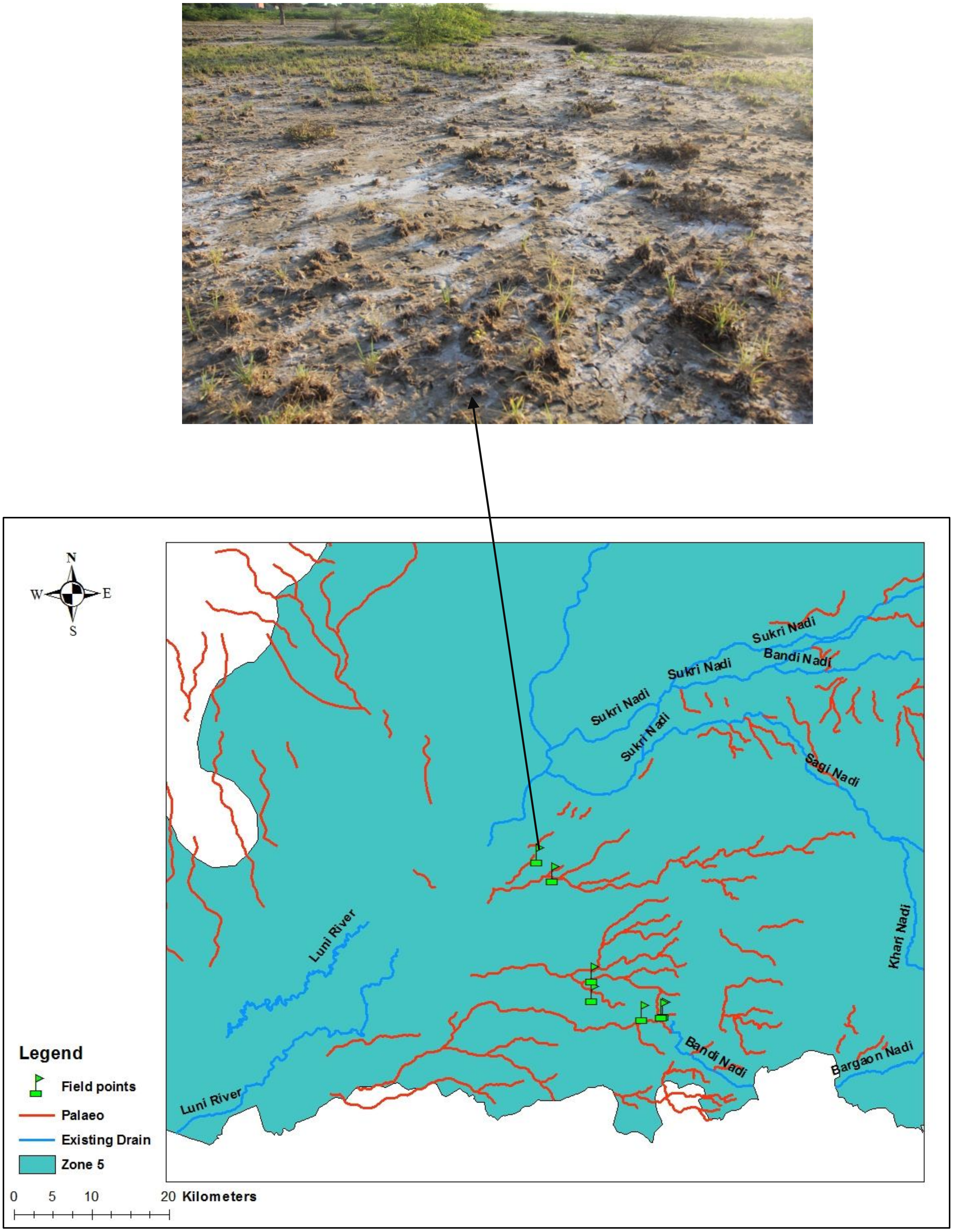


Figure 117: Location of Field investigation points in Jalore

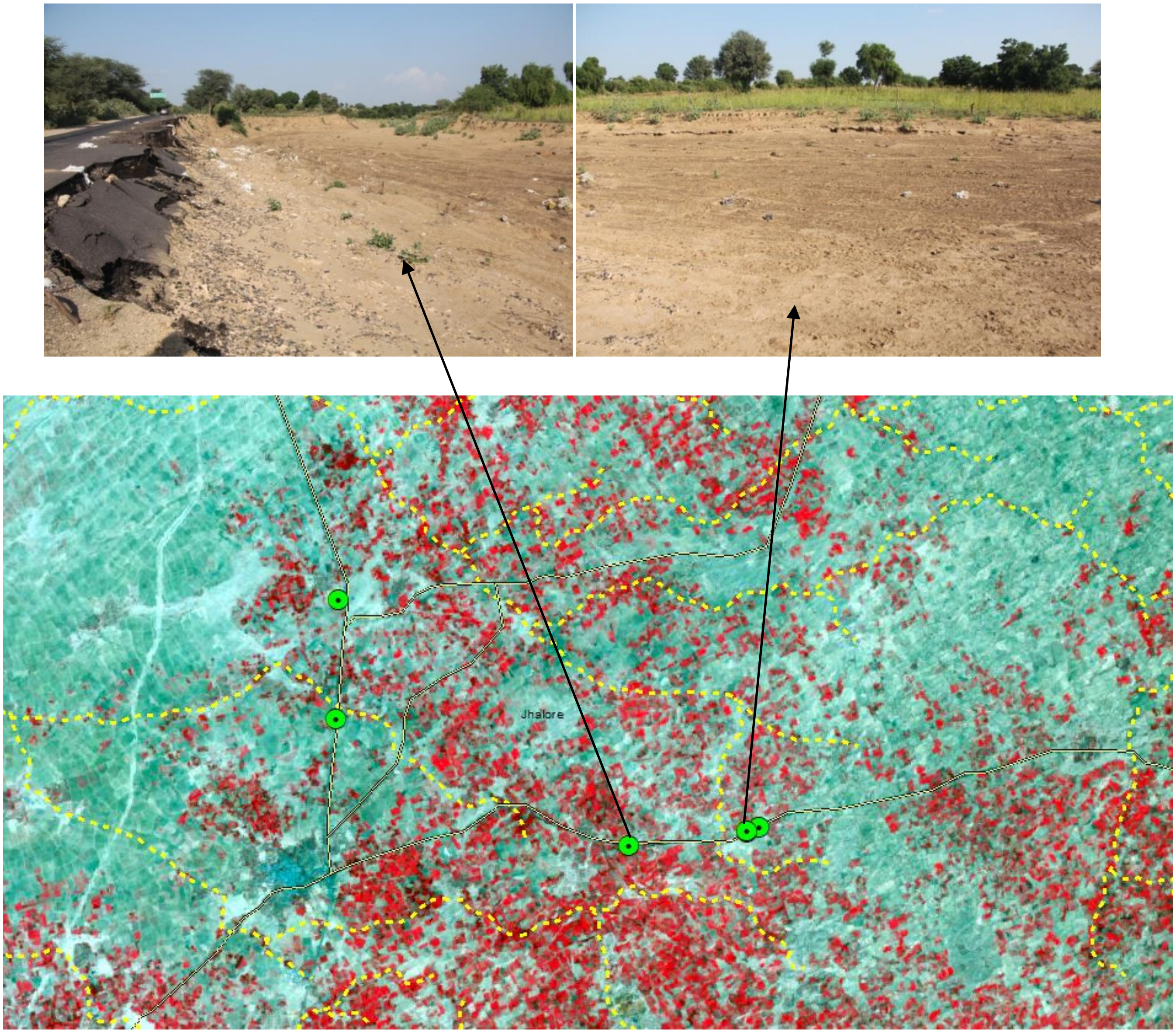


Figure 118: Damaged road by the flow of drain during flood flowing on the old path

The signatures of palaeochannels are found in the form of small local drainage. Water accumulation and the clay soil are found in the low lying areas. Due to heavy and well distributed rainfall in 2016 and 2017 the water has taken the old path which is identified as palaeo drainage. This surface shows a significant evidence of palaeo drainage which are at present under crops.

