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A REMOTE SENSING (RS) APPROACH USING NORMALIZED DIFFERENCE VEGETATION INDEX AND NORMALIZED DIFFERENCE WATER INDEX (NDVI & NDWI) FOR MAPPING THE ARCHAEOLOGICAL LANDSCAPE OF LORALAI DISTRICT, BALOCHISTAN.

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Abstract
The remote sensing imagery of Normalized Difference Vegetation Index and Normalized Difference Water Index (NDVI & NDWI), and field explorations has given a richer understanding of the archaeological landscape of the Loralai district in Balochistan, Pakistan. A systematic survey was conducted by the first author in 2020, 2021, and 2022, examining a 379 sq. km area around Borai and Mekhtar tehsils over three weeks, which yielded 27 archaeological sites. The current location of archaeological sites does not necessarily represent their original environmental context, as landscapes and river systems shifted in proto-historic times. Generally, the remotely sensed data revealed that most archaeological sites are currently associated with water sources and arable land areas. The exact understanding of the archaeological landscape can be gained via geoarchaeological and palaeoenvironmental studies.

INTRODUCTION

Remote sensing (RS) is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information (Natural Resources Canada 2007: 5). RS offers new perspectives in archaeological research. RS, as a non-destructive method, may be used as part of the investigation of an archaeological or historical site before any excavation or other intervention. On a micro scale, geophysical surveys can provide valuable information on underground monuments, while on a macro scale, aerial photography and satellite images can locate traces of previously anthropogenic residues (Gojada & Posluschny 2016: 133). RS can be utilized to locate archaeological sites, and the establishment of cultural resource management can be used to monitor archaeological sites that are under threat. Additionally, this tool can be used to assess general landscape risks and identify important geomorphological features within the landscape. Moreover, this can be used to record vegetation, soil, and water and predict the location of the archaeological site in a specific area (Parcak 2009: 174). In addition to this, RS is an efficient tool to give information on the earth's surface processes at regional and global scales, and it can be used to cover a wide range of parameters such as land use, vegetation types, surface temperature, soils, water, geology, forestry, and surface elevation. RS is concerned with the measurement and acquisition of information about an object without physically touching it (Garg 2024: 30-31). This method, combined with field explorations, was used for mapping the archaeological landscape of Loralai District, Balochistan, Pakistan. Loralai district holds rich archaeological potential, first highlighted by Fritz Noetling (1893–1898) at sites such as Rana Ghundai and Dabar Kot (Khan et al., 2010: 9). Aurel Stein (Stein 1928: 377-380) later documented several sites in Loralai and Zhob, followed by Brigadier Ross's detailed study of Rana Ghundai (Ross 1946: 291-316). Subsequent contributions include Piggott's analysis of potsherds (Piggott 1950: 118-131) and Fairservis's reevaluation and new site identifications (Fairservis 1959: 287-289).In addition to this, Loralai is located in the semi-arid region of Balochistan, having fertile valleys and water sources, which were significant for agriculture and pastoral activities in the region. The region has a high concentration of prehistoric sites (Neolithic period to the Bronze Age) (Khan et al., 2010: 10). These prehistoric sites in northern Balochistan are located in landscape where perennial water supply was available and considered more fertile during this period than during the early twentieth century, given the significant number of settlements (Stein1929: 90-91). Moreover, the irrigation system has been present in the area since ancient times, and climate change has been noted, but there is a lack of paleoenvironmental studies in the area. That this might have supported the settled population indicated in the shape of size and number of sites (Ross 1946: 311). Raikes and Dyson argue that present-day conditions in the Indus–Baluchistan region reflect major environmental changes, as shown by recent hydrographic evidence. The decline of fauna, loss of flora, and rapid population growth have disrupted the natural balance (Raikes & Dyson 1961:280). Given the lack of paleoenvironmental and geoarchaeological data available for Loralai district, this study, applying NDVI and NDWI methods, serves as a basis for assessing environmental-archaeological linkages in the region and offering insights into human settlement during the 5th-3rd millennia BCE.

The Study Area

Physiogeographically, Loralai is occupied by rugged mountains and small valleys, which vary in elevation from 900 to 3,000 meters in (Fig. 1).

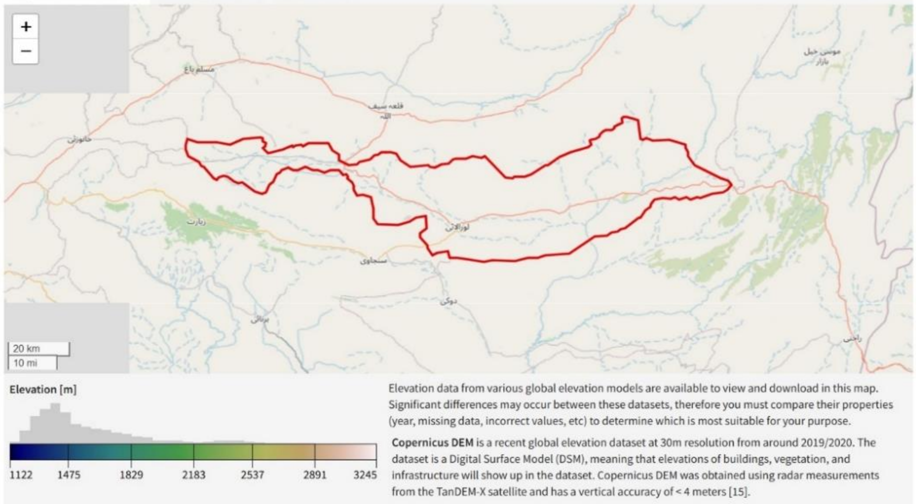

Figure 1: Elevation of the study area, Loralai district. Courtesy geofolio.org.

