

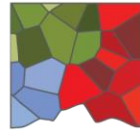


**Hagler Baily** Pakistan



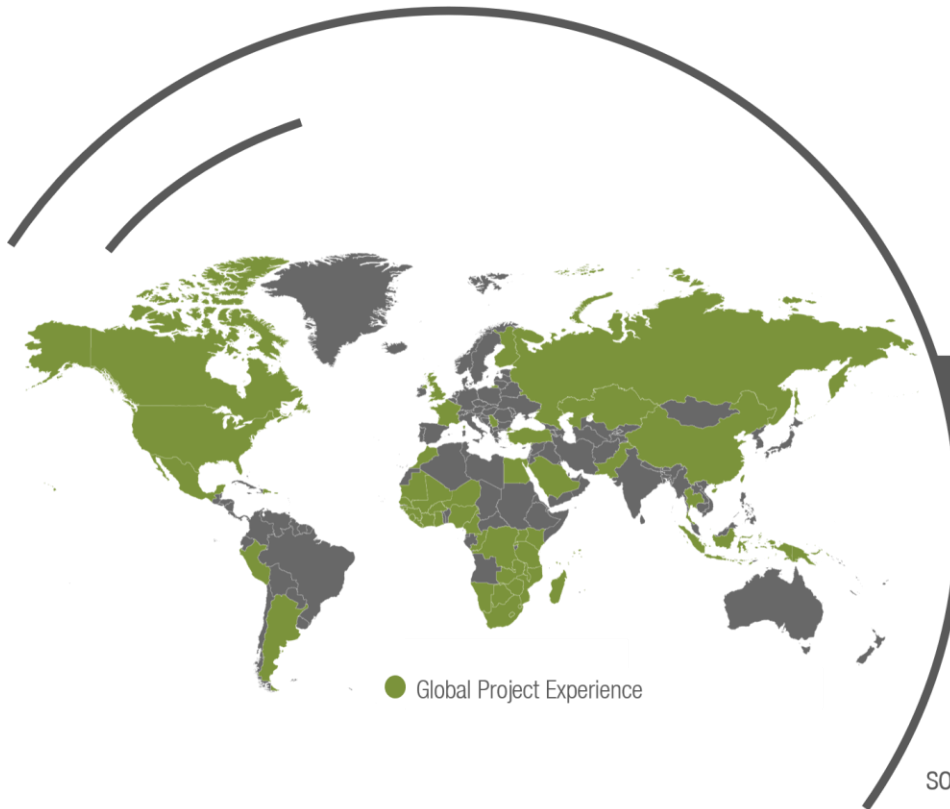
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## Appendix X: Remote Sensing Report



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## Reko Diq Remote Sensing Assessment: Phase 2

### Remote Sensing

**Prepared for:**  
Barrick Gold Corporation

**Project Number:**  
BAR7212-03



June 2024



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## EXECUTIVE SUMMARY

Digby Wells Environmental has undertaken a remote sensing based assessment which specifically aims at the identification of potential water usage receptors in the region surrounding the proposed Reko Diq Mine. Along with the identification of these receptors, the remote sensing assessment aimed to create a historical baseline that utilises remote sensing technologies. Based on the first phase analysis that was conducted as part of the assessment, the sensitive receptor locations which are referred to as the focus assessment areas, include:

- The Lav Ab/Rig Chah region (located in Iran) which is located 20-kilometers from the border between Pakistan and in close proximity to the Gaud-i-Zirreh/Hamun-e-Helmand system ;
- The upper Tahlab region, located on the Pakistan/Iran border; and
- The Hamun-i-Mashkhel region, representative of the lower Tahlab region, also located on the Pakistan/Iran border.

While there are well-documented dispersed settlements around the proposed mine development site, a focus was placed on receptors that have a significant water usage association, which in the region is largely dominated by agricultural practice.

The region, along with the focus assessment areas, were subjected to a series of analytical procedures conducted in a Geographic Information Systems (GIS) based environment to understand the landcover and vegetation dynamics in relation to precipitation and groundwater mass indicators between the year 2000 and 2023. The quantitative assessment was conducted for every 3 years using the available archives of remotely sensed data, which was subjected to a series of algorithms to produce landcover inventories in the form of a landcover classification and an assessment of vegetation response and coverage.

The results indicate a positive relationship between received rainfall and the occurrences of vegetation, where increases in rainfall are associated with increases in vegetation response. When compared to the focus assessment areas, which are largely composed of agricultural activity, the level of relationship is significantly lower indicating that there is no specific reliance on precipitation for the sustenance and growth of the vegetation. These findings are consistent with the existing baseline knowledge of Chagai district, particularly in the north-western sector which is regarded as water scarce and relies heavily on groundwater abstraction. The landcover analytics indicate that the focus assessment areas have significantly grown in terms of agricultural land usage, far outweighing the growth in settlement activity, further characterising the areas as agricultural production zones.

The results observed from the remote sensing assessment are largely consistent with observations of the regional groundwater mass for the area, indicating that large-scale groundwater abstraction is the primary source for the rapid rates of plantation development observed in the focus assessment areas from the period between 2000 and 2023.

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## ACRONYMS, ABBREVIATIONS AND DEFINITION

CHC	Climate Hazards Center
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
GIS	Geographic Information Systems
GRACE	Gravity Recovery and Climate Experiment
mamsl	meters above mean sea level
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NIR	Near Infra-Red
nm	nanometers
USGS	United States Geological Survey

## 1. Introduction

Digby Wells Environmental (hereafter Digby Wells) has been appointed to undertake a remote sensing based assessment that aims to identify areas of environmental sensitivity. The assessment utilised a series of Geographic Information Systems (GIS) and remote sensing based techniques to delineate land cover classes in the region. Of particular importance for the study, was to identify the potential water usage receptors in the region in the form of settlements and agricultural produce areas.

The assessment was conducted using a phased approach, where Phase 1 included a landcover classification and vegetation indices using imagery sourced from 2023, which aimed at creating a baseline representative dataset of the region in its current state. In addition, the Phase 1 assessment aimed at identifying focus areas that could be subjected to a time-based assessment ranging from the year 2000 through to 2023, which forms this report, the Phase 2 assessment. The specific objectives for the Phase 2 assessment were:

- Creating data inventories for landcover and vegetation indices, for the Winter and Summer periods for each year;
- Investigating the changes observed in the flagged focus areas where potential receptors were identified as part of Phase 1; and
- Interpreting and supporting the observations through the available remotely sensed climate indicators available.

## 2. Project Background

### 2.1. Locality

The assessment area is located in the Chagai District, in the North Western region of the Balochistan Province of Pakistan. The district region shares a border with Afghanistan to the North and Iran to the West and South. The regional topography has a high variance, with elevations within the dry lake/river bed regions of Gaud-i-Zirreh and Hamun-i-Mashkhel averaging between 450 and 500-meters above mean sea level (mamsl) to the Koh-i-Sultan volcanic feature at approximately 2,000 mamsl. Figure 2-1 shows the regional topography for the area.

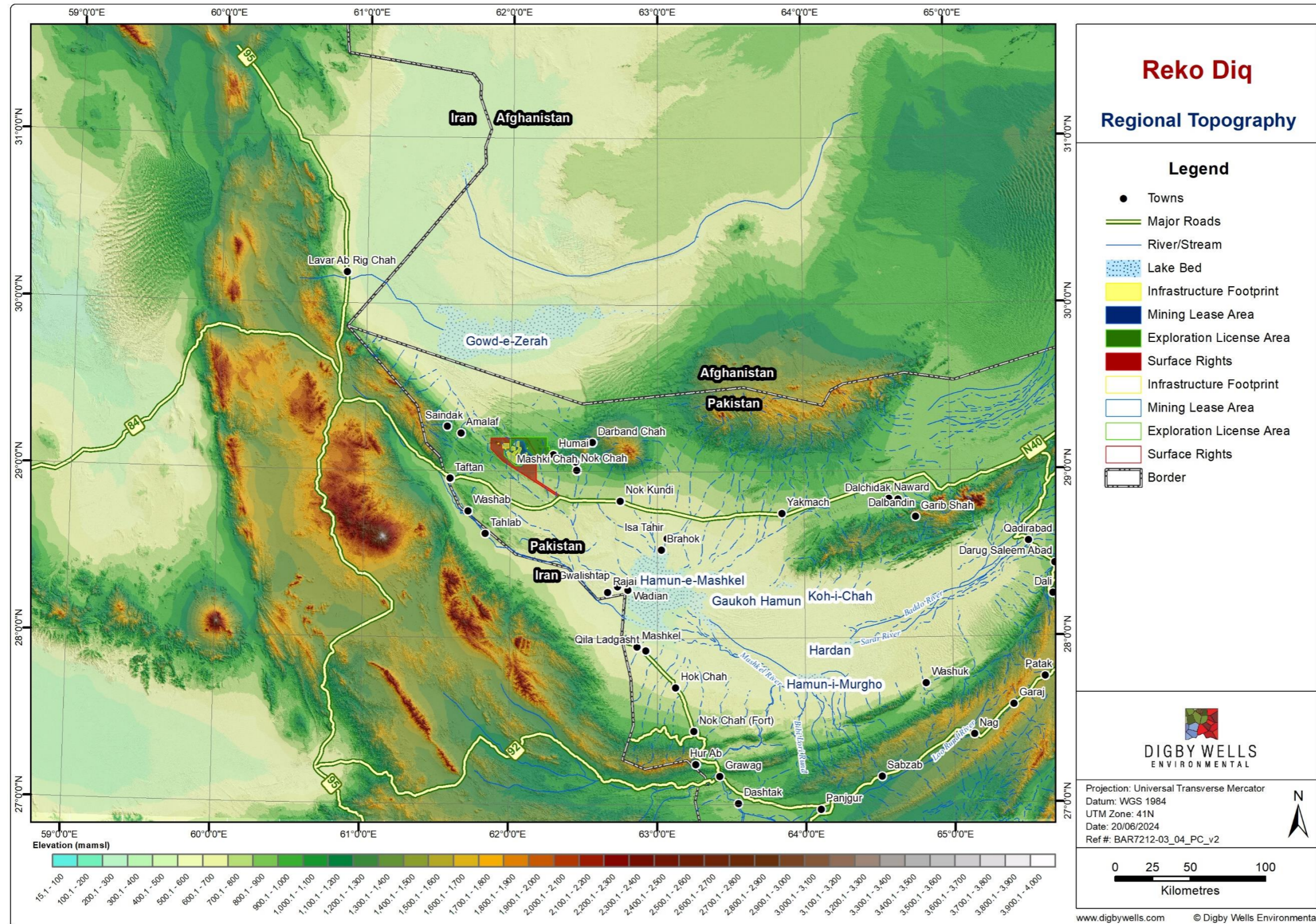


Figure 2-1 Regional topography

## 2.2. Land Usage in the Region

As per the 2017 census for the district, there are approximately 33,000 households with a population estimated at 226,000. Landcover in the area is characterised by dry desert plains with exposed rock outcrops, many of which form part of the linear folded mountains in the region. There are innumerable channels and hill torrents which originate from the mountains and flow downwards during rains; these are known as Nawars or seasonal nullahs. Very little water, however, reaches the lake basins (hamuns). In the assessment area, besides the seasonal streams, two rivers are of principal importance. One is the Tahlab River, which originates in Iran, and enters Chagai from the southwest near Killa/Qila Sufed. It flows along the southwest of the district and the southern boundary with Iran. In the rainy season, it has enough water to reach Hamun-i-Mashkel. The other, a tributary of the Tahlab, is the Mirjawa River. There are occurrences of isolated herbaceous plants, small trees and grasses that occur along river bed courses. There are recordings of vegetation that can be found along sand-dune formations in the Saindak region indicating an interaction between the groundwater and vegetation in the region at a local scale. Date Palm plantations along with other relatively small-scale agricultural activity can be found along water courses and sections of dry lakes where groundwater usage practices sustain the agricultural activity.

## 2.3. Regional Climate

Historical climate from the western Chagai district indicates a dry summer ranging from May to September, followed by a relatively wetter winter period from October to April, as shown in Figure 2-2.

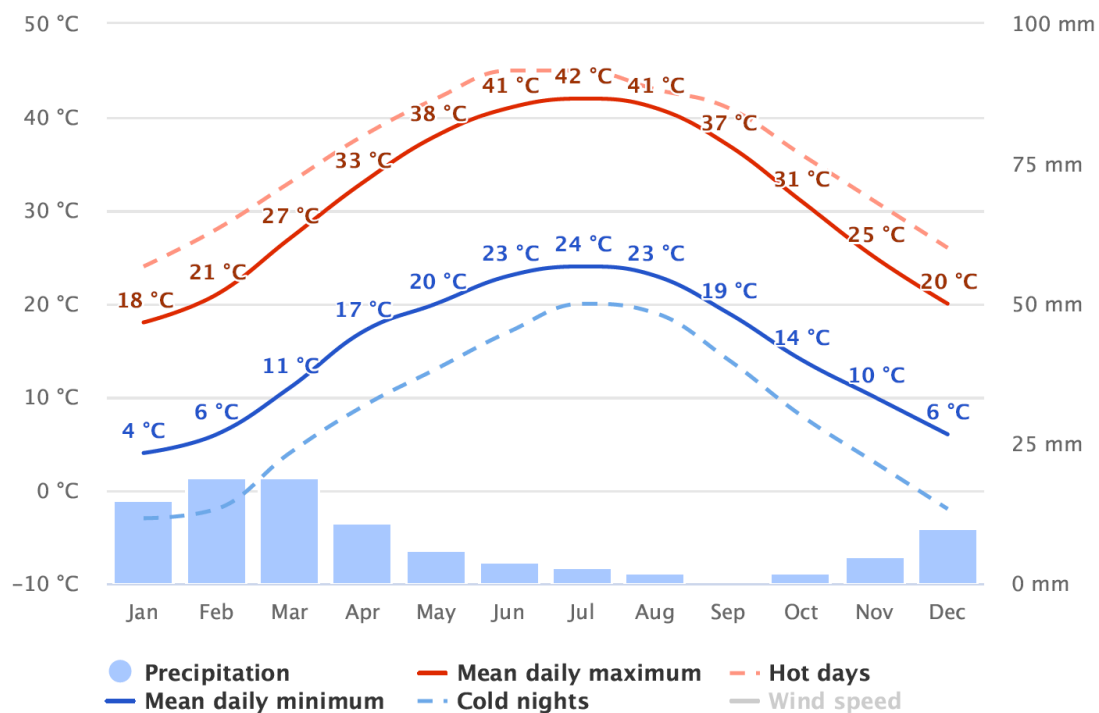
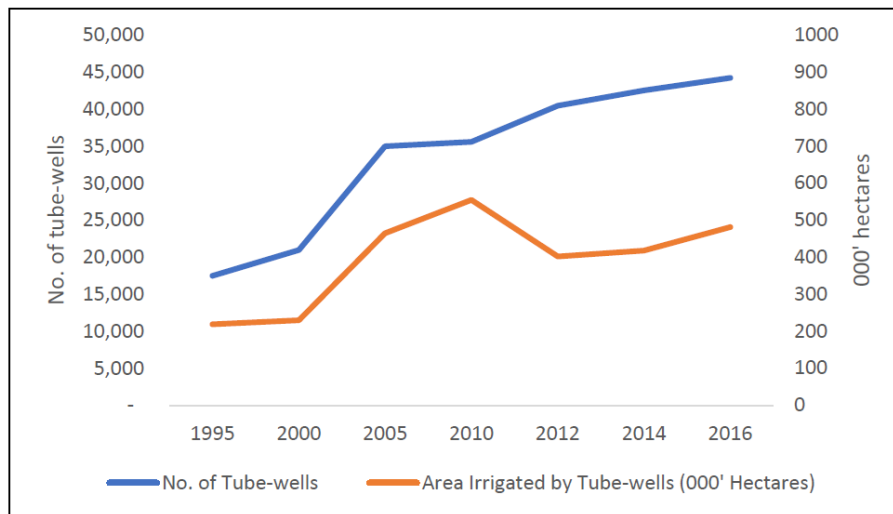


Figure 2-2 Historical climate data for the western Chagai district (Meteoblue, 2024)

The region has been described as water scarce, with groundwater being the main source of water for sustenance for agricultural activity and livelihood. Groundwater has historically been accessed by shallow wells and karezes; a system of tunnels that collect and deliver groundwater over a length between 500-meters to 300-kilometers (van Steenberg, 2002). The region receives on average 13.4-millimeters of rainfall per annum, of which the majority of the received rainfall flows to shallow depressions where high rates of evaporation occur. Direct rainfall for the region accounts for less than 15% of the total crop water requirements, with the remainder being supplied by irrigation practices (Qureshi *et al.*, 2004). The surface water resources are marginally sufficient to support agricultural practices throughout the year which places a dependency on groundwater resources in the region.