Figure 119: Alluvial soil under crop

Figure 120: Associated vegetation along the palaeochannels

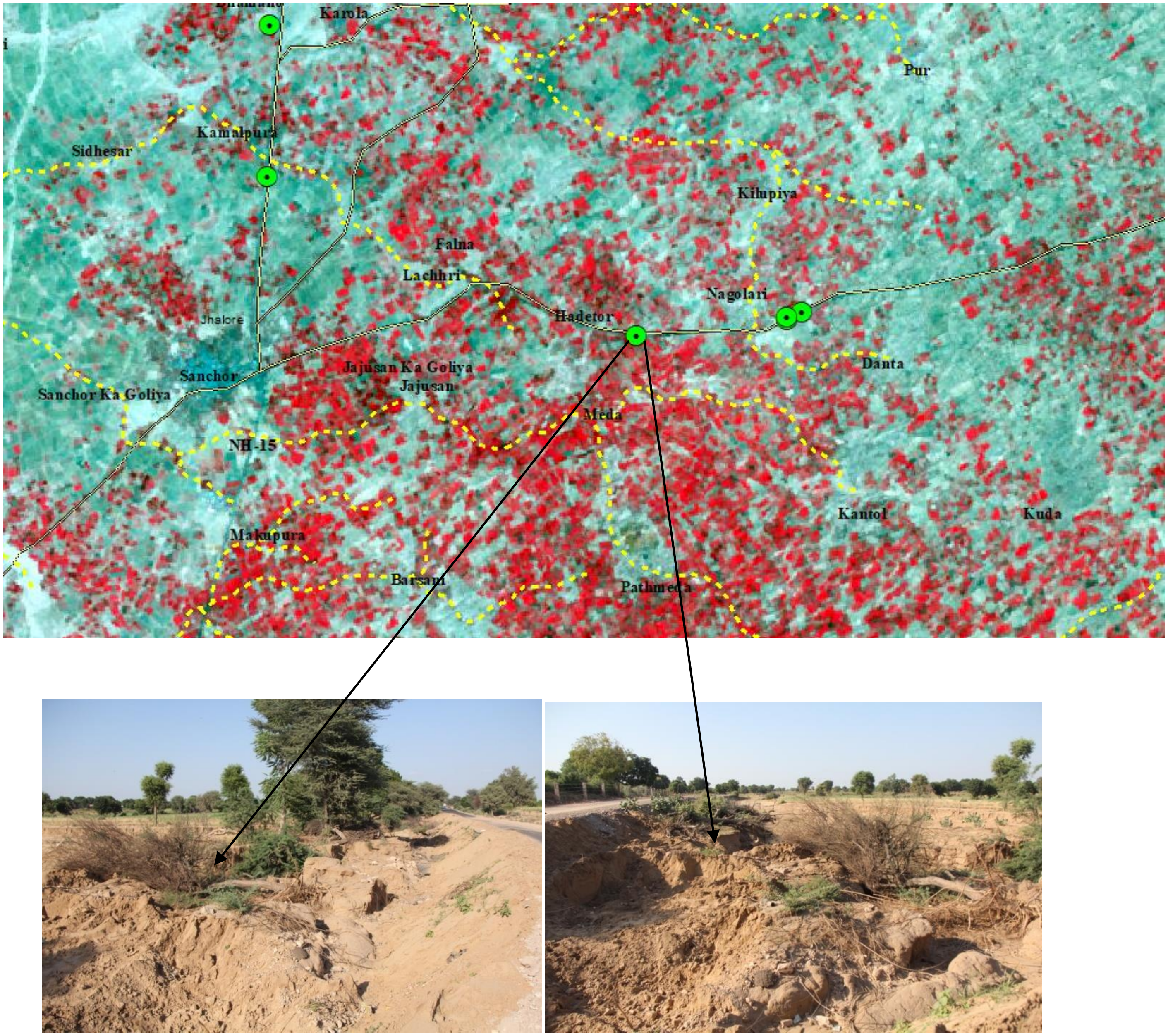


Figure 121: Old path of the drainage

During field observation immediately after monsoon season a network of drainages is marked under the village Hadater where surface runoff initiated from agriculture fields and followed the path of palaeo drainage which has been identified in remotely sensed data are shown in the associated photos. One of the villagers named Ukha Singh was interviewed who explained that in earlier times water used to flow through the same route from nearby hilly areas(Bhakra) from East to West direction and used to floe from this place and reaches upto Rann of Kutch through the villages Hadater-Kamalpura-

Palri-Harecha and meet with the drainages of Luni River. There is one more network of drainages south of this drain which passes through the lower Sanchor, Dantiya, BhikaNaikiDhani and merged into the existing drainage near Rann of Kutch.