The district lies between 29°37′-31°27″ N and 67°43′–70°17′ E (Fig. 2) and comprises two tehsils, Borai and Mekhtar (Fig. 3, Fig. 4) (District Census Report, 1998: 1). It is bounded by three hill ranges: Damangarh in the north, Kru and Gadabar in the centre, and the Dabar range in the south. The drainage system is dominated by the Anambar River, supported by seasonal rivers. Three major streams-Loralai, Mara, and Sehan and connect with the Anambar River, differing in water-carrying capacity (Imperial Gazetteer of India, 1984: 109).

Figure 2: Map of Pakistan showing different areas of the country. In green, the position of the district Loralai in the northwest part of Balochistan province (Source: District Profile 2017).

ISSN: 2710-4060 2710-4052 Volume 6, Issue 6, 2025

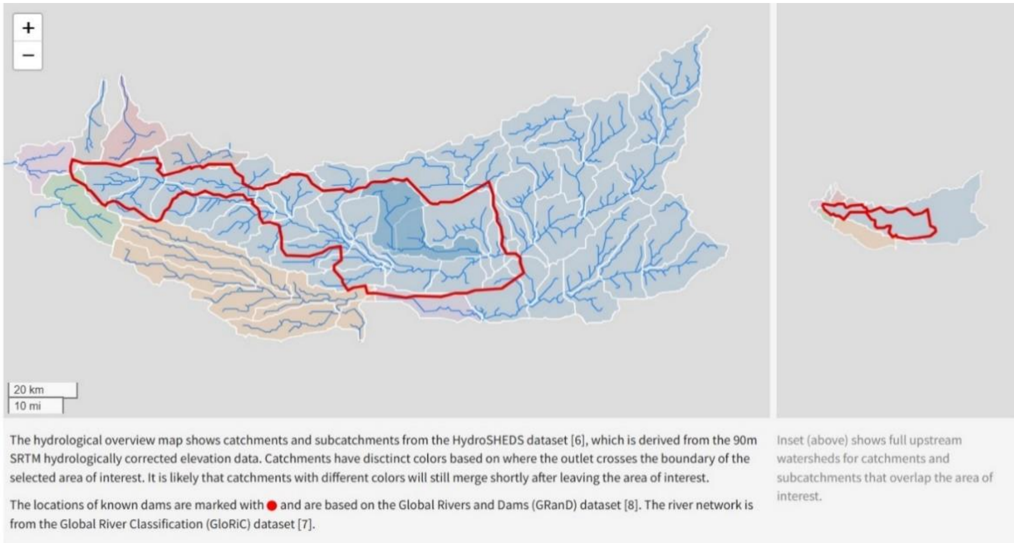

Figure 3: The hydrological map of Borai tehsil, Loralai district. Courtesy geofolio.org.

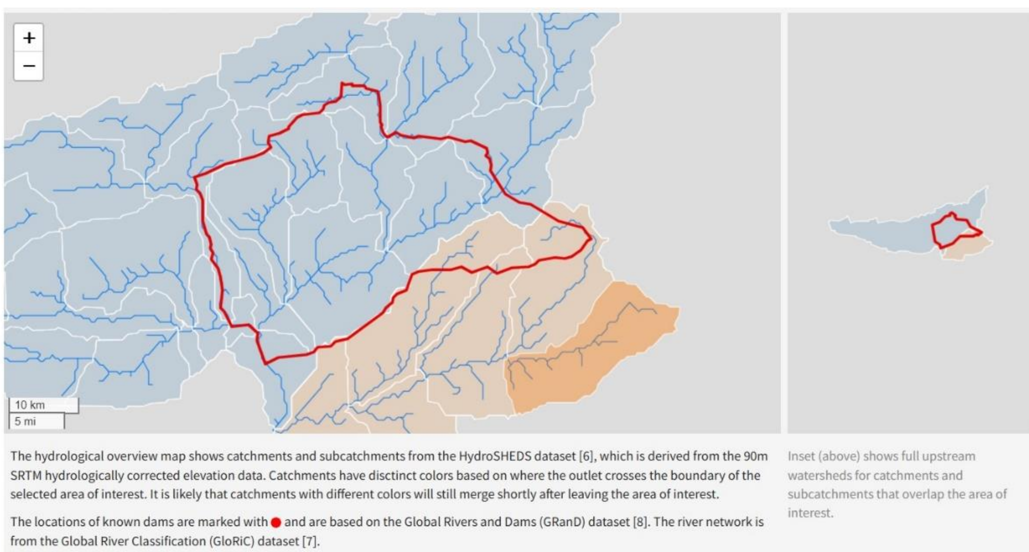

Figure 4: The hydrological map of Mekhtar tehsil, Loralai district. Courtesy geofolio.org.

The Anambar River, the main river of the district, flows smoothly but floods nearby houses and fields during the rainy season. Seasonal streams with broad channels also traverse Loralai, remaining dry most of the year but filling in the monsoon. The district lacks ponds or lakes, with irrigation dependent on tube wells and kareezes. The Borai Valley, encircled by the Damanghar and Kru ranges, extends westward into Murdarghar, covering about 80 miles with limestone and shale hills. To the northeast lies Sabra Valley, bounded by the Lwara watershed, Sappar, and Torghar ranges, with peaks such as Salai, Narai, Buj, and Hazarghat. In the southeast, Barakan Valley drains into the Rakhni watercourse. Geologically, the district is dominated by Upper Cretaceous formations, with Lower Cretaceous and Jurassic outcrops in the west and north, and stratified sandstone with volcanic pebble beds in the east and southeast. Jurassic limestone forms the high southern mountains near Chinjin, while Triassic rocks occur in the northwest. Eocene strata, notably the Laki series, contain coal deposits (Fig. 5) (Balochistan District

ISSN: 2710-4060 2710-4052 Volume 6, Issue 6, 2025

Gazetteer Series, Vol II, 1907: 27; District Gazetteer of Balochistan 1997: 482–484).