#### **2.4. Historical Overview of Agricultural Activity in Relation to Groundwater Interactions**

In the latter part of the 1960's, dug-well development and usage was stimulated by a range of government programmes which specifically subsidised the development costs for farmers in the Balochistan province (WAPDA, 1977). In addition to the uptake in dug-wells, development was further accelerated through the provision of cheap electrification which had a flat rate for water abstraction associated with the agricultural activity, bearing no relation to the consumption of electricity (van Steenberg, 2002). As a result, many dug-wells were converted into electrified tubewells. Over-pumping activities were encouraged with a very low electricity expense with a perceived unlimited water supply. Interventions were applied by the Chief Minister in 1999 to address the flat electricity tariff for dug-well schemes, but a slow recovery of electricity charges from the process has left the abstraction of groundwater largely unchecked. The same period saw numerous developments in transportation networks, which saw an upsurge in the cultivation of high value fruits and vegetables, including the production of dates. Inevitably, the groundwater resources in the Balochistan province was recorded with a decline rate of 0.25 to 1.10-meters a year as of 1992 (WAPDA, 1992). As of 2010, the decline was estimated at 2 to 3-meters a year (Khair *et al.*, 2010). The trend of increased reliance on groundwater resources has continued since, as shown in Figure 2-3 (Balochistan Bureau of Statistics, 2017), with a continued trend in the decrease in groundwater resources.



**Figure 2-3 Growth of recorded tubewells and area irrigated by tubewells between 1995 and 2016**

## 2.5. Date Palm Tree Plantations in the Chagai Region

The agricultural produce in the assessment area are predominately date palm plantations, with the previous section highlighting the reliance on groundwater resources for sustenance. The daily net irrigation requirement of date palm trees in arid areas such as the assessment area varies from 97-litres/day per tree in December (Representative of the wet season) to 854-liters per day per tree in June (Representative of the dry season) (Abdul-Salam and Al-Mazrooei, 2007). The minimum water for one tree per year for minimal vegetative growth and yield is estimated at 25m<sup>3</sup>. In the assessment area, date palm plantations are typically scattered in isolated locations that are closely linked to the availability of groundwater resources. The plantations in the region are typically divided into irrigated plantations and non-irrigated plantation systems.

Where the plantations are irrigated, the groundwater is typically a depth of over 17-meters. The date palm tree does not extend its roots more than 2-meters below the surface. If there is a deficiency of irrigation water, the tree will extend its roots to access the water in the range of its root system. The more mature trees rely exclusively on pumped groundwater to provide the irrigation water, with the root systems being adapted to the depth at which the water is available. Due to groundwater in these irrigated areas being deeper, its access appears to be supported by the availability of cheap electricity and diesel fuel. Water is delivered to the date palm plantations through unlined surface channels connected to a holding basin or a small reservoir which is fed by a pump. In irrigated areas, plantations are irrigated approximately twice a week in the summer and once a week in the winter (Abul-Soad *et al*, 2009).

Where the plantations are non-irrigated, the depth of groundwater typically is less than 4-meters, where the mature trees depend on the shallow groundwater and are not irrigated by the growers (Abul-Soad *et al*, 2009).

## 2.6. The Gaud-i-Zirreh Depression

The Gaud-i-Zirreh depression is the lowest part of the Sistan Basin. The Sistan Basin, covering large parts of Afghanistan and Iran, is composed of a complex system of rivers, shallow lakes that drain into the Hamun wetlands in south eastern Iran region. The Hamun wetlands are comprised of three areas known as Hamun-i-Puzak, Hamun-i-Sabari and Hamun-i-Helmand that are fed by various seasonal water tributaries, with the main source being the Helmand River that originates from the central region of Afghanistan. The Helmand river traditionally flows into the hamuns in a counterclockwise direction (Shroder & Ahmadzai, 2016), starting at Hamun-i-Puzak (Located in Afghanistan), flowing into Hamun-i-Sabri (a transboundary Hamun located on the border) and then onto Hamun-i-Helmand. Outflows from the Hamun-i-Helmand, which are reported to occur every decade, head back into Afghanistan via the Shela Rud to Gaud-i-Zirreh.

The Sistan basin has historically been a sensitive region with regards to disputes over the distribution of water from the Helmand River. The construction of various dams and barriers along rivers that from part of the Sistan Basin have had a large impact on the hamuns in both Afghanistan and Iran, ultimately affecting Gaud-i-Zirreh. Notable dams and barriers in the region include –

- The Kajaki Dam, constructed between 1951 and 1953 is located on the Helmand river approximately 160-kilometers northwest of Kandahar. The Kajaki Dam controls the output of the main watershed that feeds the Sistan Basin.
- The construction of four Chahnimehs (artificial lakes) in Iran in 1981 ( Goes *et al*, 2015,) to supply water to the Iranian cities of Zahedan and Zabol (Sharifikia, 2013) have contributed to negative impacts on the water resources within the Hamun wetlands (Van Beek et al. 2008), which in turn affects Gaud-i-Zirreh. The chahnimehs are fed by a diversion canal located at the Helmand Fork; and
- The Kamal Khan Dam, located on the Helmand river approximately 70-kilometers south of Zaranj was completed in 2021, furthering the control in the region over water resources the handle the regions agricultural and infrastructure challenges. Water from the Kamal Khan dam is diverted towards the Gaud-i-Zirreh via the Kushk Rud, with a recorded discharge in 2022 as shown in Figure 2-4.

Figure 2-5 provides an overview of the Sistan Basin summarising the descriptions above.

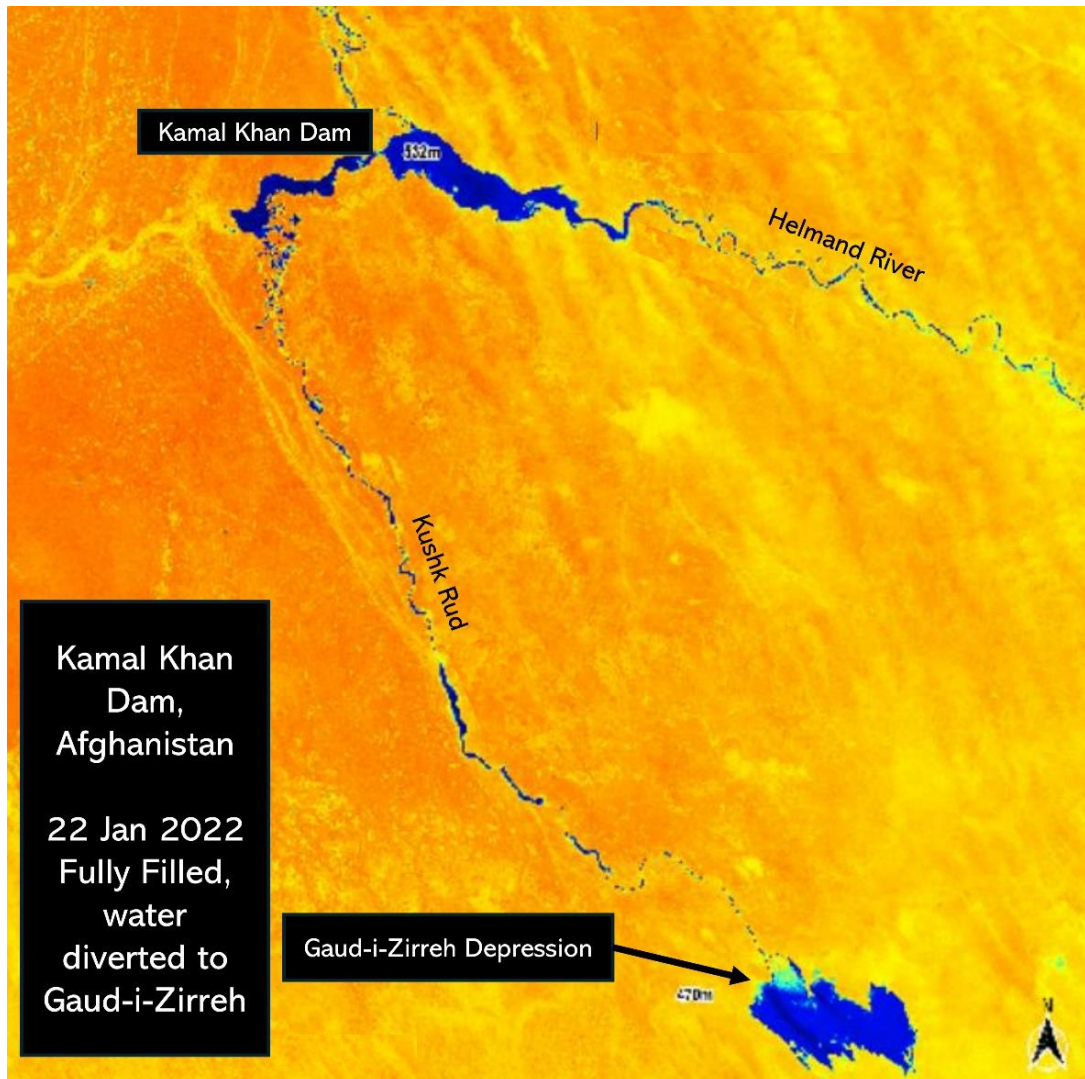


Figure 2-4 Kamal Khan Dam - Gaud-i-Zirreh Interactions (Modified, Soar Earth, 2022)