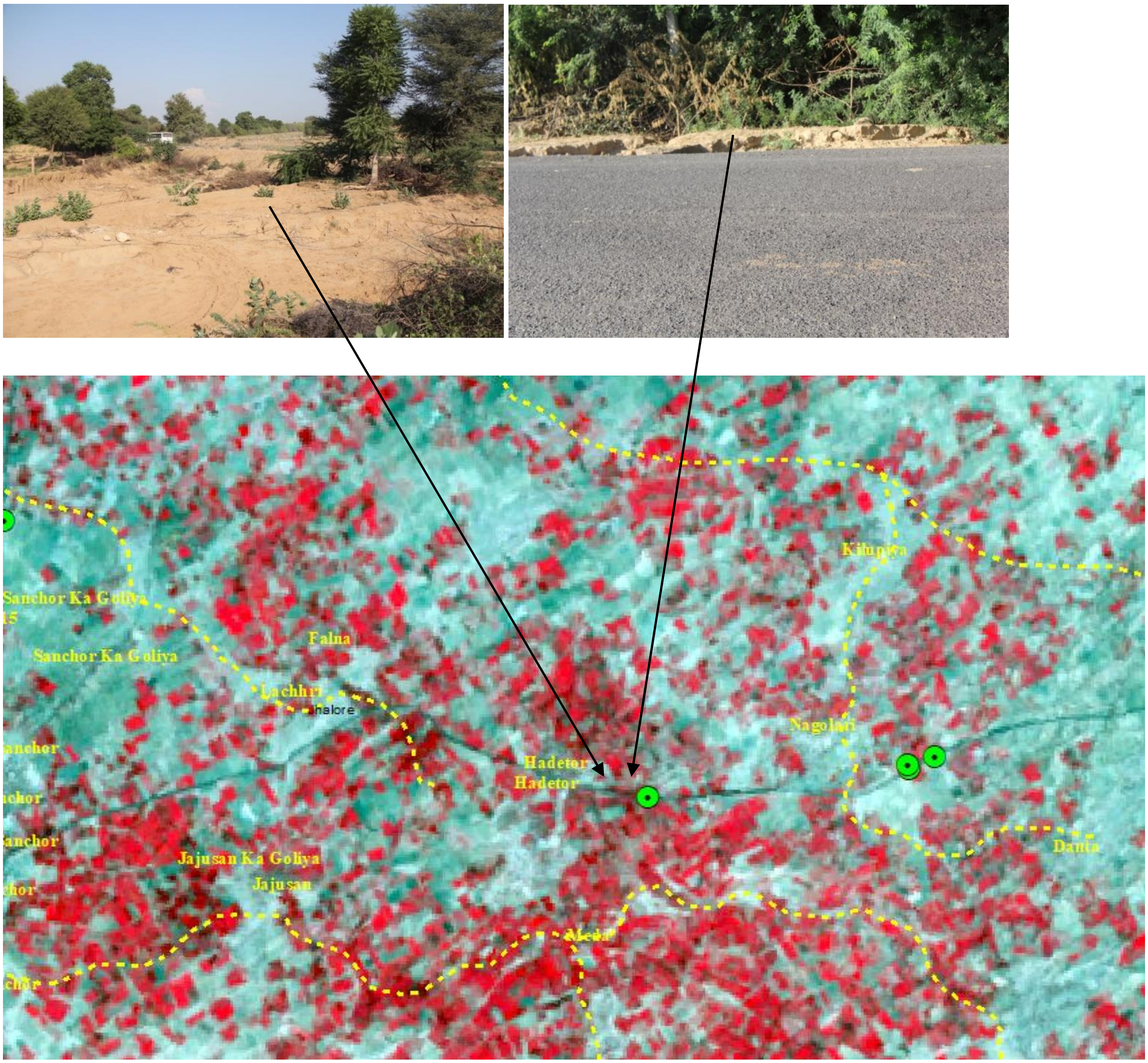


Figure 122: Drainage following the old path during flood along the road and crossing many agricultural fields

Non potential zones of palaeo channels:

Zone 4:

This zone comprises of the runoff zone of Pali district which is parallel to Aravalli range. This belt is slightly away from Aravalli range and is parallel to the hills forming the first valley from Aravalli and Aravalli is the possible source of water in the surface runoff (Luni river belt).