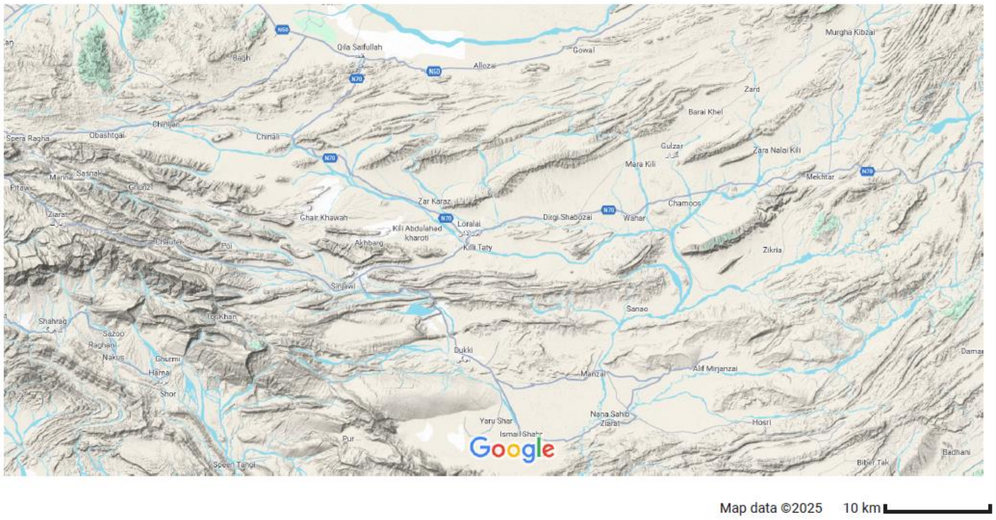

Figure 5: A general Map of the Loralai district with river systems and villages. Courtesy Google Maps

Tengberg and Thiébault analyzed 21 charcoal samples from five Balochistan sites such as Mehrgarh, Nausharo, Lal Shah, Shahi Tump, and Miri Qalat. It reveals continuous human occupation since the 7th millennium B.C. and shifts in vegetation. Tamarix and Prosopis were common species across sites (Tengberg & Thiébault 2003: 21-63). The region's vegetation includes juniper, macrocode, pistachio on hills, and olive at lower elevations. Phulai (Acacia modesta) grows along the Anambar River into Borai Valley, while ash, myrtle, beer gargantua, bushak, and pamangi serve local needs. Saba and Sargrah are cultivated in Mekhtar, Zahra, and Barad. Wild shrubs include gangu (Orthonopsis intermedia), gangdera (Nerium odoratum), leghunae (Daphne oleoides), trishaw (Artemisia), and makhae (Caragana) in highlands (District Census Report 1998: 3). Fauna comprises wolves, jackals, hyenas, foxes, and abundant mongoose in Barakan. Black bears occur in Surghar, Behu, and Hazarghat, with leopards in Torghar, Behu, and Buj ranges. The Sulaiman range supports mountain sheep and markhor, while Anambar hosts chikor and sisi. Birds include vultures, kites, doves, sparrows, larks, hoopoes, and starlings. Snakes and scorpions are widespread and sometimes fatal (District Gazetteer of Balochistan 1997: 504).

Methodology

Different methodologies have been applied to document systematically the rich cultural heritage of the Loralai district and better comprehend the vibrant interaction between human societies and their environments over time. The data was obtained from satellite remote sensing techniques such as Google Earth Pro, Landsat, Advanced Spaceborne Thermal Emission and Reflection Radar (ASTER), Global Digital Elevation Model (GDEM), and field walking and processed in Quantum Geographic Information Systems (QGIS). In 2020, 2021 and 2022, a 379 sq km area of the district Loralai, Balochistan, was examined. Whereas, the satellite images from Landsat 8 were taken from 2014 and 2024, where the red and near-infrared (NIR) bands were used to have NDVI, and bands green and NIR bands were processed to obtain NDWI. Later on, the Images yielded from NDVI and NDWI were processed in the QGIS application to come up with the desired results. To have a positive result and verify the data, a field walking survey was initiated in the Bori and Mekhtar tehsil in the district of Loralai to locate the archaeological sites, artefacts, and architecture or other archaeological phenomena associated with the geological features. In the field walking survey, 27 archaeological sites were discovered and categorized as mounded, scattered, natural hill, cave, building and flat sites. The information gathered from Landsat 8 images and field walking enhanced the potential of the cultural heritage of the Loralai district.

Results

The systematic survey was conducted in 2020, 2021 and 2022 in the Loralai district over three weeks. Due to the vastness of the study area and other constraints, it was not possible to survey the entire District. In this survey, it was decided to visit the villages in Borai tehsil, such as Ponga, Dargai Kudezai, Pathan Kot, Azghaloon, and Saggar and covered a total area of 48.8 sq. km within the geographical zone. Also, the first author documented sites in the tehsil of Mekhtar in the villages of Ghabarga, Barad, Zarah, Kishkai Hamzazai, Dargai Sarwaz, and Dargai Shaplo, Sabarwala, Naly Azam and a 331 sq km area was covered during the survey. These tehsils were chosen before the archaeological survey, having rich archaeological sites. These archaeological sites discovered were never visited in the previous surveys by archaeologists and are given in

Table 1 below, and (Fig. 6) and Table 2.