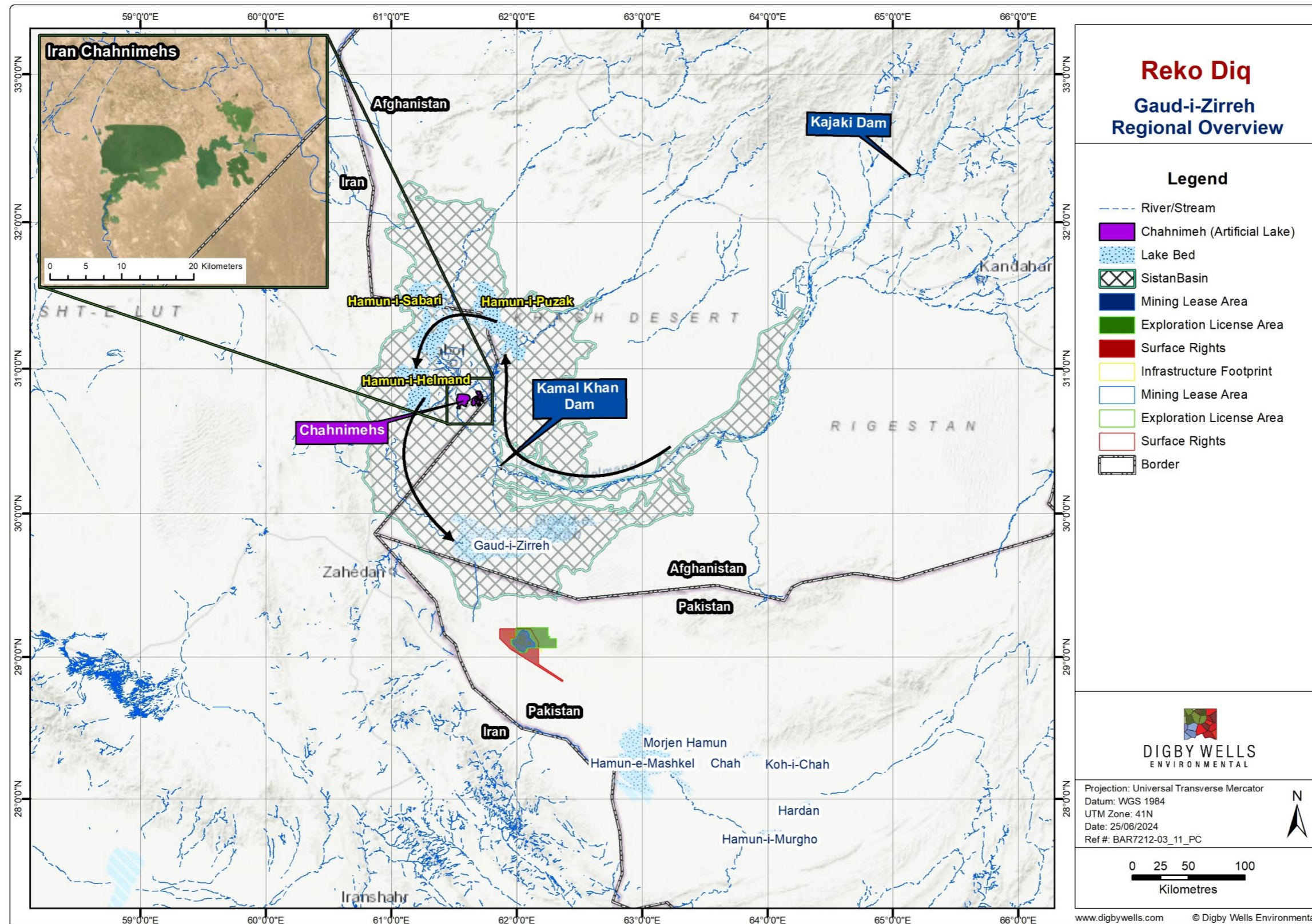


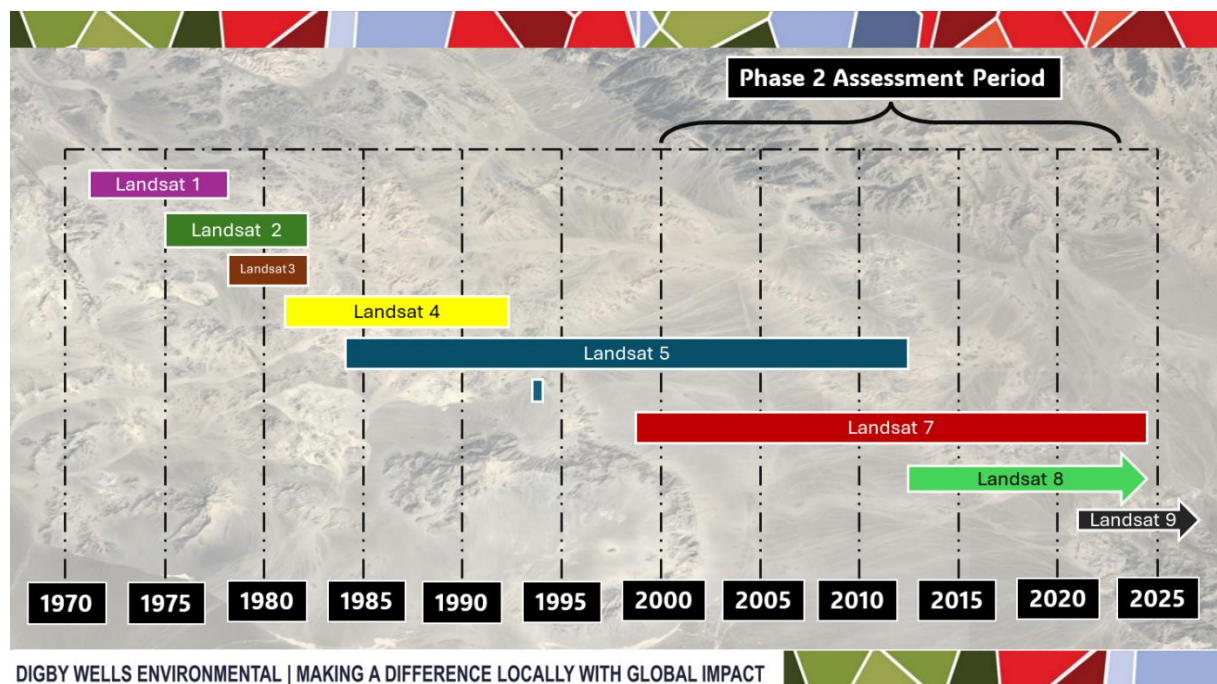
Figure 2-5 Gaud-i-Zirreh Regional Overview

### 3. Data

Remotely sensed data in the form of satellite imagery was utilised in this assessment, ranging from the year 2000 up to 2023. The focus of the Phase 1 and Phase 2 assessments was to utilise readily available imagery from the Landsat programme to gain a regional understanding of the assessment area. Various other readily available satellite imagery sources were also used to compliment the assessment, in the form of Moderate Resolution Imaging Spectroradiometer (MODIS) and the Google Earth platform. The Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data was also used to further support the trends and changes observed in the focus areas. More information relating to each data component is detailed below.

#### 3.1. Landsat Satellite Imagery

The Landsat programme is jointly managed by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS). The programme, spanning for the last 50 years since the launch of Landsat 1 in 1972 represents one of the largest repositories of continuous monitoring over the Earth's surface. For this particular assessment, the Landsat 7, 8 and 9 sensors were utilised as they coincide with the assessment date range between the year 2000 and 2023. Figure 3-1 provides an overview of the Landsat programmes timeline and the Phase 2 assessment period. Table 3-1 provides the details of Landsat satellite usage for each assessment period.



**Figure 3-1 Landsat programme timeline in comparison to the Phase 2 assessment period**

**Table 3-1 Landsat Acquisition details for Phase 2**

Acquisition Year	Acquisition Month	Representative Period	Satellite
2000	January	Winter, Higher Precipitation	Landsat 7
	June	Summer, Low Precipitation	Landsat 7
2002	January	Winter, Higher Precipitation	Landsat 7
	June	Summer, Low Precipitation	Landsat 7
2006	January	Winter, Higher Precipitation	Landsat 7
	June	Summer, Low Precipitation	Landsat 7
2009	January	Winter, Higher Precipitation	Landsat 7
	June	Summer, Low Precipitation	Landsat 7
2012	January	Winter, Higher Precipitation	Landsat 7
	June	Summer, Low Precipitation	Landsat 7
2015	January	Winter, Higher Precipitation	Landsat 8
	June	Summer, Low Precipitation	Landsat 8
2018	January	Winter, Higher Precipitation	Landsat 8
	June	Summer, Low Precipitation	Landsat 8
2021	January	Winter, Higher Precipitation	Landsat 8
	June	Summer, Low Precipitation	Landsat 8
2023	January	Winter, Higher Precipitation	Landsat 9
	June	Summer, Low Precipitation	Landsat 9

Each Landsat scene covers an area of approximately 170 kilometres north-south and 183 kilometres east-west, and has a spatial resolution (referring to the size of each discrete pixel) of 30 x 30 meters. Multiple scenes were utilised per acquisition period, with priorities given to acquisition dates that were either acquired on the same day, or within a 16 day period (where the 16 day period refers to the typical Landsat programmes temporal resolution; the frequency at which the satellite captures an image over the same area). Figure 3-2 shows the general assembly of Landsat scenes encountered throughout the assessment per year.

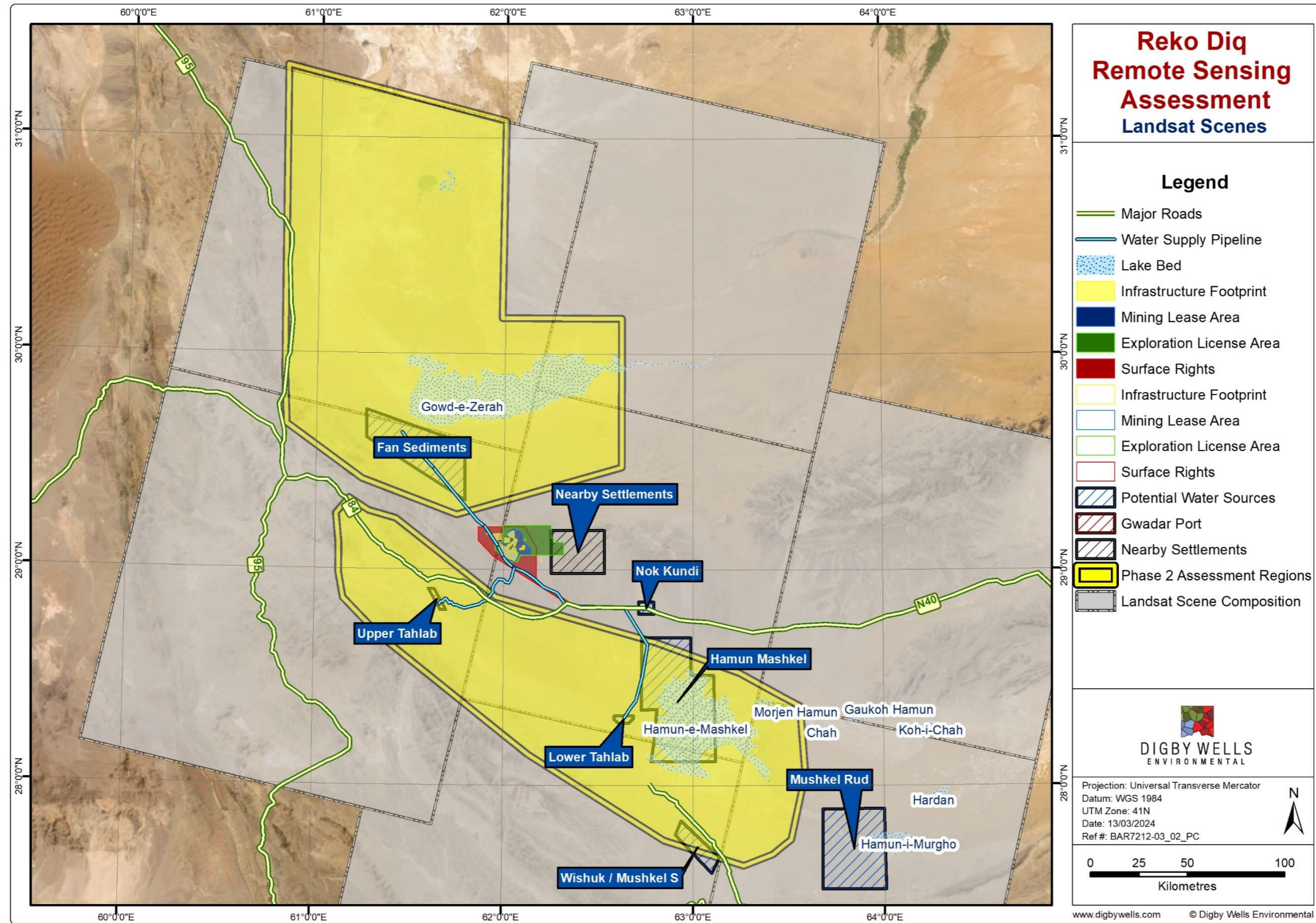
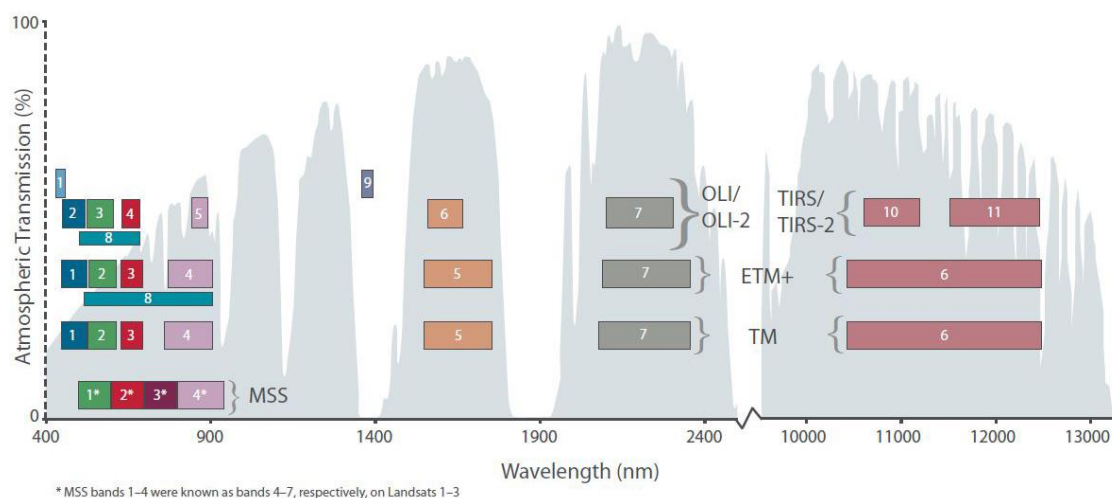


Figure 3-2 Landsat scene composition

In order to utilise various scenes across all assessment periods, the Landsat Level 2 products were utilised to eliminate the requirement for atmospheric correction, resulting in a significant time reduction in the processing and amalgamation of the outputs from the analysis.

The band composition of the various Landsat satellites is shown in Figure 3-3. The full band range from Landsat 7, 8 and 9 were applied as part of the landcover classification, while the Red, Green, Blue and Near-InfraRed bands from the same satellites were used as part of the vegetation assessments.



**Figure 3-3 Landsat band composition**

### 3.2. MODIS

MODIS is an instrument on board the Terra and Aqua satellites, acquiring imagery across the Earth with 36 spectral bands at spatial resolutions between 250 meters and 500 meters. The MODIS data acquired throughout the assessment area provides a means of cross referencing the trends observed in the vegetation assessment through a linear vegetation trend analysis.

### 3.3. CHIRPS

CHIRPS is a quasi-global rainfall dataset with over 35 years of recorded data. The dataset is supported by the USGS and Climate Hazards Centre (CHC), with the aim of producing and recording rainfall data in regions where in-situ data is sparse. The dataset incorporates data from several meteorology focused satellite sensors along with station measurements located on site. Interpolation techniques along with predictive models are applied for sparse areas that lack ground station data. The spatial resolution is relatively coarse at 31 square kilometres. The CHIRPS data provides an additional layer of context to the assessment in the form of detecting rainfall patterns through time.

### 3.4. GRACE

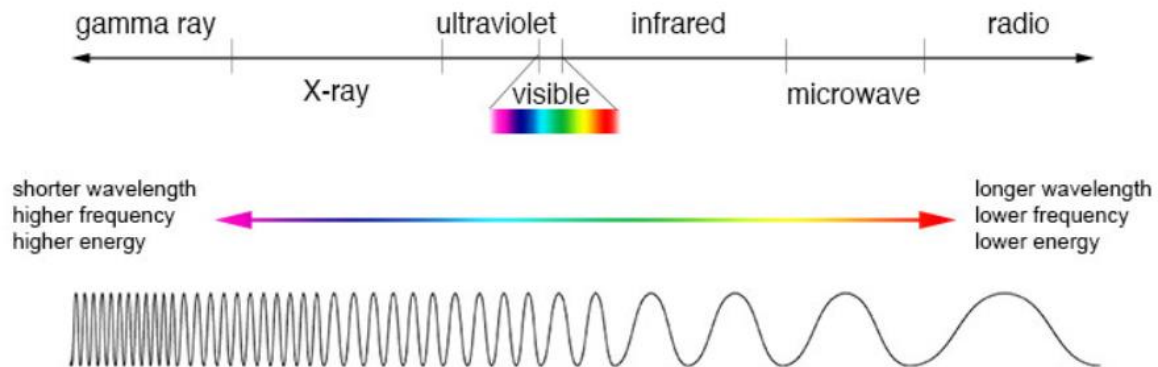
The Gravity Recovery and Climate Experiment (GRACE) data used in this assessment originates from a twin satellite constellation that focuses on measuring details of the Earth's gravitational field changes. These gravitational changes have relationships to the Earth's water resources, which is the focus of application in this assessment. The dataset has 15 years of recorded data, with a spatial resolution of approximately 400 square kilometers, providing regional context to an area's water changes over time. For this assessment, access of readily available GRACE data was for the period between 2004 and 2016 and was restricted to the defined focus assessment areas. The GRACE data is portrayed in units of equivalent water thickness which represents the deviations of mass in terms of vertical extent of water in centimetres.