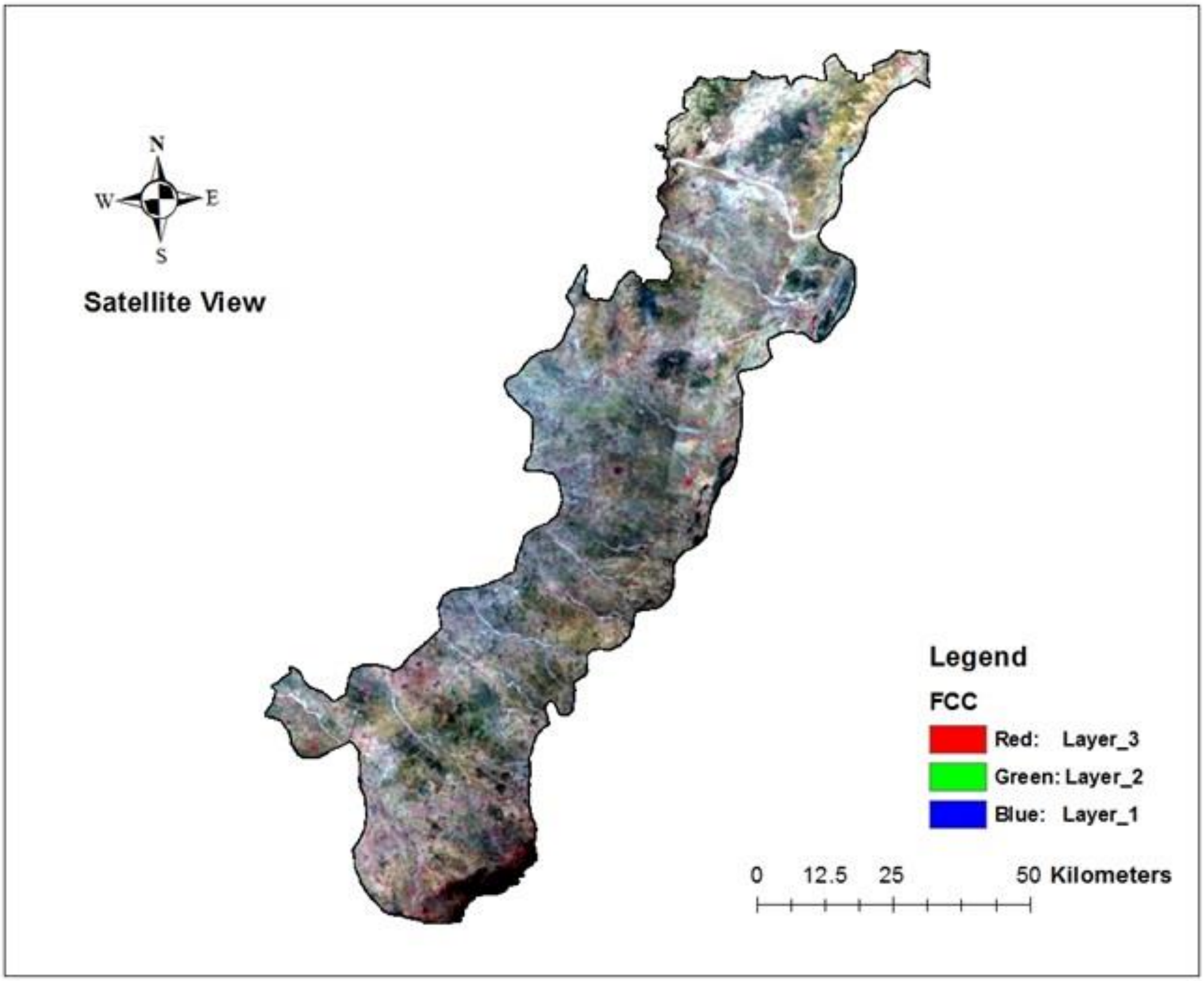


Figure 123: Satellite image of zone 4

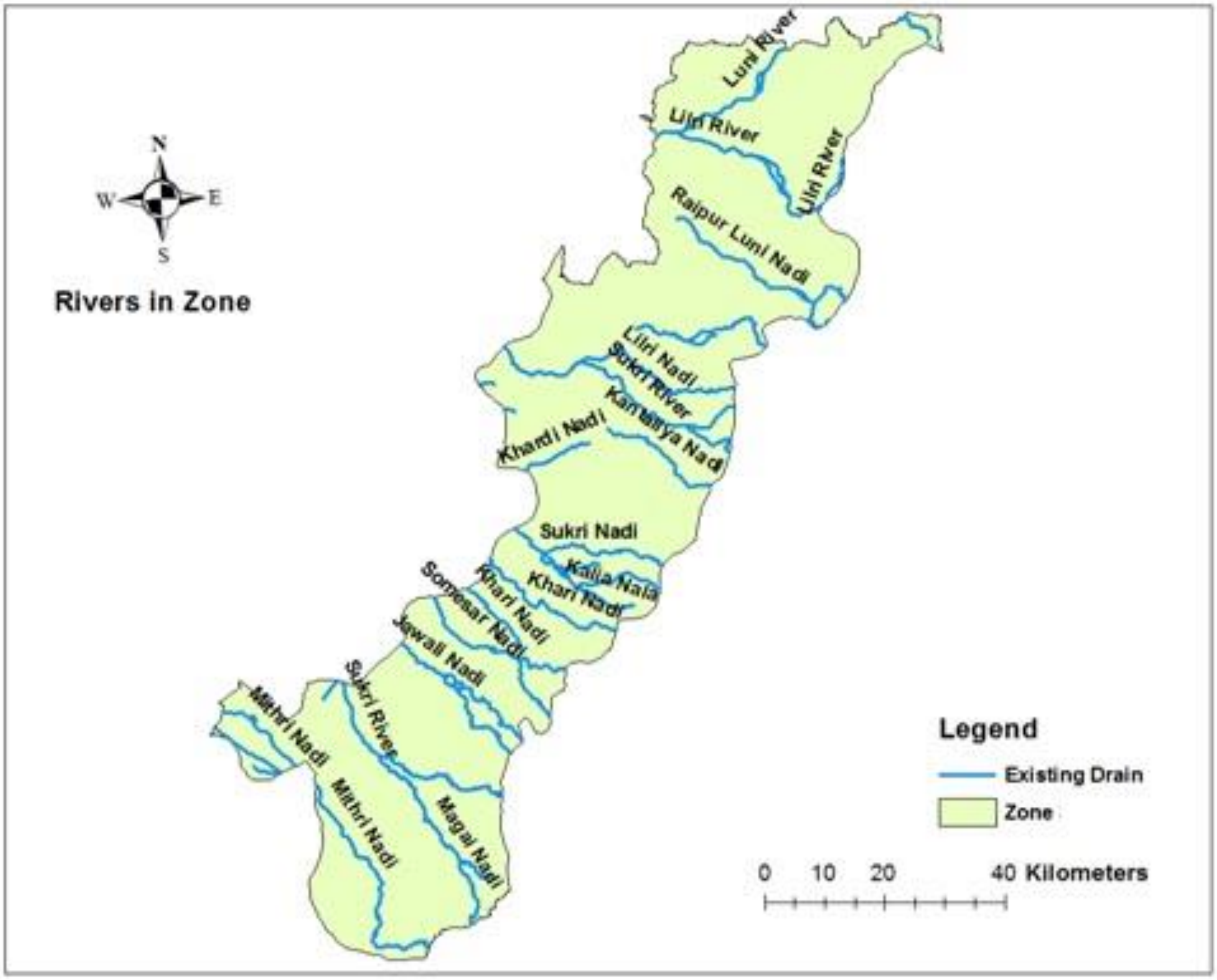


Figure 124: Existing Drain in Zone 4

Because of rocky and pediment area with slope that increases the surface runoff due to which most of the rain water goes waste and do not contribute in the process of groundwater recharge. Hence there could be no contribution of this area towards palaeo network and the pattern found could only represent the sheet wash due to local surface drainage.

All the rivers in this zone exactly flow through structures and so good correlation between lineaments and drainage has been found. All of these rivers are tributaries of the Luni river that flows towards west of Rajasthan and drains in to Rann of Kutch. Since it contains good existing drainage the signatures found in this zone could be the part of existing drain and could not be the signatures of the palaeo drainage (Figure 123 and 124).

Zone 5:

Remaining parts including Western part of Churu district, includes North Eastern part of Jhunjhunun, Nagaur and Pali district and Western part of Barmer district does not show any indication of availability of palaeo channels. This area includes two major clusters of groundwater one is in northwestern part of Churu district and another in western part of Barmer district (Figure 125).Both these clusters have comparatively good groundwater level as well as good pre monsoon water levels in each year under examination. This is because the groundwater in these areas is not usable due to high level of salinity in them. Thus no water is reduced and it increases due to process of percolation, structures as well as rainfall.