	Borai	Mekhtar
Study Area in (Sq. km)	48.8	331
Sites	09	18
Mounded	06	03
Scattered	02	02
Natural hill	00	02
Flat	01	06
Cave	01	02
Building	00	02

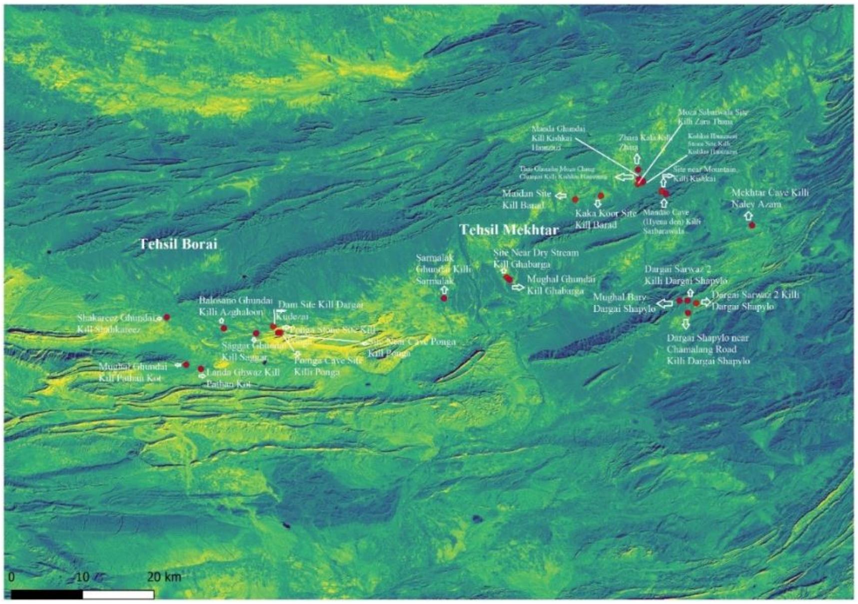

Figure 6: Map showing the distribution of all 27 archaeological sites within the survey areas in the study region. Satellite image Landsat 8 and ASTER GDEM. Courtesy of USGS.

S.No	Site Name	Latitude	Longitude	Zone
1	Mughal Ghundai Killi Ghabarga	30°27'13.05" N	69° 1'15.58"E	Mekhtar
2	Mandao Cave (Hyena den) Sarbarawala	30°34'41.48" N	69°14'54.76" E	Mekhtar
3	Zhara Kalam Killi Zhara	30°36'47.80" N	69°12'27.18" E	Mekhtar
4	Dargai Shapylo near Chamalang Road, Killi Dargai Shapylo	30°24'19.40" N	69°16'49.09" E	Mekhtar
5	Kishkai Hamzazai Stone Site	30°35'41.87" N	69°12'50.53" E	Mekhtar
6	Moza Sabarwala site. Killi Zara Thana	30°35'33.37" N	69°12'26.12" E	Mekhtar
7	Mekhtar Cave Naley Azam	30°31'57.07" N	69°22'24.44" E	Mekhtar
8	Sarmalak Ghundai near Siyab Manda, Killi Sarmalak	30°25'35.75" N	68°55'31.31" E	Mekhtar
9	Ponga Cave Site, Killi Ponga	30°22'35.86" N	68°41'21.34" E	Borai
10	Ponga Stone Site, Killi Ponga	30°22'48.31" N	68°41'2.32"E	Borai
11	Dam Site, Killi Dargai Kudezai	30°23'8.16"N	68°40'35.40" E	Borai
12	Landa Ghwaz ,Killi Pathan Kot	30°19'26.76" N	68°34'17.40" E	Borai
13	Balosano Ghundai, Killi Azghaloon	30°22'58.80" N	68°36'17.64" E	Borai
14	Mughal Ghundai, Killi Pathan Kot	30°19'48.36" N	68°32'60.00" E	Borai

15	Mughal Bary, Killi Dargai Shapylo	30°25'23.70" N	69°16'4.09"E	Mekhta r
16	Saggar Ghundai, Killi Saggar	30°22'31.80" N	68°39'7.20"E	Borai
17	Shakarez Ghundai, Killi Shahkareez	30°23'56.76" N	68°31'18.48" E	Borai
18	Kishkai Hamzazai Site, Zhara Tana	30°35'50.00" N	69°12'49.10" E	Mekhta r
19	Site Near Cave Ponga ,Killi Ponga	30°22'35.62" N	68°41'13.61" E	Borai
20	Site near dry stream, Kill Ghabarga	30°27'25.69" N	69° 0'59.14"E	Mekhta r
21	Thas Ghundai Moza Cheng Chungai, Kishkai Hamzazai	30°35'59.56" N	69°12'32.34" E	Mekhta r
22	Dargai Sarwaz 1. Killi Dargai Shapylo	30°25'23.88" N	69°16'46.84" E	Mekhta r
23	Site near Mountain, Killi Kishkai Hamzazai	30°34'56.01" N	69°14'30.49" E	Mekhta r
24	Manda Ghundai, Killi Kishkai Hamzazai	30°35'49.47" N	69°12'51.88" E	Mekhta r
25	Kaka Koor Site, Killi Barad	30°34'12.47" N	69° 6'58.08"E	Mekhta r
26	Maidan Site, Killi Barad	30°34'31.33" N	69° 9'12.84"E	Mekhta r
27	Dargai Sarwaz 2	30°41'96"N	69°2'922.69" E	Mekhta r

Table 2: archaeological sites discovered within the survey areas in the study region.

4.1 The Vegetation Detection and Change

The NDVI is a simple model that represents green vegetation. An NDVI image of a scene known to contain green vegetation is a thematic map that predicts the relative absorbing power of chlorophyll from pixel to pixel (Adams & Gillespie, 2006: 253-344). It can be compared with dry years followed by wet years in modern times, to get an indication of changing vegetation patterns (Van der Elst 2010: 140). It was used to analyse the status and spatiotemporal dynamics of terrestrial green vegetation, including herbaceous vegetation and forests (Sellers, 1985: 1335-1372). Accordingly, it was used in numerous regional and global applications for studying vegetation with various sensors (Hame et al., 1997:3211-3243; Tucker and Sellers 1986: 1395-1416), and the widely applied NDVI has proven to be valuable to contribute to an explanation of spatial ecological patterns (Pettorelli et al., 2005:503-510). The first author examined the landscape using satellite images to analyze vegetation and change detection. NDVI and NDWI were applied to identify archaeological sites and study vegetation and water, using 11 years of Landsat data (2014–2024). For NDVI, bands 4 and 5 were processed in QGIS, as vegetation indicates suitable agricultural soil. The classified results (Fig. 7, Fig. 8) show denser vegetation near water resources, with settlements utilizing these areas. Red dots mark archaeological sites located close to water structures.