### 3.5. Google Earth

Google Earth is a geo-browser that accesses and displays spatial data over a three-dimensional globe. At any location on the Earth, Google Earth will render a satellite image of a resolution based on viewing distance, along with the available vector based data for context (Rivers, towns, political borders, roads, etc). The platform uses a variety of satellite imagery from various sources and is served at no cost. The utilisation of Google Earth in this assessment was to proof the landcover process and add an additional level of integrity to the landcover classification through a digitising campaign specifically aimed at the built-up area locations of settlement. There are spatial resolution limitations associated with the data coverage, as there is no guarantee of a full archive collection within the Google Earth platform from 2000 up to 2023. Any available imagery at the time of the compilation of this assessment was utilized.

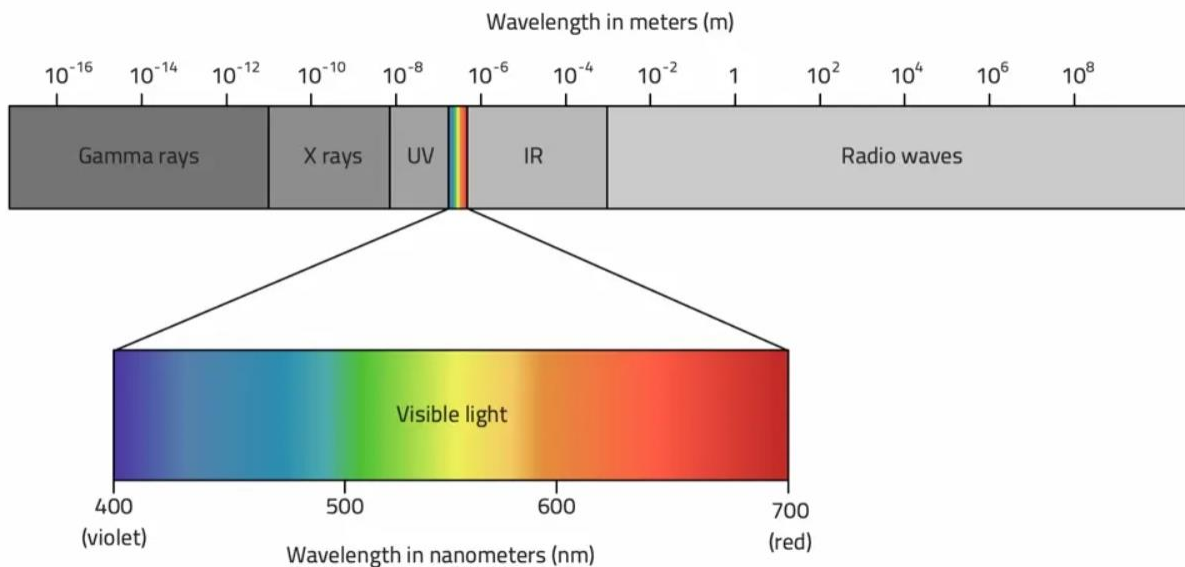
## 4. Methodology

Remote Sensing is the science of acquiring information about an object without physical contact. Common remote sensing techniques include satellite imaging, aerial photography, radar and sonar surveys. The principle of remote sensing revolves around the Electromagnetic Spectrum, which represents all types of electromagnetic (EM) energy radiated from or reflected by the earth's surface, of which the Sun is the most abundant and widely used source in the field of remote sensing. Figure 4-1 below provides a graphical illustration of the electromagnetic spectrum, which is broken into Gamma Rays, X-Rays, Ultraviolet, Visible, Infrared, Microwave and Radio waves.



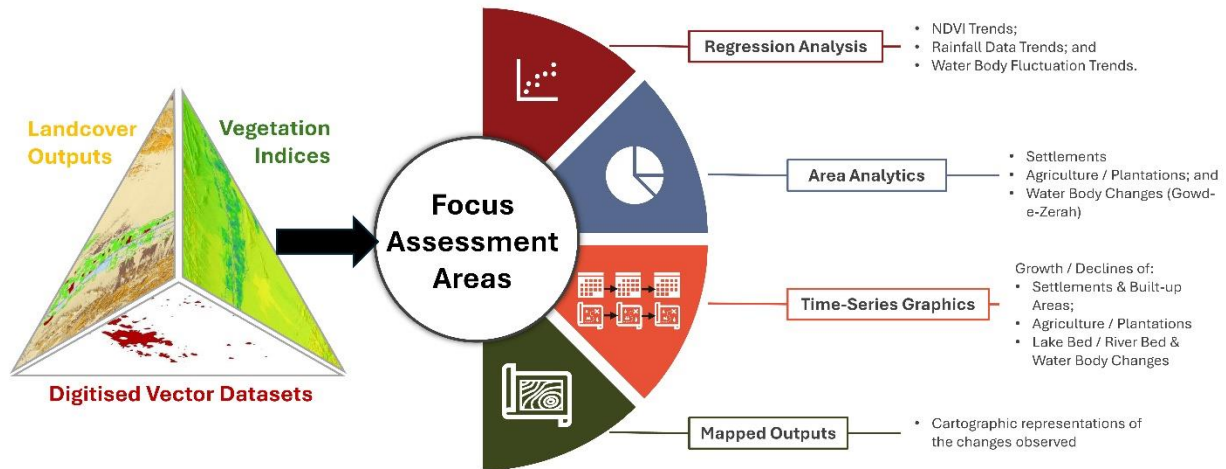
**Figure 4-1 Electromagnetic spectrum**

Each portion of the EM spectrum is characterized by wavelength (measured in meters), and we can therefore assign various portions with specific wavelength intervals as per Figure 4-2. The visible portion of the spectrum, through which human eyesight operates ranges from 400 to 700 nanometers (nm), which is a small portion relative to the entire spectrum. Remote sensing aims to understand what interactions occur both inside and outside of the visible spectrum in the environment by measuring the amount of reflected / radiated off a surface.



**Figure 4-2 Visible light (Blue, Green, Red) component of the Electromagnetic spectrum**

The sub sections that follow provide outlines of the methodology followed for the landcover and vegetation assessment components. Figure 4-3 provides a summary of the overall methodology applied.



**Figure 4-3 Summarised methodology overview**

#### 4.1. Landcover Classification

In order to categorise pixels that make up each image, a semi-supervised landcover classification process was applied to each scene, which was subsequently merged with the intention to create a seamless landcover representation for each period over the assessment areas. The general workflow for the classification is outlined below.

- **Collection of training data** – This was done using a discrete selection of pixels of which the landcover class was assessed against high resolution satellite imagery (in this case, Google Earth reference imagery). The properties of the unique class including the numeric values from the full range of the Landsat imagery is stored in a library.
- **Training of the classifier** - The classifier, which is based on a Google Earth Engine framework, is then trained using the library of stored known classes. Several reference points for any single class are statistically compared for similarities, from which the classifier through a machine learning algorithm approach further refines the parameters to determine discrete classes.
- **Classification of pixels that are statistically different from the library** - Pixels that deviate significantly from the library are further subjected to a unsupervised classification procedure, where the algorithm is used to assemble the numeric values of pixels that make up the image and generate a defined number of unique landcover classes. For this particular application, 14 classes were generated as part of the unsupervised component of the classification.
- **Application of the classifiers using the trained library and unsupervised collection** – The classification process was run as part of a two-step approach, starting with the supervised, trained library, subsequently followed by the unsupervised classifier. The outputs from the trained supervised process were given a higher priority than the unsupervised outputs, which were used for general regional characterisations of the assessment area.

- **Incorporation of digitised data from high resolution sources** – To supplement the landcover classification in the focus areas of assessment, further enhancements to the landcover outputs were made to more accurately represent settlement areas and vegetation. These elements were rasterised and overlaid onto the classification outputs to form the current finalised version of the landcover set.

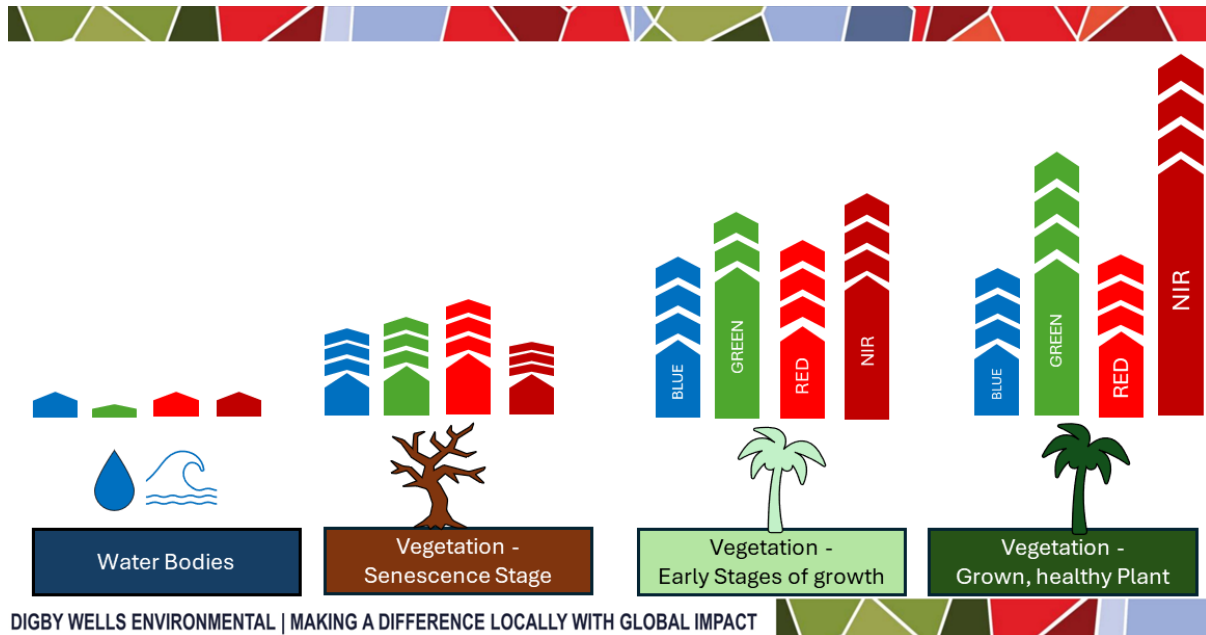
The following output classes were recorded –

- Sand
- Rocky Outcrops
- Water Bodies
- Vegetation
  - Natural Vegetation
  - Agricultural Areas
- Settlements
- Dry Lakes

## 4.2. Vegetation Analysis

An analysis of the vegetation for the assessment areas was conducted through the application of band indices applied to the Landsat imagery data sources. As shown in Figure 3-3, the wavelengths of operation for the Landsat satellites includes data across the visible spectrum (Blue, Green and Red) and information in the InfraRed portion of the spectrum which is beyond the limits of human eyesight. Research findings have shown that infrared light is sensitive to chlorophyll content in a plant, which provides a foundation to perform vegetation health assessments using sensors that acquire information using the Infrared portion of the EM spectrum. These assessments are commonly done using indices, which use pixel values to calculate a numerical value that represents biomass health. One of the most popularly utilized indices is the Normalised Difference Vegetation Index (NDVI).

The NDVI is defined as  $(NIR - Red) / (NIR + Red)$ , where NIR and Red are the amounts of near-infrared and red light reflected off the surface and measured by the satellite sensor (Pettorelli et al., 2020). Green leaves are known to absorb a high proportion of the red and blue wavelengths of the EM spectrum, whereas there is a low absorption of the green wavelength. Green leaves absorb very little near-infrared light, and therefore have a very high reflectance in the near infrared spectrum, which results in positive NDVI values. As a result, the NDVI has been shown to have a high correlation to chlorophyll content in biomass, which is an indicator of photosynthetic activity. Similarly, an index can also be applied for the mapping of water bodies, known as a Normalised Difference Water Index (NDWI) which is defined as  $(Green - NIR) / (Green + NIR)$ . Figure 4-4 shows a graphical relationship between wavelength, waterbodies and vegetation.



**Figure 4-4 Relationship between water, vegetation and wavelength**

Each scene acquired from Landsat was subjected to an NDVI calculation to yield values ranging from -1 (representing water features) to +1 (representing vigorous biomass activity and density). The individual NDVI outputs were then merged to produce a single coverage NDVI representation of the assessment area. The NDVI computations were used as a means of verifying and enhancing the landcover classification outputs for the water bodies.

Figure 4-5 illustrates graphical outputs of the landcover classification and NDVI computations over the Tahlab region. All digital variants of the landcover classification outputs and NDVI computations have been made available in GeoTiff and ArcAscii format as part of the assessment.

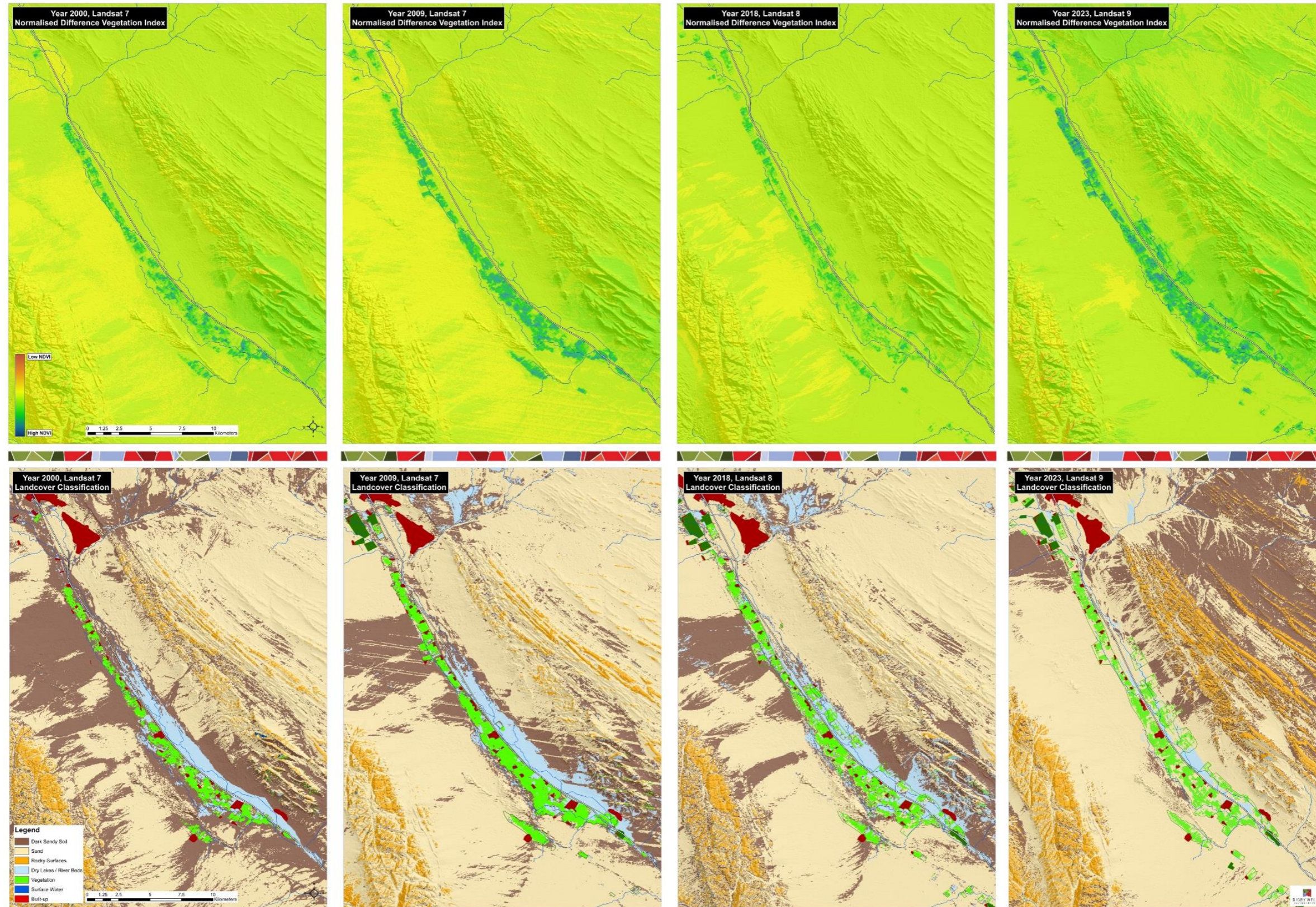


Figure 4-5 NDVI and landcover classification output illustration

## 5. Results

The results observed from the computed outputs are presented in this section. Determinations of the areas around which the results are focused are based on the concentration of settlement and agricultural activity in the respective regions which are potential receptors in terms of water supply and usage in the region. Due to the quantitative nature of the results from the landcover classifications (area measurements) and vegetation analysis (NDVI values), the results have been structured and reported as –

- Identification of focus areas for reporting;
- Regression analysis - Vegetation and Precipitation; and
- Time-based area analysis.