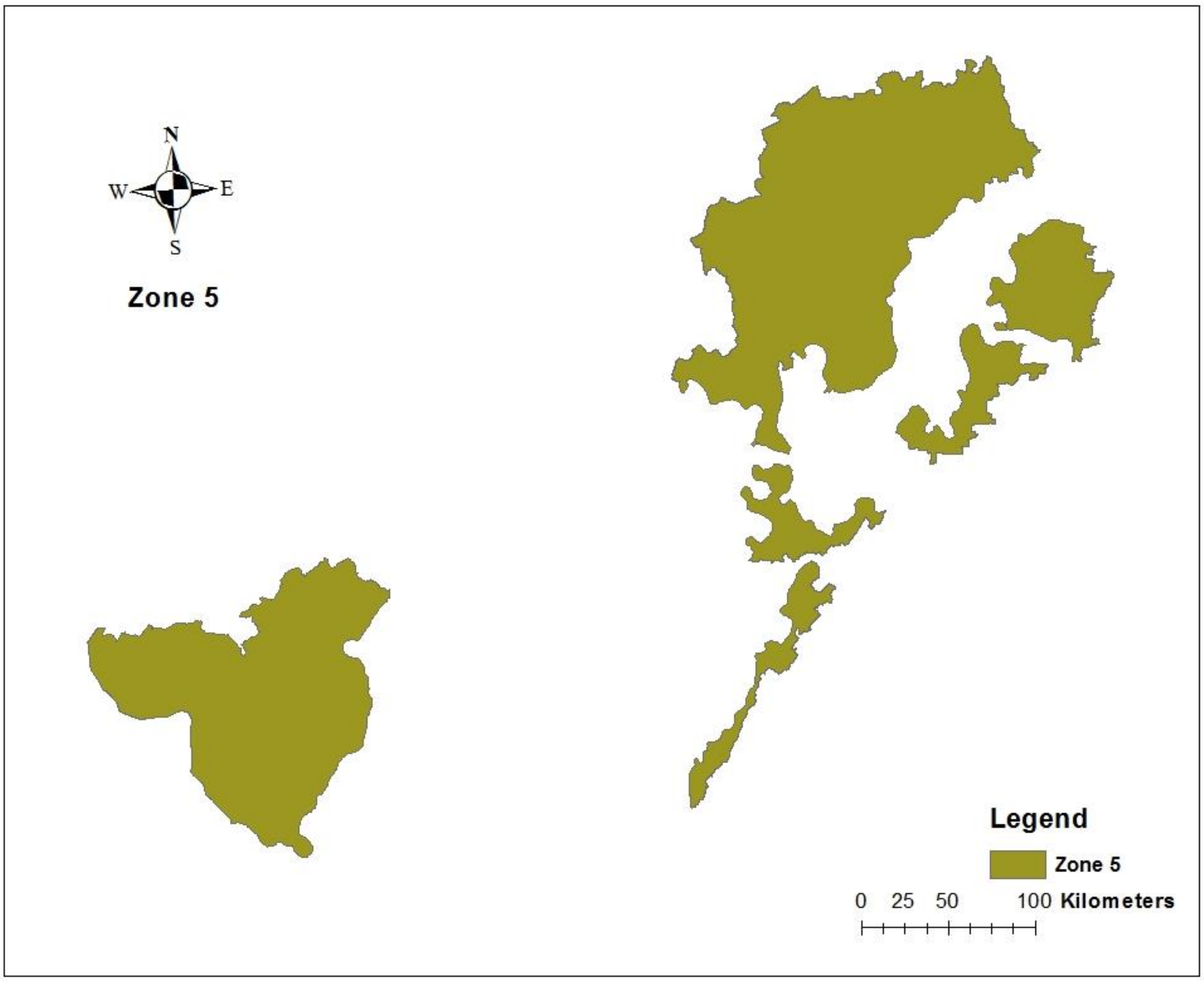


Figure 125: Spatial location of Zone 5

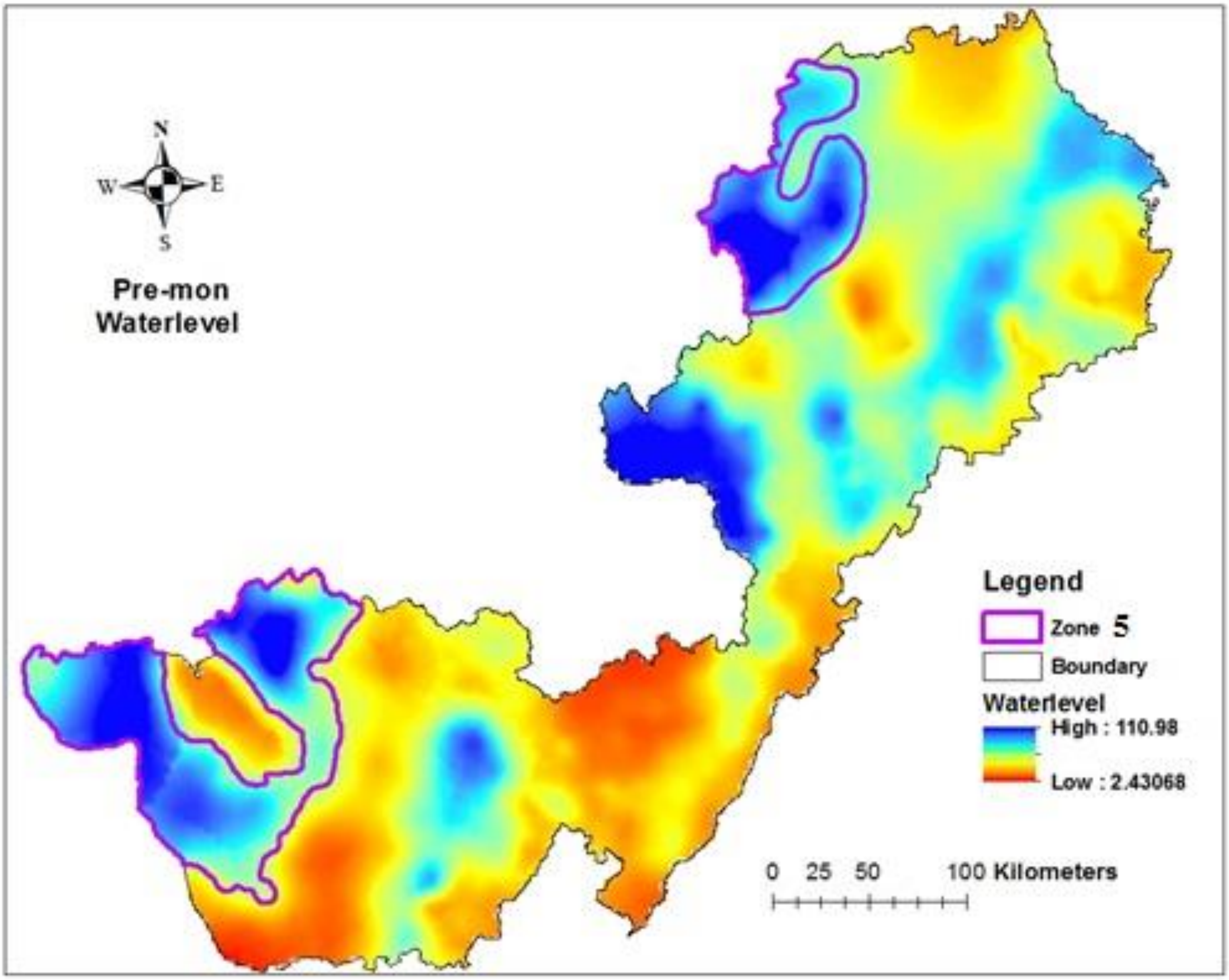


Figure 126: Pre-monsoon water level 2009

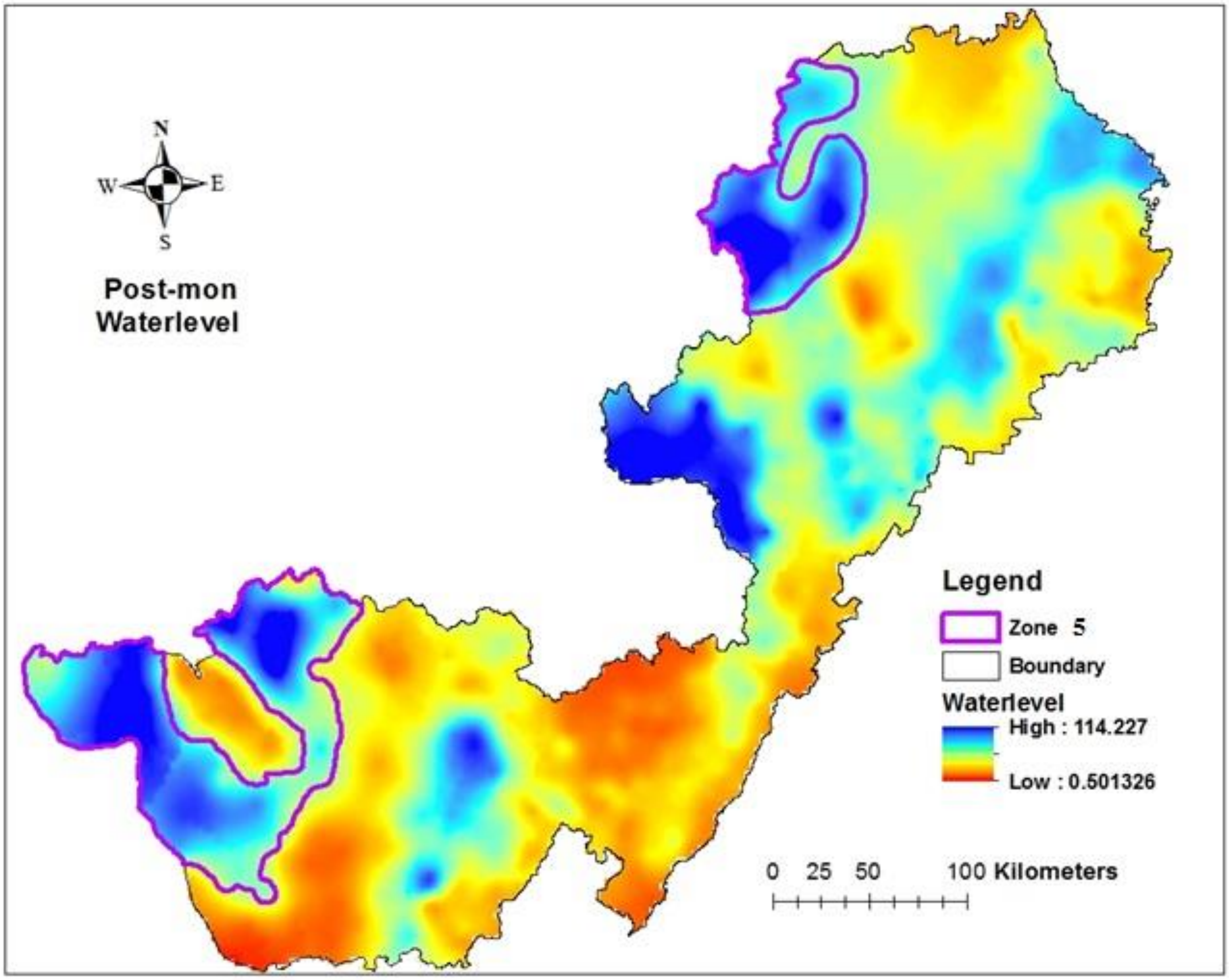


Figure 127: Post- monsoon Water level 2009

From the figures 126 and 127 given below, it is clearly seen that in both pre-monsoon and post monsoon the water level in zone number 5 remains high. Similarly if we check the trend of ground water depth for the last 10 years, the depth to ground water for zone 5 remains the same.