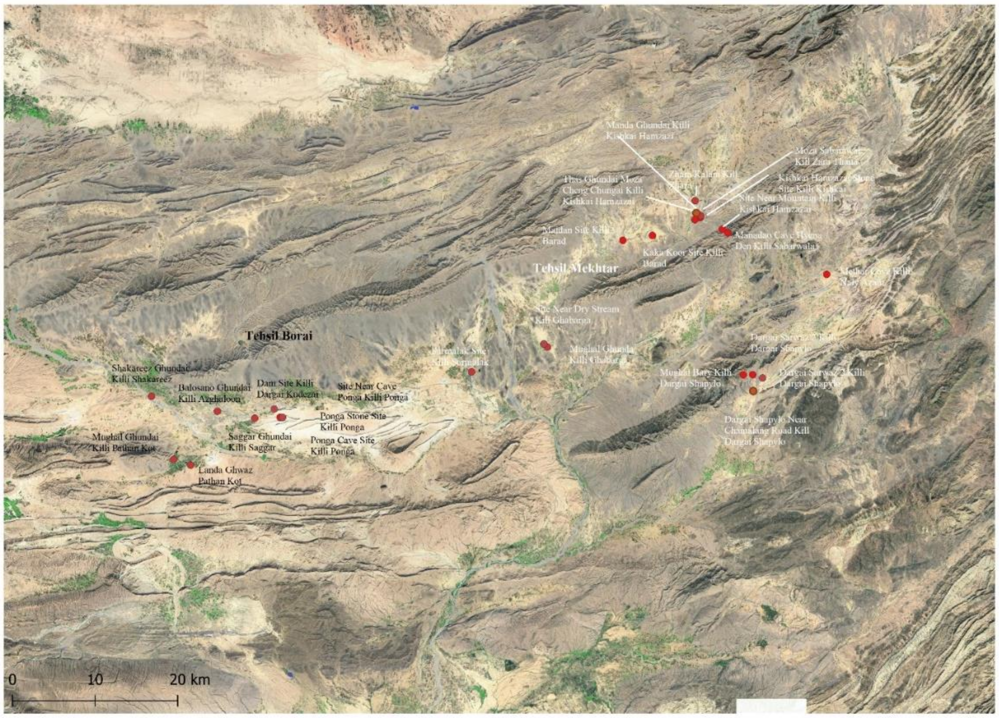

Figure 7: Landsat 8, bands 4 and 5 image captured in 2014, healthy green vegetation can be seen generated using the NDVI algorithm, and red points indicate archaeological sites of district Loralai.

In (Fig. 8), green indicates healthy vegetation, concentrated where water is available, helping visualize rivers, streams, and water resources. The images show that people transformed the natural landscape into a cultural one for cultivation, irrigation, and settlement. Vegetation was denser in 2014 than in 2024. NDVI, using the near-infrared spectral band, measures healthy vegetation and highlights fertile soil. This method is useful for detecting archaeological features, as buried remains alter surface vegetation, revealing sites and fertile areas where past settlements and cultural materials are found. The NDVI equation is: NDVI = (Near Infrared − Red) / (Near Infrared + Red). This equation can also be used on the high-resolution satellite images, where plant activity could be deduced related to the healthy vegetation index (Lasaponara & Masini 2016: 115).

ISSN: 2710-4060 2710-4052 Volume 6, Issue 6, 2025

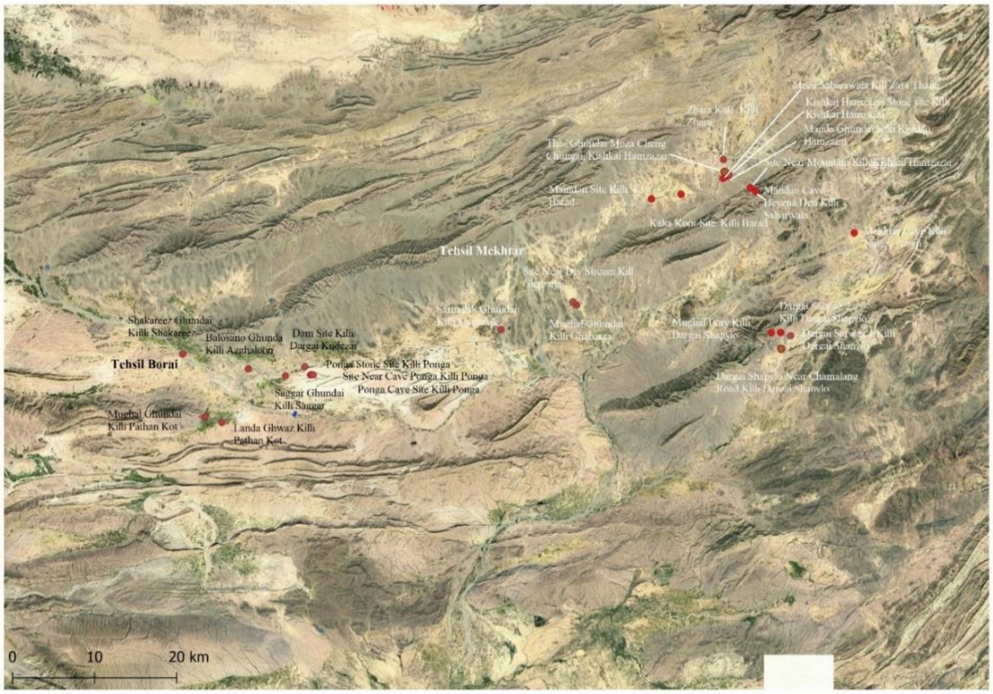

Figure 8: Landsat 8, bands 4 and 5 image captured in 2024, healthy green vegetation can be seen generated using the NDVI algorithm, and red points indicate archaeological sites of district Loralai.