### 5.1. Identification of focus areas for reporting

The focus areas were identified from the landcover classification outputs, along with trends observed in the vegetation analysis. These areas are consistent in terms of settlement and agricultural activity in the region, and are therefore considered as potential receptors. These areas were identified as:

- **Lavar Ab / Rig Chah**, a settlement in Iran approximately 20-kilometers from the Pakistan border with agricultural activity. The area is located within the Gaud-i-Zirreh region, 140-kilometers north-west from the proposed mine development site;
- **The upper Tahlab border region**, comprised of settlements and agricultural activity, located on the border between Pakistan and Iran approximately 50-kilometers from the proposed mine development site; and
- **The Lower Tahlab (Hamun-i-Mashkhel) region**, comprised of settlements and agricultural activity. The area is located towards the lower Tahlab on the border region between Pakistan and Iran. The area is located approximately 110-kilometers from the proposed mine development site.

The areas are shown in Figure 5-1.

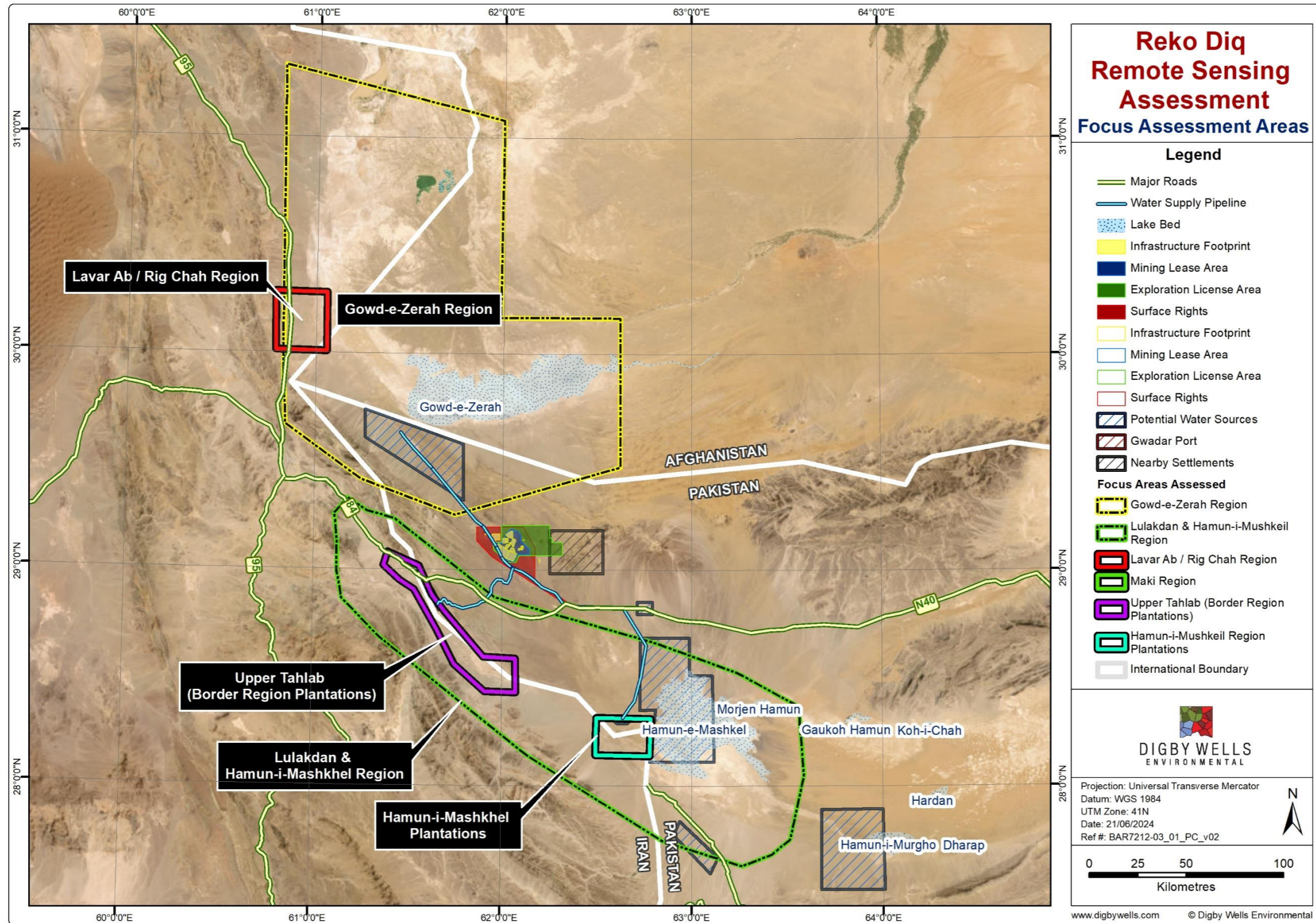


Figure 5-1 Focus assessment areas

## 5.2. Regression analysis - Vegetation and Precipitation

The regression analysis was performed using NDVI values which are representative of vegetation cover and response against precipitation data across each identified focus area for the same period. The Landsat NDVI values were supplemented with MODIS to obtain monthly indicators, while the precipitation data was obtained from the CHIRPS platform. Assessments were computed from the year 2000 up to 2023.

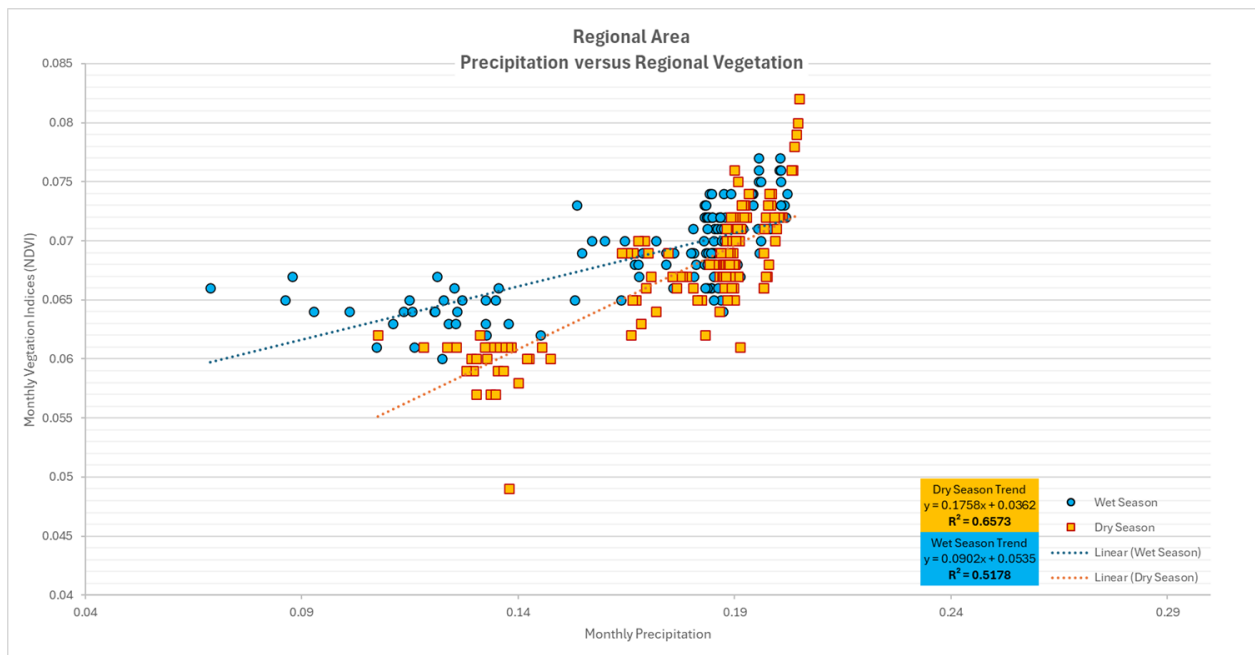
The regression analysis was used as a means of measuring the strength of relationship between the rainfall (independent variable) against the vegetation response (dependent variable) for each area on a seasonal basis. In addition, a regression was also performed for the regional study area to gain an understanding of the regional trends seen between rainfall and vegetation cover and growth. Importantly, the regional assessment area takes into account the natural occurring vegetation areas which predominantly occur along the river beds, with an additional area of naturally occurring date palms in the Hamun-i-Mashkhel salt lake region. The summarised results for the regression analysis is presented in Table 5-1.

**Table 5-1 Regression analysis results summary**

Region	R <sup>2</sup>		Relationship between Rainfall and Vegetation in the Region
	Wet Season	Dry Season	
Overall Assessment Area	0.52	0.66	Moderate to high positive relationship in the Wet Season. Relatively higher positive relationship in the Dry Season.
Lavar Ab / Rig Chah Region	0.28	0.07	Low positive relationship in the wet season. Very low relationship in the dry season.
Upper Tahlab Region (Border Plantations)	0.51	0.53	Moderate positive relationship in both the wet and dry season.
Hamun-i-Mashkhel Plantations (Lower Tahlab)	0.27	0.39	Low positive relationships in both the wet and dry season.

### 5.2.1. Regression Analysis – Regional Assessment Area

The regression results for the regional assessment area indicates a moderate to high positive relationship in the Wet Season ( $R^2 = 0.52$ ), with a higher positive relationship in the Dry Season ( $R^2 = 0.66$ ). This indicates that there is marginally stronger relationship between the vegetation growth and rainfall regionally in the dry season. The positive relationship indicates that the vegetation experiences increased growth with increased rainfall. The higher level of relationship in the dry period indicates that in the dry period, the vegetation has a higher growth rate when compared to the wet season, indicating that the sustenance of vegetation in the region is largely driven by alternate supplies in the form of groundwater based irrigation techniques. Importantly, the regional level regression results are inclusive of natural vegetation in the region. While there are isolated occurrences of natural vegetation, the large majority of vegetated landcover originates from the agricultural activity in the regional area. The regression graph for the regional assessment area is shown in Figure 5-2.



**Figure 5-2 Regression graph - Regional assessment area**

### 5.2.2. Regression Analysis – Lavar Ab / Rig Chah Region

The regression results for the Lavar Ab / Rig Chah area indicates a low positive relationship in the Wet Season ( $R^2 = 0.28$ ), with a very low relationship in the Dry Season ( $R^2 = 0.07$ ). The level of relationship between the vegetation growth which is primarily plantations and the rainfall received is insignificant, indicating that the areas agricultural activity has no dependency on precipitation and surface water usage. Seasonal variations are observed in the vegetation response figures shown on the vertical axis. The regression graph for the regional assessment area is shown in Figure 5-3.

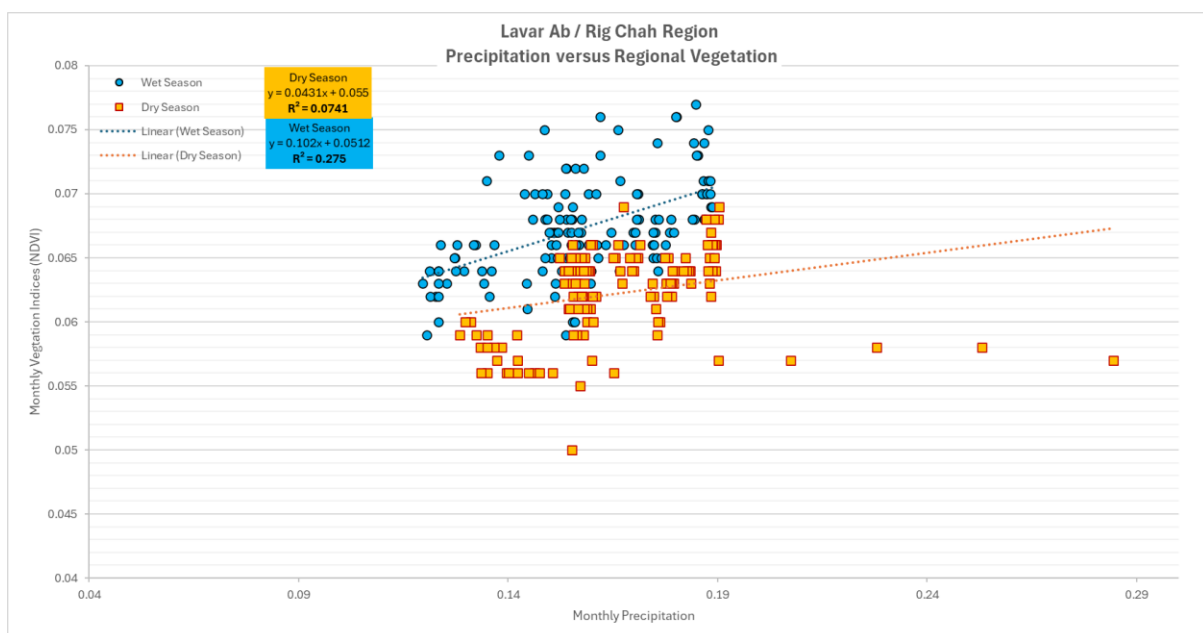
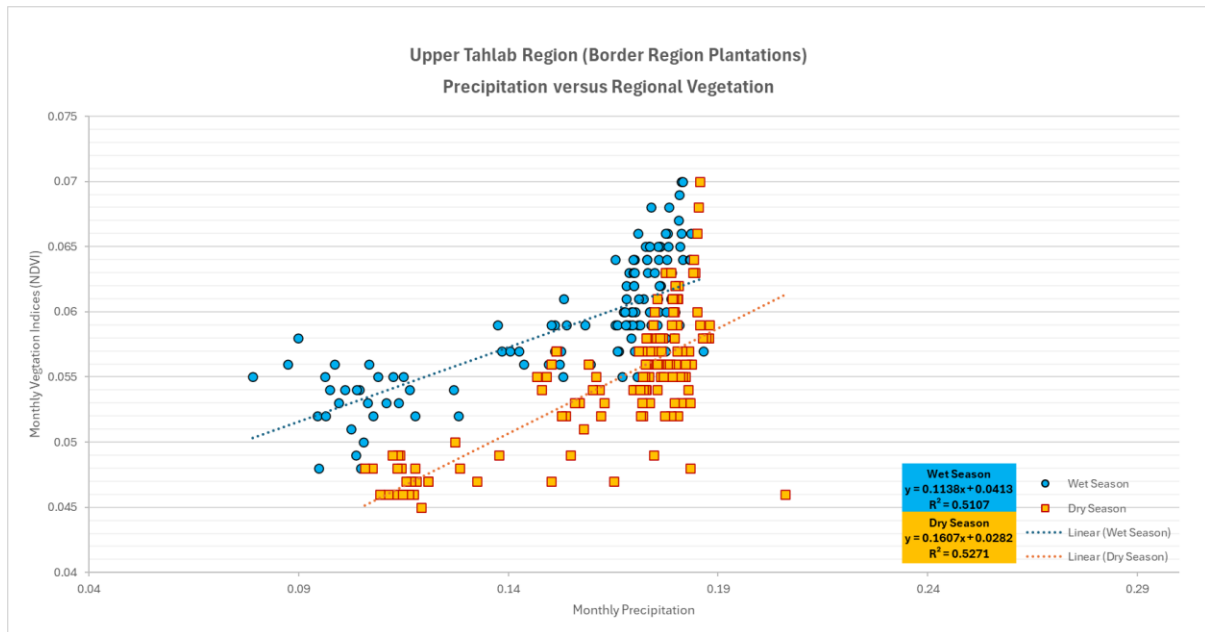