Though the ground water quantity is comparatively high in this area there cannot be the possibility of occurrence of palaeochannels in this zone as because palaeochannels are the source of fresh water i.e. it can be used for drinking and other purposes but the groundwater in these areas are high in salinity and so they cannot be used. Hence there is no possibility of palaeochannels in this zone.

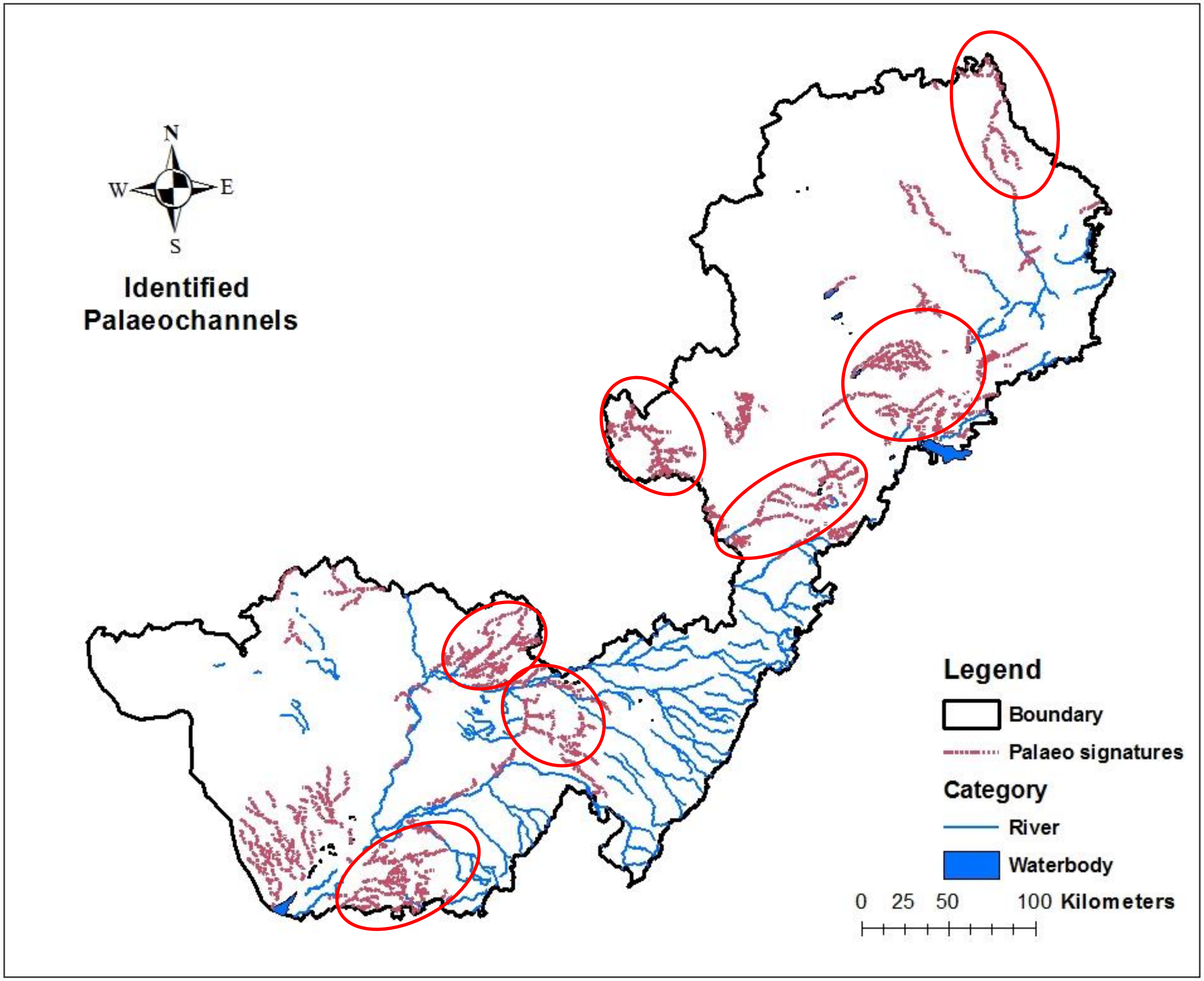


Figure 128: Identified Palaeochannels in the area

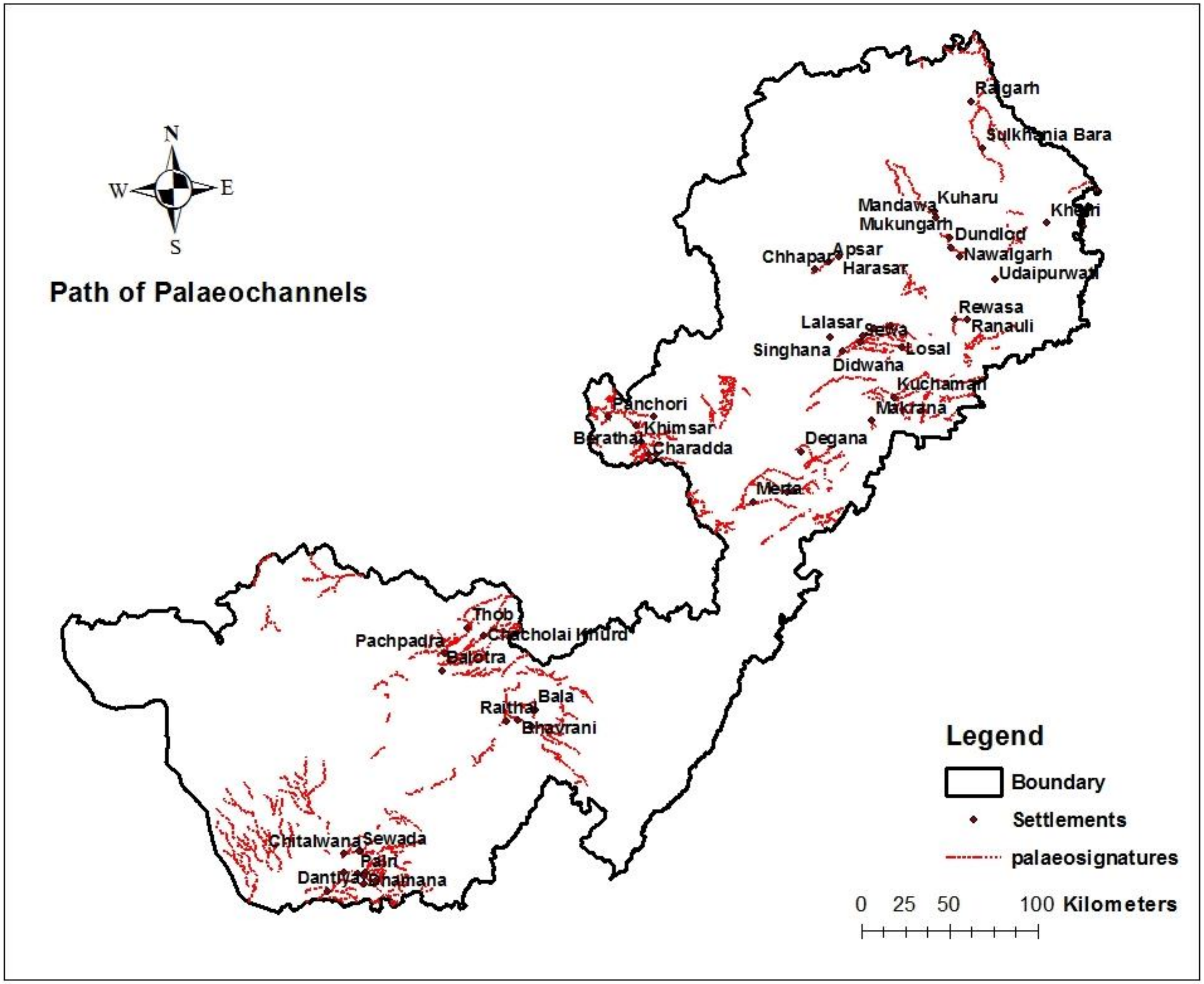


Figure 129: Path of identified Palaeochannels

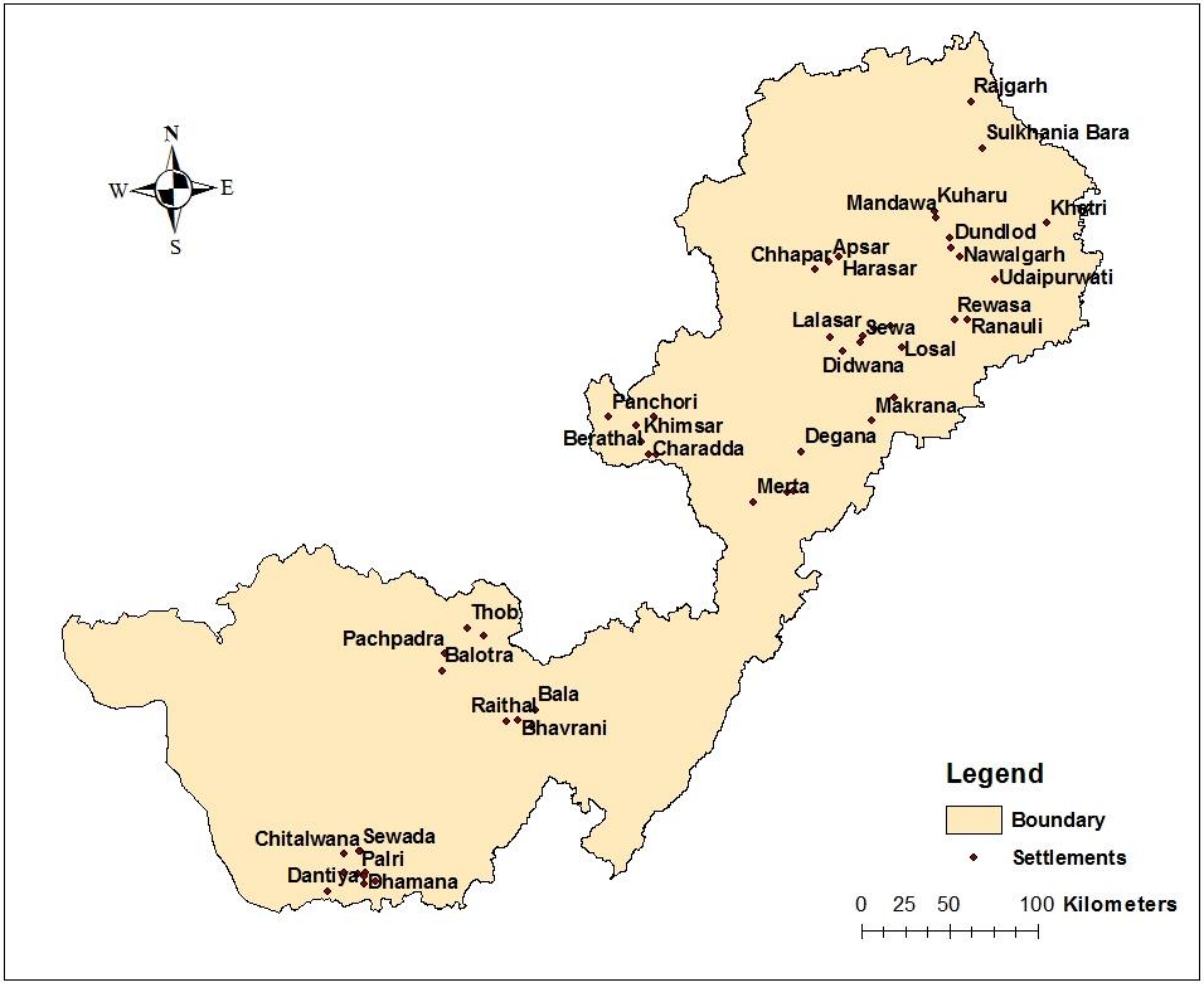


Figure 130: Settlements along the Palaeochannels

Conclusion

Analysis of satellite images of various seasons of years shows strong signature of Palaeochannels in to scattered form in various parts of the study area in the form of long elongated valleys, coarse to medium grained fluvial deposits at various stock, fluvial clay deposits in sub surface vegetation patterns, availability of good quality groundwater at comparatively shallow depth, series of playas in the direction of the of palaeo drainages, field investigations and interviews also strengthen the availability of palaeochannels through disjointed drainages, availability of river sand and concrete in the subsurface area, spill way, and culverts on the road which are constructed long back, series of ponds, comparatively higher yield of wells in the area, long runoff, and sheet wash areas, natural depressions of the fluvial deposits etc. During field investigations interviews of local people confirms the occurrence of water flows during rainy season in the identified palaeochannels area especially in Kantli river basin, drainages along Nawalgarh, Mukundgarh, Mandawa, Dundlod, Kuharu village, Sanchor and in the Pachpadra.