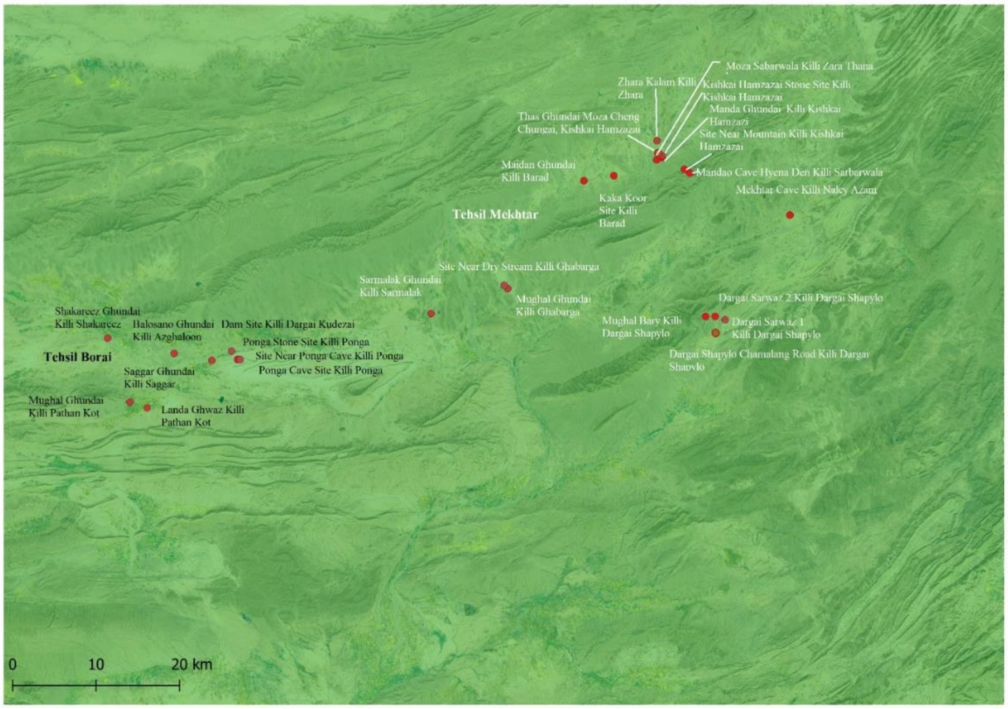

Figure 9: Landsat image illustrating change detection between the 2014 and 2024 satellite images. Green illustrates where healthy, green vegetation has increased, and yellow illustrates where there has been a decline in vegetation over the 11 years.

Landsat 8 bands 4 and 5 from 2014 and 2024 were used to detect vegetation change through remote sensing. The method compares pixel values of earlier and later NDVI images (ΔNDVI = NDVIt2 -NDVIt1) to show increases or decreases in vegetation. Results indicate overall vegetation growth, though some areas show decline, particularly in the Mekhtar tehsil, where archaeological sites cluster near the river. Yellow marks in (Fig. 9) represent non-vegetated areas over the 11 years.

4.2 Surface Water Detection and Change

The concept of the NDWI was first introduced by McFeeters in the delineation of open water features (Ouma & Tateishi 2006: 3157). The NDWI is a new method that has been developed primarily to delineate open water features and to enhance their presence in the remotely sensed digital imagery while simultaneously eliminating soil and terrestrial vegetation features. The NDWI is used in the delineation of open water features. (McFeeters 1996: 1431). It was McFeeters who developed the NDWI using green and NIR bands of a Landsat Thematic Mapper (TM) image to maximize water feature identification (Acharya et al., 2018:2). The other one is a band-ratio approach using two multispectral bands. One is taken from visible wavelengths and is divided by the other, usually from NIR wavelengths. As a result, vegetation and land presences are suppressed while water features are enhanced. However, the method can suppress non-water features but not remove them, and therefore, the NDWI was proposed by McFeeters to achieve this goal (Hanqiu 2006:3025).

In archaeology, it is common to assess surface water using satellite images. For this study, Landsat 8 images from 2014 to 2024 were analyzed. The equation is given below:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

With NDWI, it applies bands 3 (Green) and 5 (NIR) to detect water density (McFeeters 1996: 1425-1432). Positive NDWI values indicate surface water, while negative values reflect soil and vegetation (Fig. 10, Fig. 11). Fig. 10 shows water not only near fluvial areas but also in plain surfaces, whereas Fig. 11 illustrates a decline by 2024, with minimal surface water and reduced availability even near water resources, affecting agricultural land. Overall, water remains limited to rivers and seasonal streams.

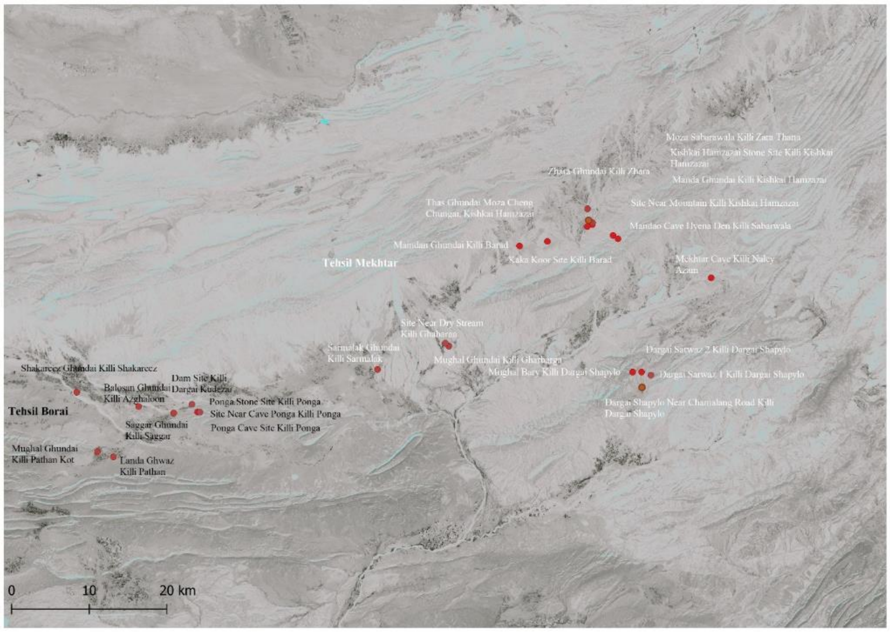

Figure 10: Landsat 8, bands 3 and 5 image captured in 2014, water can be seen generated using the NDWI algorithm, and red points indicate archaeological sites of district Loralai.