Figure 5-3 Regression graph - Lavar Ab / Rig Chah area

### 5.2.3. Regression Analysis – Upper Tahlab Region

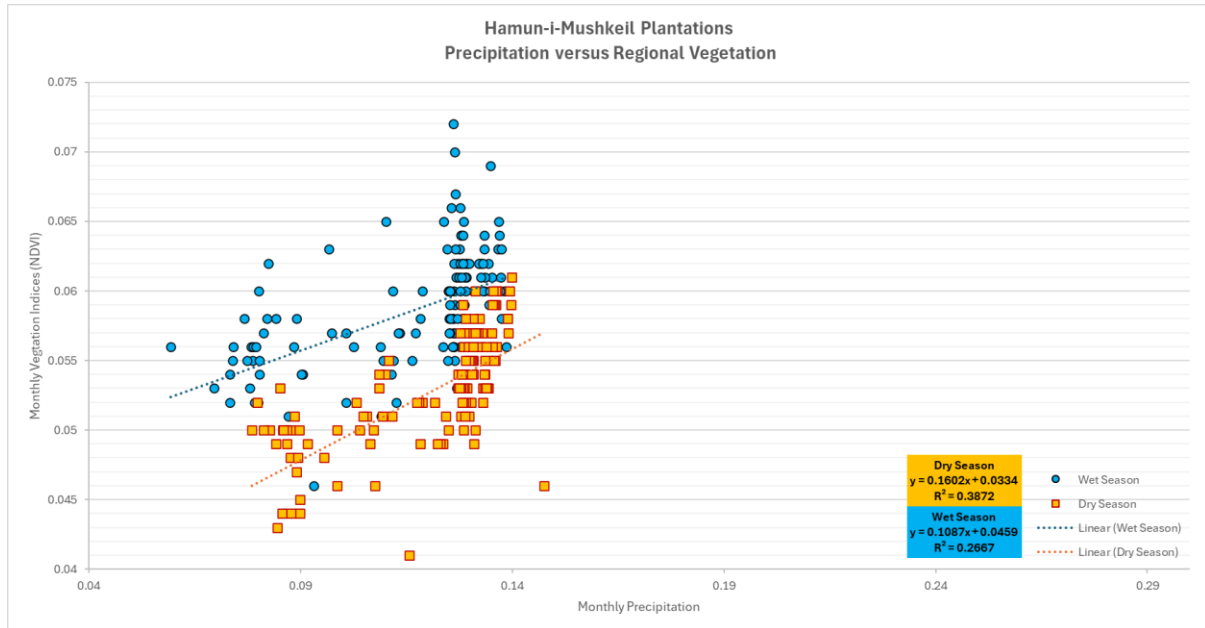
The regression results for the Upper Tahlab area indicates a moderately positive relationship in the Wet Season ( $R^2 = 0.51$ ) and Dry Season ( $R^2 = 0.53$ ). The similarity in vegetation cover and response to the area's rainfall statistics, along with the general shape distribution observed in the regression graph indicates that the area's agricultural activity is not dependent on precipitation and surface water usage. The graph also indicates that the higher rainfall periods are generally associated with higher vegetation responses, likely due to easier access for the plantations to groundwater resources. The regression graph for the regional assessment area is shown in Figure 5-4.



**Figure 5-4 Regression graph - Upper Tahlab area**

### 5.2.4. Regression Analysis – Lower Tahlab (Hamun-i-Mashkhel) Region

The regression results for the Lower Tahlab area (Hamun-i-Mashkhel region) indicates a low positive relationship in the Wet Season ( $R^2 = 0.27$ ) and Dry Season ( $R^2 = 0.39$ ). The similarity in vegetation cover and response to the area’s rainfall statistics, along with the general shape distribution observed in the regression graph indicates that the area’s agricultural activity is not dependent on precipitation and surface water usage. The graph does however indicate that in period with high rainfall events, the vegetation has had a higher response, which is likely due to the close proximity to the Hamun-i-Mashkhel system which fans out to the south west with natural occurrences of trees and shrubs. The region is also located within a low-point with relatively easier access to groundwater resources. Periods of aquifer recharge are therefore likely associated with increased vegetation cover and response. The regression graph for the regional assessment area is shown in Figure 5-5.

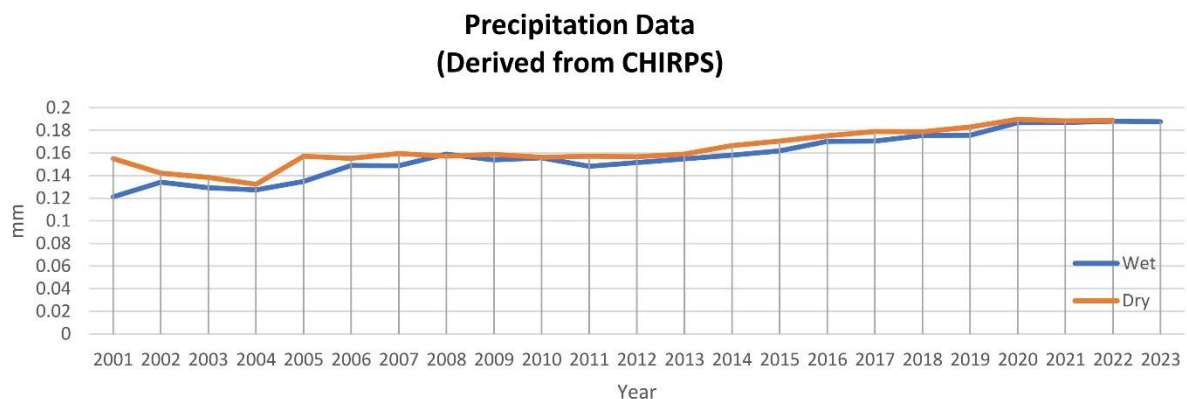


**Figure 5-5 Regression graph - Lower Tahlab region (Hamun-i-Mashkhel)**

### 5.3. Time-based area analysis

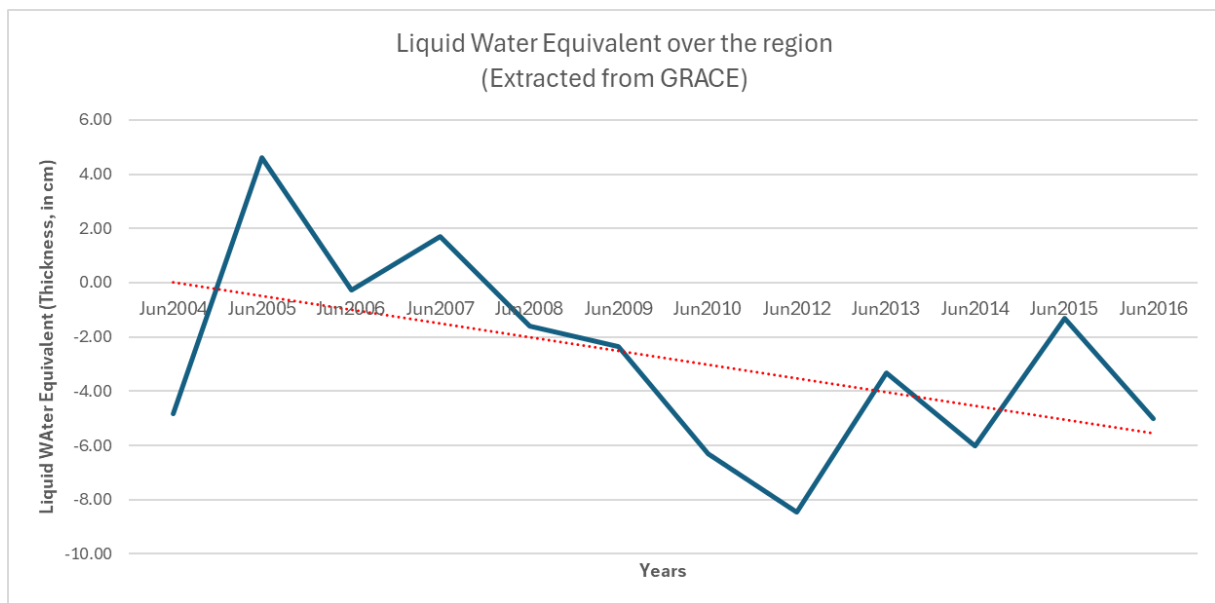
Changes observed in the settlement and agricultural classes of the landcover classifications were computed using the footprint extents for all periods from 2000 up to 2023 for the focus assessment areas. The Gaud-i-Zirreh depression was also run as part of the area calculations for each year with seasonal comparisons.

The precipitation data extracted from the CHIRPS platform was processed to represent the wet and dry periods per year graphically from 2000 up to 2023, as shown in Figure 5-6. The rainfall data indicates a gentle overall upwards trend in rainfall data received for the assessment period.



**Figure 5-6 Precipitation data for the wet and dry seasons per annum, from 2000 to 2023**

The GRACE satellite platform was used to detect water mass movement in the assessment area. The GRACE pixel size is coherent for the entire basin region (i.e. the data for each focus assessment area will produce the same figures and trend). The data indicates that while the trends in rainfall volume have been increasing steadily over time which in turn largely recharges the aquifer system and groundwater resources, there has been a large loss of water mass from the region in both surface and groundwater. The period around the year 2012 shows significant losses in water mass for the region, which has been steadily increasing over time. Figure 5-7 shows the changes observed from 2004 through to 2016.



**Figure 5-7 GRACE time series, detecting water mass movement over the assessment area**

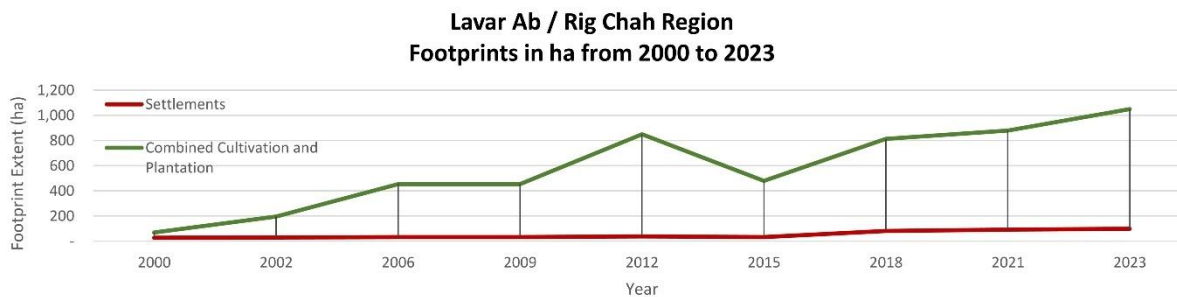
The results of each assessment area is presented in the subsections that follow.

### 5.3.1. Area Analytics - Lavar Ab / Rig Chah Region

The Lavar Ab/ Rig Chah region analysis indicates that the settlement footprints grew by 255% between the year 2000 and 2023. In 2015, there was a decrease in the size of settlements observed in the area, down 14% when compared to the 2012, while 2018 saw a large expansion of 145% when compared to 2015.

The agricultural footprints grew by 1,403% between the year 2000 and 2023. 2002 (182%, compared to 2000) and 2006 (131%, compared to 2002) were periods of large agricultural growth in the area, followed by 2012 (87%, compared to 2006 and 2009). In correlation to the decrease in settlement activity and visible structures in 2015, the agricultural activity saw a decrease of 43% when compared to 2012, with steady increases observed up to 2023.

Figure 5-8 provides a graph of the settlement and agricultural area changes observed from 2000 to 2023. .



**Figure 5-8 Lavar Ab / Rig Chah Region - Settlement and agricultural area changes observed from 2000 to 2023**

Figure 5-9 shows the landcover progression from 2000 to 2023 for the Lavar AB / Rig Chah region, while Figure 5-10 provides a graphical depiction of the agricultural and settlement changes in the area between 2000 and 2023.