Looking to the direction of flows, size, depth and interconnectivity of playas, field observations clearly indicates availability of two good network of palaeochannels- one is associated to Kantli river basin where number of palaeochannels, rivulets, valleys are available and which are collectively flowing towards the Ghaggar river bed. KantliRiver is now flowing up to Sulkhania village during high rainy season and there is clear visibility of track of flow towards Ghaggar with other evidences of alluvial deposits. Another network is associated with Luni river system which encompasses the inland drainage system of Sambhar, Didwana, Nawa, Ranauli, Pachpadra, extending up to Rann of Kutch. These playas in the form of salt lakes are probably the remnants of old drain network which are getting inflow from the waters from the channels flowing from north east and east directions which was the direction of Palaeo drainage which are associated to the Vedic Saraswati River. This shows the area was sometime drained by large network of river associated with Saraswati river system. Some of the areas have very prominent signatures of the palaeo drainage like from Samod to Sambhar as Anokhi buried channel, drainage from hill in the north of Sikar district at Ranauli. Starting from hills near Nawa, a channel merges in Jojri River flowing through Jodhpur district which ultimately merges in “Luni River” near Balotra. There are numerous evidences around Degana, Merta area in Nagaur district in form of disorganised flow, natural depressions and presence of clay soils. It seems that this area was the part of large river system which has deposited the large amount of sediments in this area.Even now in this area water accumulates during rainy season which supports good agriculture. Only before 50 years or more this area was having very good ground water potential and the area was known for cash crops. In North and North East of Balotra there are many number of channels coming and merging with Luni River, it seems that these channels are the part of Ancient River flowing from Sikar, Nagaur, Jodhpur districts and now dried up due to increase in aridity in the area.