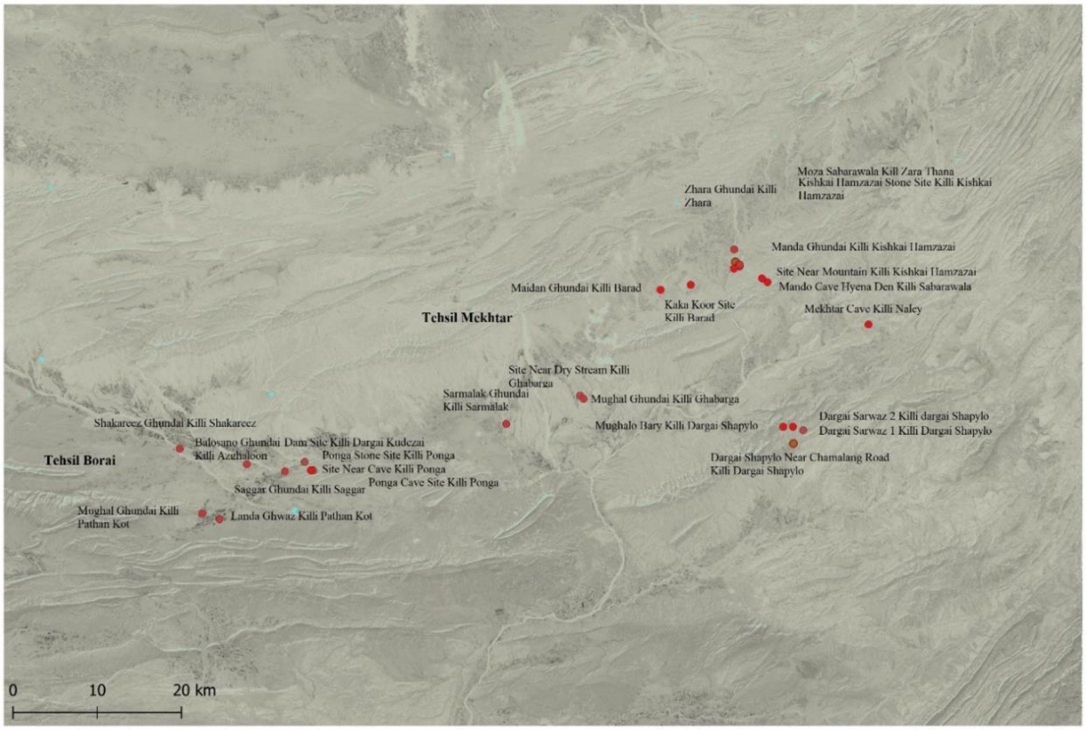

Figure 11: Landsat 8, bands 3 and 5 image captured in 2024, water can be seen generated using the NDWI algorithm, and red points indicate archaeological sites of district Loralai.

The change detection equation was applied to surface water using Landsat 8 images from 2014 and 2024. Similar to NDVI, the NDWI of the earlier period was subtracted from the later (ΔNDWI = NDWIt2 - NDWIt1). The result (Fig. 12) indicates a decline in surface water, particularly along rivers where cultivation occurs close to the banks. Limited areas of surface water increase are marked in red, but overall, the study area shows reduced water availability, with cultivation near rivers influencing their course.

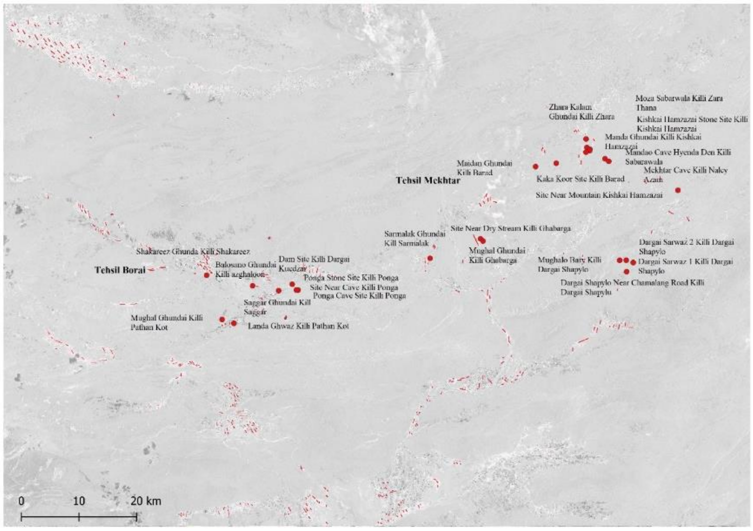

Figure 12: Landsat imagery with red areas showing where surface water has decreased over the 11 and red dots indicate archaeological sites.