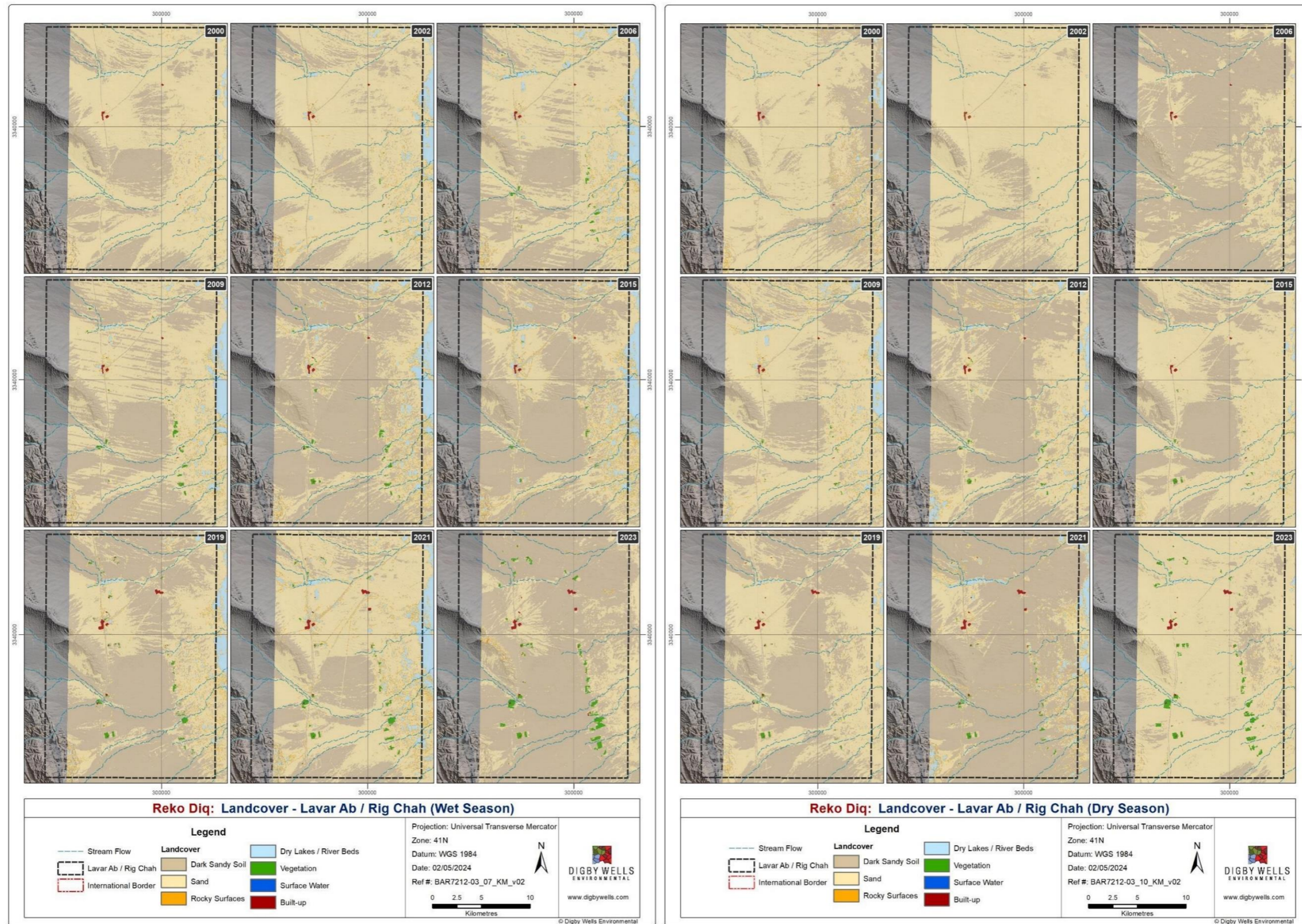


Figure 5-9 Landcover progression - Lavar Ab / Rig Chah, 2000 - 2023

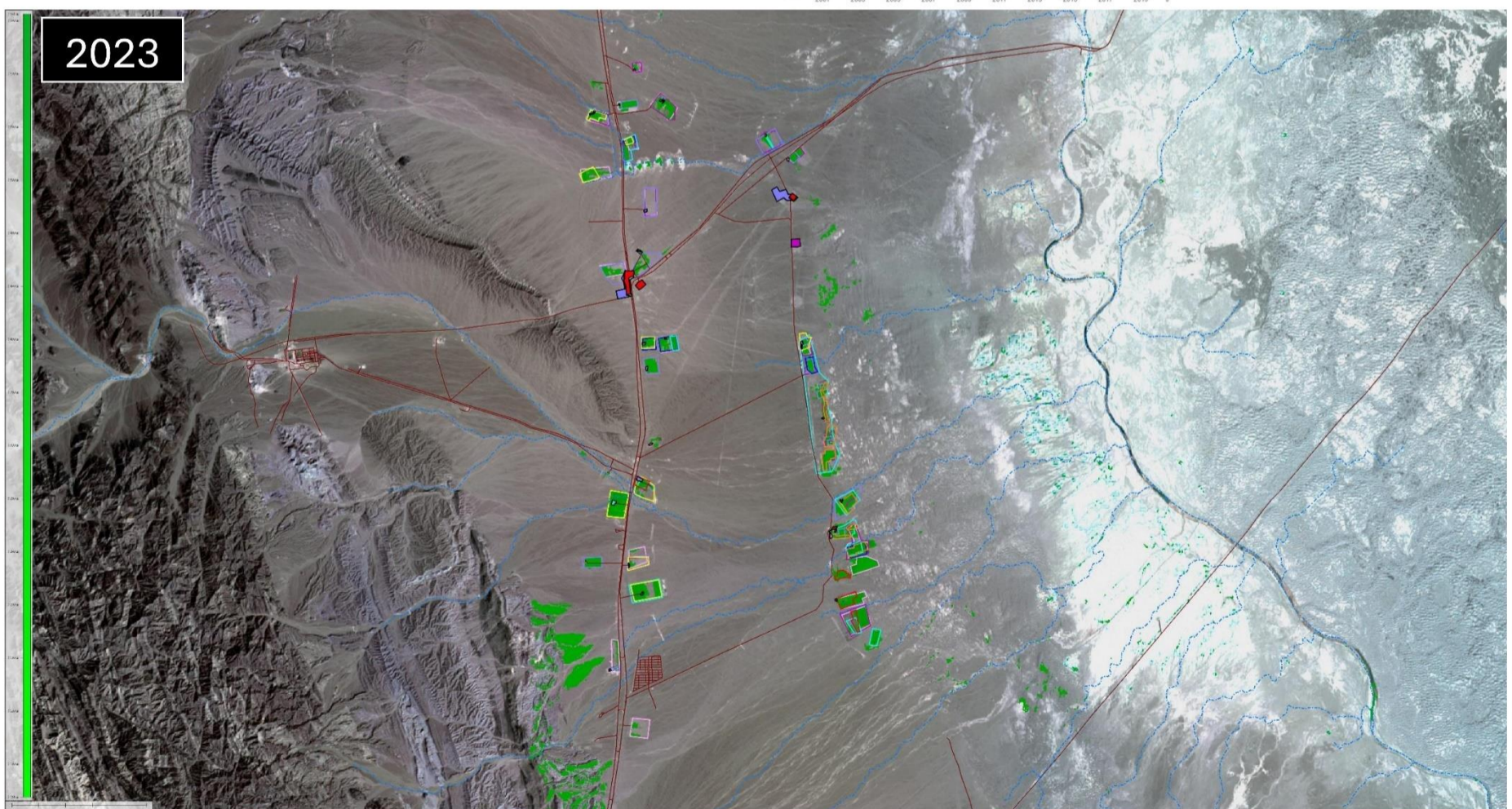
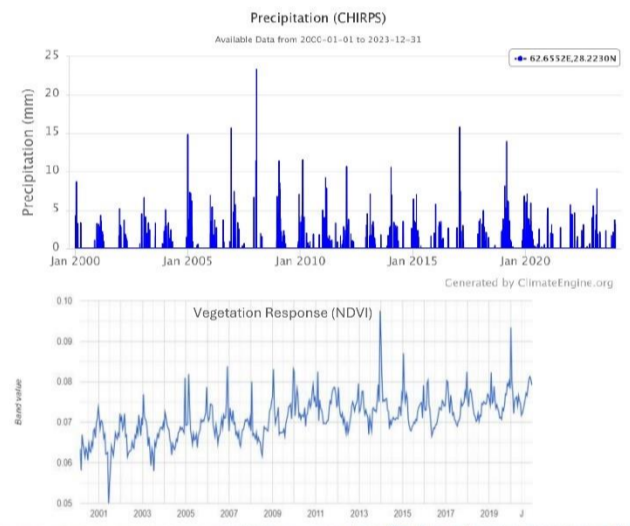
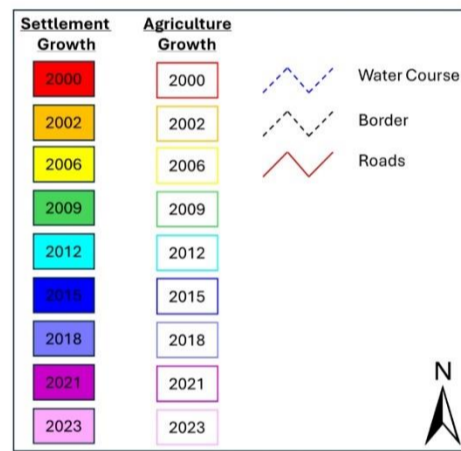
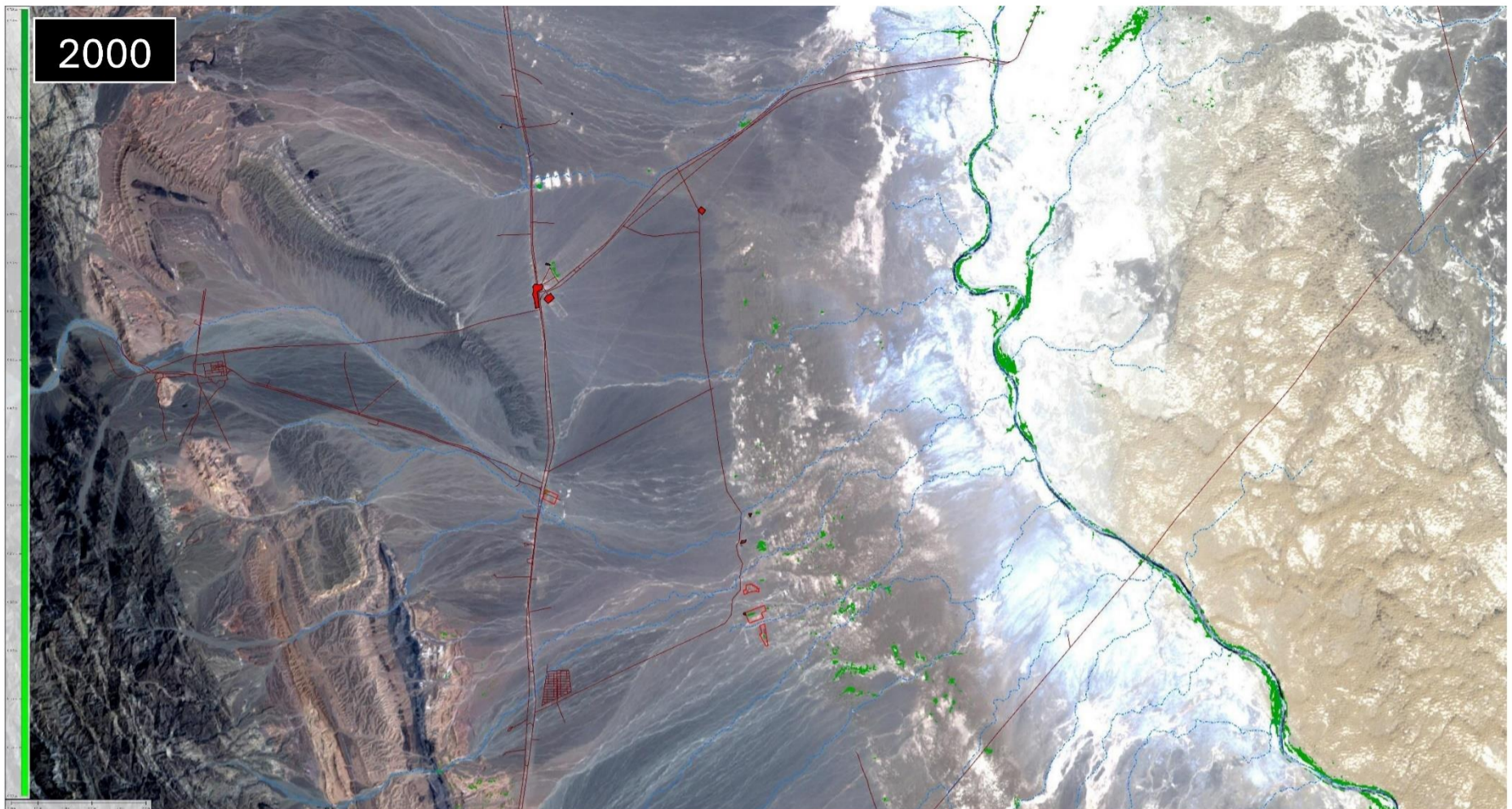
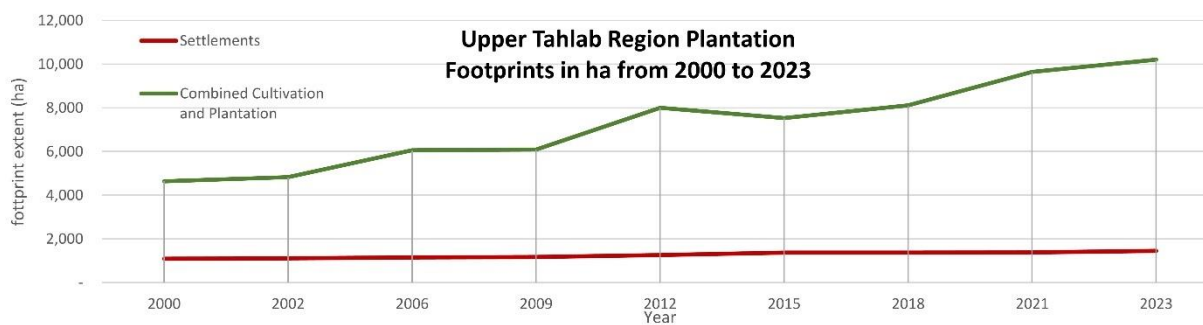


Figure 5-10 Lavar Ab / Rig Chah region comparison from 2000 to 2023 – Changes in agriculture and settlements

### 5.3.2. Area Analytics – Upper Tahlab Region

The Upper Tahlab region analysis indicates that the settlement footprints grew by 33% between the year 2000 and 2023. The growth has been steady, averaging 3.6% year to year.

The agricultural footprints show a growth of 120% between 2000 and 2023. 2006 was a period of significant growth at 26% when compared to 2002, followed by 2012 which was a 31% increase from the year 2009. 2021 had a 19% increase in agricultural areas when compared to 2018. Figure 5-11 provides a graph of the settlement and agricultural area changes observed from 2000 to 2023.



**Figure 5-11 Upper Tahlab Region - Settlement and agricultural area changes observed from 2000 to 2023**

Figure 5-12 shows the landcover progression from 2000 to 2023 for the Upper Tahlab region, while Figure 5-13 provides a graphical depiction of the agricultural and settlement changes in the area between 2000 and 2023.