In Pali district a network of small channel basins emerges and flow for long distance and merges in to Luni river right at the town. There are numerous channels, inter dunal flats visible in Southern most part of Jalore and Barmer districts which ultimately merges into Rann of Kutch. In ancient times this area may be a low lying land converging in to sea after making a delta like structure. Water is still flowing in some of the sandy rivulets during rainy season and going into Rann of Kutch. Due to the dynamic nature of this area it is difficult to identify the individual channels-whether it is Palaeo or recent drainage.

The investigating team has identified some of the concrete Palaeo drainage network as below

1. From Sulkhania Bara of Jhunjhunu near Rajgarh, Bhadra, Noharto GhaggarRiver bed.
2. Promising area found near Mandawa in Kuharu village flowing from Nawalgarh-Dundlod-Mukungarh-Mandawa-Kuharu village which is associated with elongated, narrow, deep valleys, sand dunes and is a high moisture and high vegetated area.
3. Singhana near Khetri originating from Udaipurwati hills and flowing through Nawalgarh to Mukungarh
4. East to West flowing channels emanating from nearby Bhakra hills flowing from Hadater-Kamalpura-Palri-Harecha and ultimately meets Luni River.
5. One more palaeo-drainage passing through Sanchor, Dantiya, BhikaNaikiDhani and meets merges into Rann of Kutch.
6. Another drain flowing from village Hadater through Dhamana village near Palri where intermittent surface ponding is observed.

As per the project proposal geophysical survey was to be conducted in the identified Palaeo channels after doing the investigations and analysis it id found that palaeochannels are very much scattered in large area and so it is difficult to verify the presence of palaeochannels by 10, 20 or 30 number of geophysical points. At the same time project is delayed due to administrative difficulties. Therefore the idea of going for geophysical survey looks impractical. What was possible in Remote Sensing and field investigation is which is present in the report.

References

Subramanya, K. (2013). Engineering Hydrology, 4e. Tata McGraw-Hill Education.

Kalyanaraman, S. (1999). Sarasvati River, Goddess and Civilization. MEMOIRS-GEOLOGICAL SOCIETY OF INDIA, 25-34.

Danino, M. (2010). The Lost River: On the Trail of the Sarasvatī. Penguin Books India.

Ghose, B., Kar, A., & Husain, Z. (1979). The lost courses of the Saraswati River in the Great Indian Desert: New evidence from LANDSAT imagery. Geographical Journal, 446-451.

Kumar, C. P. (2014). Groundwater data requirement and analysis.

Rastogi, B. K., Kothyari, G. C., Sairam, B., Kumar, G. P., Patel, V., Goswami, O. P., & Prajapati, N. GEOPHYSICAL EVIDENCES FOR PALAEOCHANNELS AND POSSIBLE SOURCES OF GROUNDWATER: A CASE STUDY FROM KACHCHH REGION, WESTERN PENINSULAR INDIA.

Bhadra, B. K., Gupta, A. K., & Sharma, J. R. (2009). Saraswati Nadi in Haryana and its linkage with the Vedic Saraswati River—Integrated study based on satellite images and ground based information. Journal of the Geological Society of India, 73(2), 273-288.

Aslam, M. M., & Balasubramanian, A. (2001). Identification of palaeochannels around Cauvery river near Talakad, Karnataka using remote sensing data. Journal of the Indian society of Remote Sensing, 29(4), 237.

Zankhna, S., & Thakkar, M. G. (2014). PALEOCHANNEL INVESTIGATIONS AND GEO-HYDROLOGICAL SIGNIFICANCE OF SARASWATI RIVER OF MAINLAND GUJARAT, INDIA: USING REMOTE SENSING AND GIS TECHNIQUES. Journal of Environmental Research and Development, 9(2), 472.

Wang, X., Guo, Z., Wu, L., Zhu, C., & He, H. (2012). Extraction of palaeochannel information from remote sensing imagery in the east of Chaohu Lake, China. Frontiers of Earth Science, 6(1), 75-82.

Mehdi, S. M., Pant, N. C., Saini, H. S., Mujtaba, S. A. I., & Pande, P. (2016). Identification of palaeochannel configuration in the Saraswati River basin in parts of Haryana and Rajasthan, India, through digital remote sensing and GIS. Episodes, 39(1), 29-38.

Khan, Z. A., & Tewari, R. C. (2011). Paleochannel and paleohydrology of a Middle Siwalik (Pliocene) fluvial system, northern India. Journal of Earth System Science, 120(3), 531.

Sharma, J. R., Gupta, A. K., & Bhadra, B. K. (2006). Course of Vedic River Saraswati as deciphered from latest satellite data. Puratattva, 36, 187-195.

Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International journal of remote sensing, 27(14), 3025-3033.

Paillou, P. (2017). Mapping Palaeohydrography in Deserts: Contribution from Space-Borne Imaging Radar. Water, 9(3), 194.

Srivastavaa, S. K., Hamblya, B., Daviesa, P., McCalluma, A., Clewettb, T., & Gontzc, A. M. (2016). Mapping possible palaeochannels: an integration of remote sensing-based approaches. In Proceedings of the QCON14 Conference (pp. 1-16). Surveying and Spatial Science Institute (Queensland).

Meena, B. R., & Rajasthan, H. O. Monuments And Archaeological Sites Price in India.

Malik, J. N., Merh, S. S., & Sridhar, V. (1999). Palaeo-delta complex of Vedic Sarasvati and other ancient rivers of northwestern India. Memoirs-Geological Society of India, 163-174.

KHILNANI, M. Palaeodrainage and Palaeoclimate of North-West India.

Gupta, A. K., Sreenivasan, G., Sharma, J. R., & Srivastava, K. S. (2003). Confirming the presence of palaeochannels in western part of Jaisalmer district, Rajasthan through integration of space and ground methods. PROCEEDINGS-INDIAN NATIONAL SCIENCE ACADEMY PART A, 69(2), 231-240.

Mukherjee, A. (2001). RIGVEDIC SARASVATI: MYTH AND REALITY. Breakthrough, 9, 1-10.

INDIA, G. S. (2011). Geologyand Mineral Resources of Rajasthan. Rajasthan: GEOLOGICAL SURVEY OF INDIA.

I-SERVE Delhi Chapter. (2012, june 23). Retrieved october 2017, from http://serveveda.org/?p=166.

Munroe D, C. J. (2005). Regional determinants of exurban land use in the U.S. Midwest. 52nd Annual North American Meetings of the Regional Science Association . Las Vegas, USA.

Nandini, C. V. (2014). Satellite image processing sedimentology and geophysical studies to identify and map palaeochannels in a part of south eastern India. Chennai.

Papadaki, E. S., Mertikas, S. P., & Sarris, A. (2011). Identification of lineaments with possible structural origin using ASTER images and DEM derived products in Western Crete, Greece. EARSeL eProceedings, 10(1), 10.

Tirén, S. (2010). Lineament interpretation Short review and methodology (No. SSM--2010-33). Swedish Radiation Safety Authority.

Todd, D. K. (1959). Ground water hydrology. John Wiley and Sons, Inc, New York.

Ajay Srivastava, Nitin Kumar Tripathi and K.V.G.K. Gokhale (1996), Hydrological Investigations In Gangetic Basin Using Remote Sensing And Basement DEM - A Case Study, GISdevelopment.net ---> AARS ---> ACRS 1996 ---> Geoscience / DTM

Roy A.B. and Jakhar S.R(2001) late quaternary drainage disorganizationand migeration and extinceion of the vedic Saraswati,Current Science Vol.81 No 9 10 November 2001