5. Discussion

The analysis utilizing the NDVI across Landsat 8 imagery from the years 2014 and 2024 explains several significant patterns in vegetation distribution and its correlation with archaeological settlements in the Loralai district. Both imagery sets document a denser proliferation of vegetation in proximity to rivers, streams, and springs. These regions, where NDVI values denote healthier vegetation, strongly coincide with clusters of archaeological sites (indicated by red dots). It reinforces the hypothesis that ancient communities preferentially established their settlements adjacent to fertile land to facilitate agricultural practices and fulfil domestic requirements. There is another possibility that the vegetation and river courses may have changed little since prehistoric times. Additionally, the analysis reveals an overall increase in vegetation over the eleven years related to the location of ancient sites. However, specific areas, particularly near certain archaeological sites in Mekhtar tehsil, exhibited considerable declines (highlighted in yellow). This finding suggests localized environmental transformations that may be associated with alterations in land use, climatic variability, or agricultural expansion. The continuity of vegetation in proximity to various sites over time emphasizes their strategic positioning within ecologically stable zones. The observed correlation between elevated NDVI values. The site locations suggest that vegetation indices may function as effective proxies for identifying archaeologically significant zones, particularly concerning tell-like mounds and habitation areas where soil fertility was instrumental in fostering long-term settlement. Such observations align with broader archaeological applications of NDVI in remote sensing studies. For instance, (Ginau et al., 2017: 170-184) demonstrated the utility of NDVI in identifying historic landscape features and settlement mounds in the Western Nile Delta, while (Pan et al., 2017:1-20) applied Landsat NDVI time-series to analyze crop phenology and detect archaeological traces in prehistoric settlements along the Yellow River. Similarly, D'Allestro & Parente 2015:42099-42102) emphasized the effectiveness of Landsat 8 NDVI in distinguishing vegetation from non-vegetation areas, and (Ke et al., 2015:1-16) stressed its reliability when compared to multiple satellite sensors and in-situ observations. Together, these studies corroborate the Loralai findings, underlining the significance of NDVI as both a vegetation monitoring tool and a robust proxy for identifying archaeologically significant landscapes, particularly tell-like mounds and long-term habitation zones. The NDWI maps provide an additional analytical perspective by highlighting surface water dynamics and their interaction with both vegetation and patterns of archaeological settlement. The NDWI findings from 2014 illustrate the presence of surface water not only along river courses but also within minor depressions and plains, which may represent small ponds, cultivated water sources, or natural seepage. By the year 2024, these surface water features had markedly diminished, as corroborated by the preceding paragraphs. This observation confirms an overarching decline in surface water availability, particularly in vicinities adjacent to river banks where agricultural encroachment may have modified hydrological processes, diminished infiltration zones, or lowered water tables. The documented reduction in surface water over time may bear significant implications for land-use decisions, both historical and contemporary. Archaeological sites situated near residual water features indicate that ancient settlers may have strategically selected locations characterized by enduring hydrological stability. In contrast, the emerging scarcity of water underscores the vulnerability of these landscapes and stresses the importance of remote sensing technologies in the ongoing monitoring of environmental change. The importance of NDWI in such analyses is reflected in broader scholarship (Taloor et al., 2021: 1-11) proved the combined application of NDWI with land surface temperature (LST) and the normalized difference moisture index (NDMI) in the Ravi Basin to assess climate and environmental change. Similarly, Titolo (2021: 1-39) employed NDWI time-series to monitor the impacts of dam construction and fluctuating water levels on archaeological sites in Iraq. Foundational work by (Gao1996: 257-266) highlighted NDWI's capacity to capture vegetation liquid water content, complementing NDVI in ecological and archaeological studies. (Xu 2006: 3025-3033) refined NDWI methods to enhance open-water detection in remotely sensed imagery, while (Ji et al., 2009: 1307-1317) analyzed dynamic thresholds for more accurate surface water delineation. Comparative evaluations have further illustrated NDWI's utility: (Acharya et al., 2018: 1-15) tested NDVI, NDWI, MNDWI, and AWEI for surface water extraction in Nepal's varied topography, while (Mondejar & Tongco, 2019: 1-15)applied multiple water indices-including NDWI, MNDWI, AWEI, and the NIR band-to Landsat 8 imagery in the Philippines, demonstrating varying effectiveness depending on environmental context. Collectively, these studies, when viewed alongside the Loralai results, affirm NDWI as a robust proxy for monitoring hydrological variability, environmental stress, and the long-term sustainability of archaeological landscapes. The chemistry between the NDVI and NDWI indices offers a comprehensive understanding of the archaeological landscape. Ancient settlements appear to have been intentionally located in areas where vegetation and water coexisted. The converging signals from NDVI and NDWI bolster a model of settlement selection predicated on environmental optimization. The observed decline in surface water, even in certain vegetated areas, implies that while vegetation may exhibit short-term resilience, and reductions in water supply could gradually impair agricultural viability and site suitability and thereby affecting settlement continuity or instigating shifts in habitation patterns. This integrated methodology serves as a robust instrument for heritage researchers and managers. It can also work with the identification of zones exhibiting a high degree of overlap between NDVI and NDWI and reveal both known and previously undocumented sites with significant preservation potential. The temporal sequences of NDVI and NDWI can illuminate historical trends in land-use intensification, aridification, or hydrological shifts that have fundamentally influenced human adaptation. Such an integrated approach aligns with broader applications of spectral analysis in archaeology. For example, *Kalayci et al. (2019: 1-23) analysed the spectral responses of hollow ways in Upper Mesopotamia, demonstrating* how precipitation and hydrological variability directly affected their visibility and spectral contrast when examined through NDVI, NDWI, and multispectral imagery from CORONA and Landsat 8. Their work highlights how vegetation and water indices, when combined, provide a multi-scalar framework for detecting subtle anthropogenic features embedded within dynamic landscapes. In this context, the combined use of NDVI and NDWI emerges as a robust methodological tool, not only for monitoring environmental and hydrological stress but also for advancing archaeological prospection and cultural heritage management.

6. Conclusion

The archaeological explorations were conducted in three phases within the Borai and Mekhtar tehsils located in the Loralai District. A desk-based and field walking methodology was utilized. The implementation of NDVI and NDWI, in conjunction with field walking surveys, proved successful in discerning archaeological sites. These methodologies not only enabled the successful identification of sites but also gave insightful perspectives on human-environment interactions within the semi-arid landscape of Loralai, Balochistan. Significantly, such applications of remote sensing had not been previously used in Balochistan, nor extensively within Pakistan. The employed techniques were potentially effective in identifying sites and validated through ground-truthing during field surveys. The integration of remote sensing with traditional survey methodologies highlights its effectiveness in archaeological inquiry. In future, archaeological investigations should build upon and utilize remote sensing not solely for site identification but also for documentation, heritage management, strategic planning, and interpretation.

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