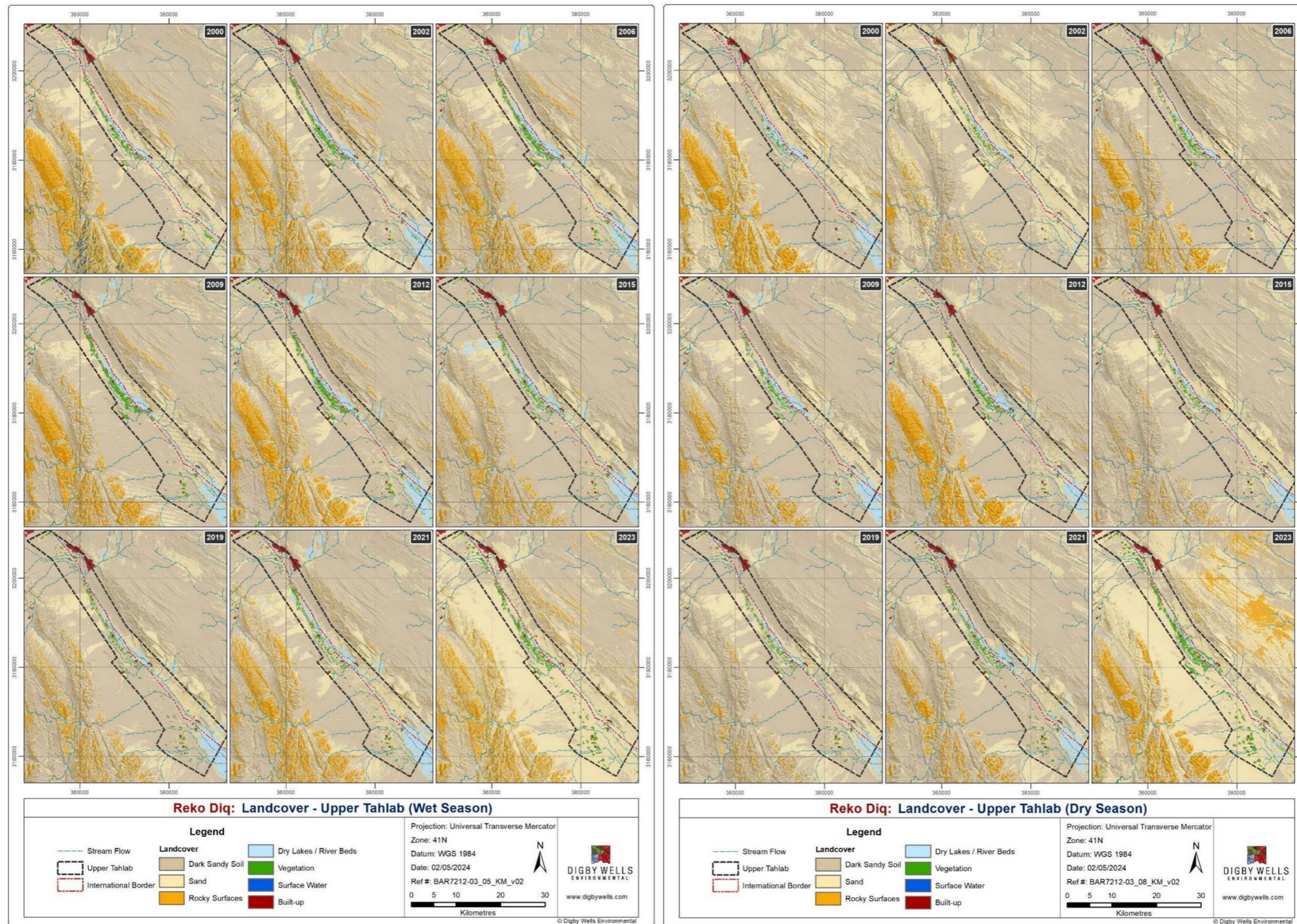


Figure 5-12 Landcover progression – Upper Tahlab, 2000 - 2023

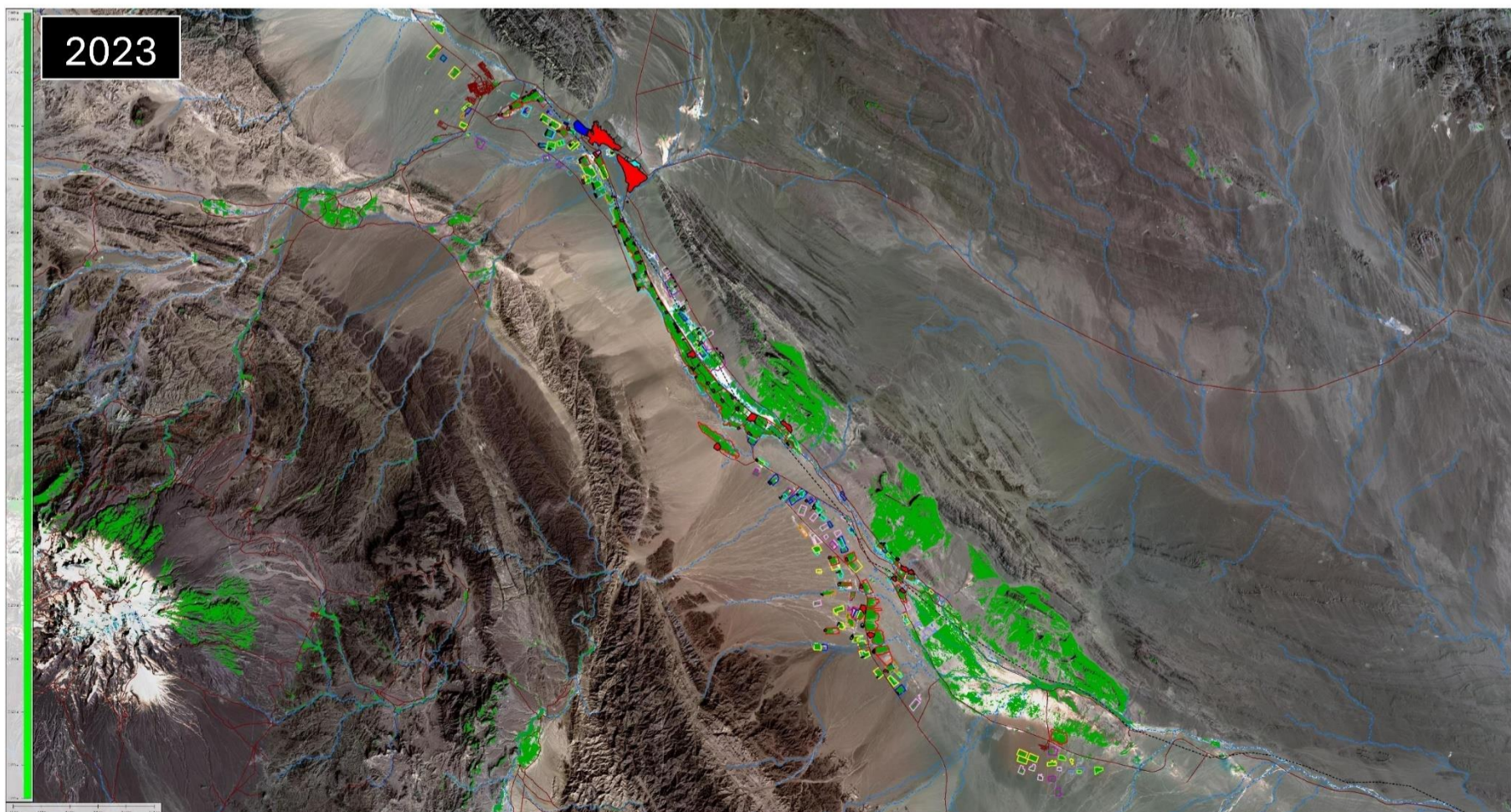
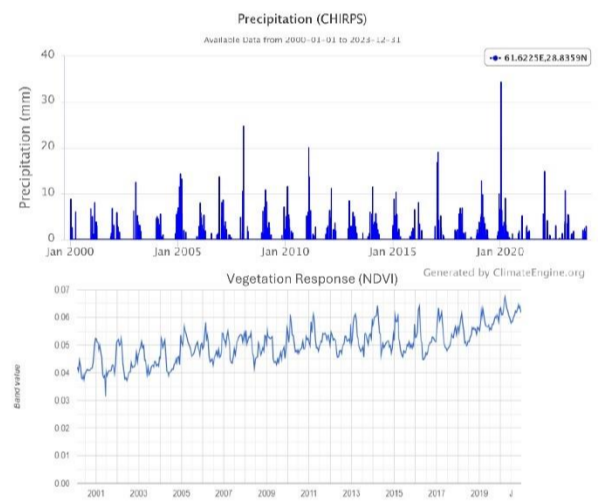
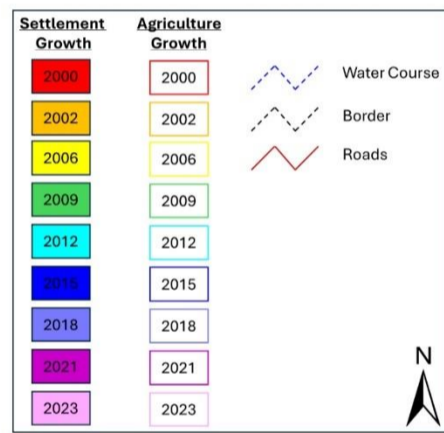
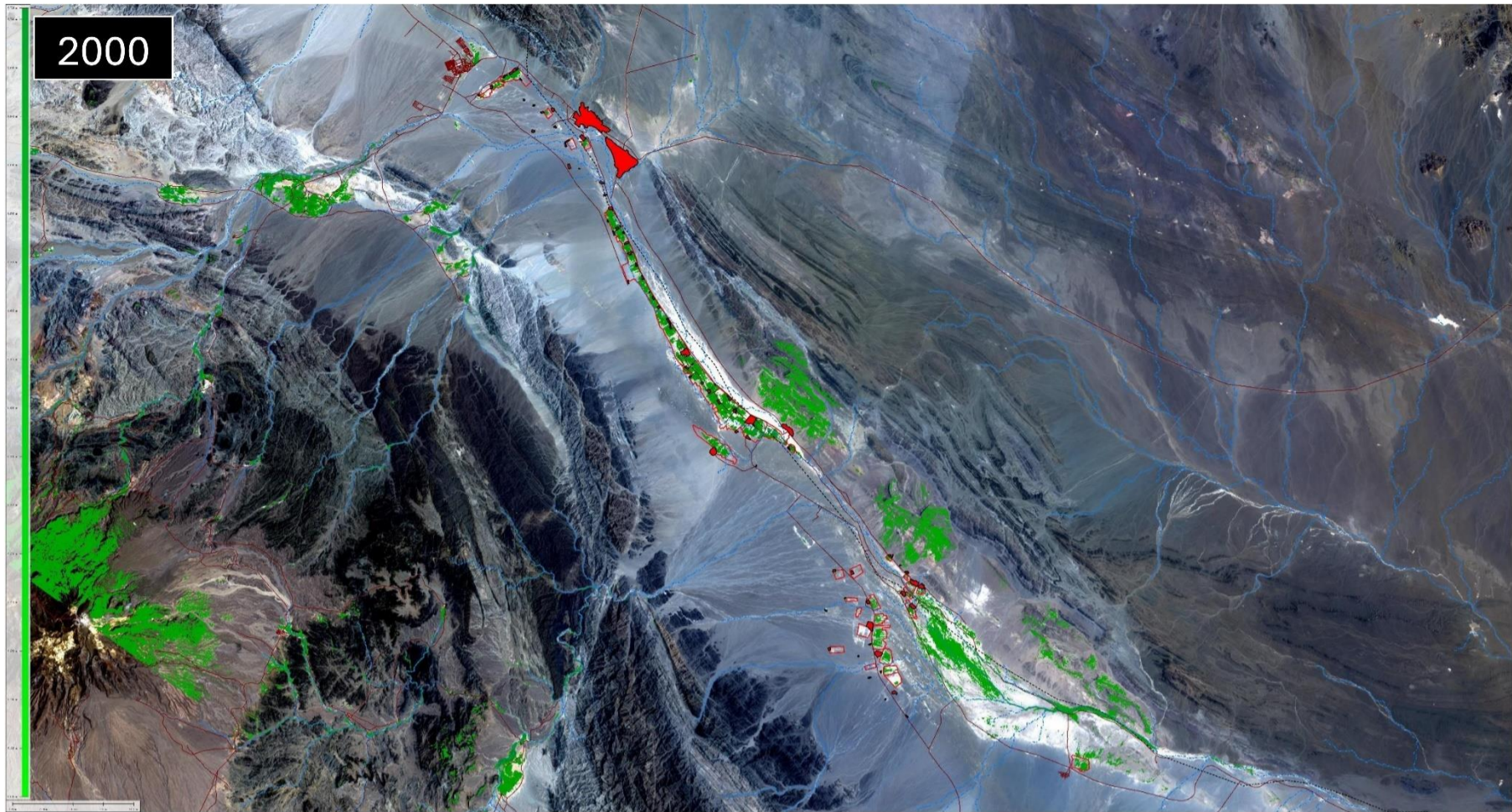
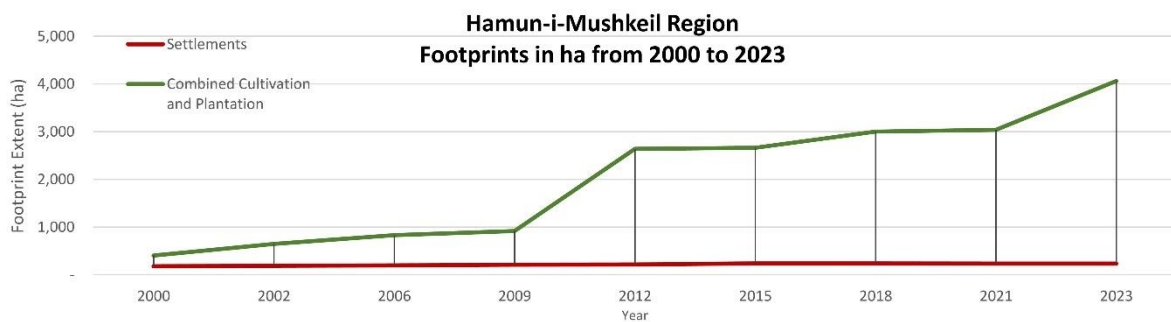


Figure 5-13 Upper Tahlab region comparison from 2000 to 2023 – Changes in agriculture and settlements

### 5.3.3. Area Analytics – Lower Tahlab Region (Hamun-i-Mashkhel)

The Lower Tahlab region analysis indicates that the settlement footprints grew by 31% between the year 2000 and 2023. The growth has been steady, averaging 3.5% year to year.

The agricultural footprints show a growth of 905% between 2000 and 2023. 2002 was a period of significant growth at 60% when compared to 2000, followed by 2006 which was a 29% increase from the year 2002. 2012 has a large increase of 187% when compared to 2009, which was followed by a 34 increase in 2023 when compared to 2021. Figure 5-14 provides a graph of the settlement and agricultural area changes observed from 2000 to 2023.



**Figure 5-14 Lower Tahlab (Hamun-i-Mashkhel) Region - Settlement and agricultural area changes observed from 2000 to 2023**

Figure 5-15 shows the landcover progression from 2000 to 2023 for the Lower Tahlab region, while Figure 5-16 provides a graphical depiction of the agricultural and settlement changes in the area between 2000 and 2023.

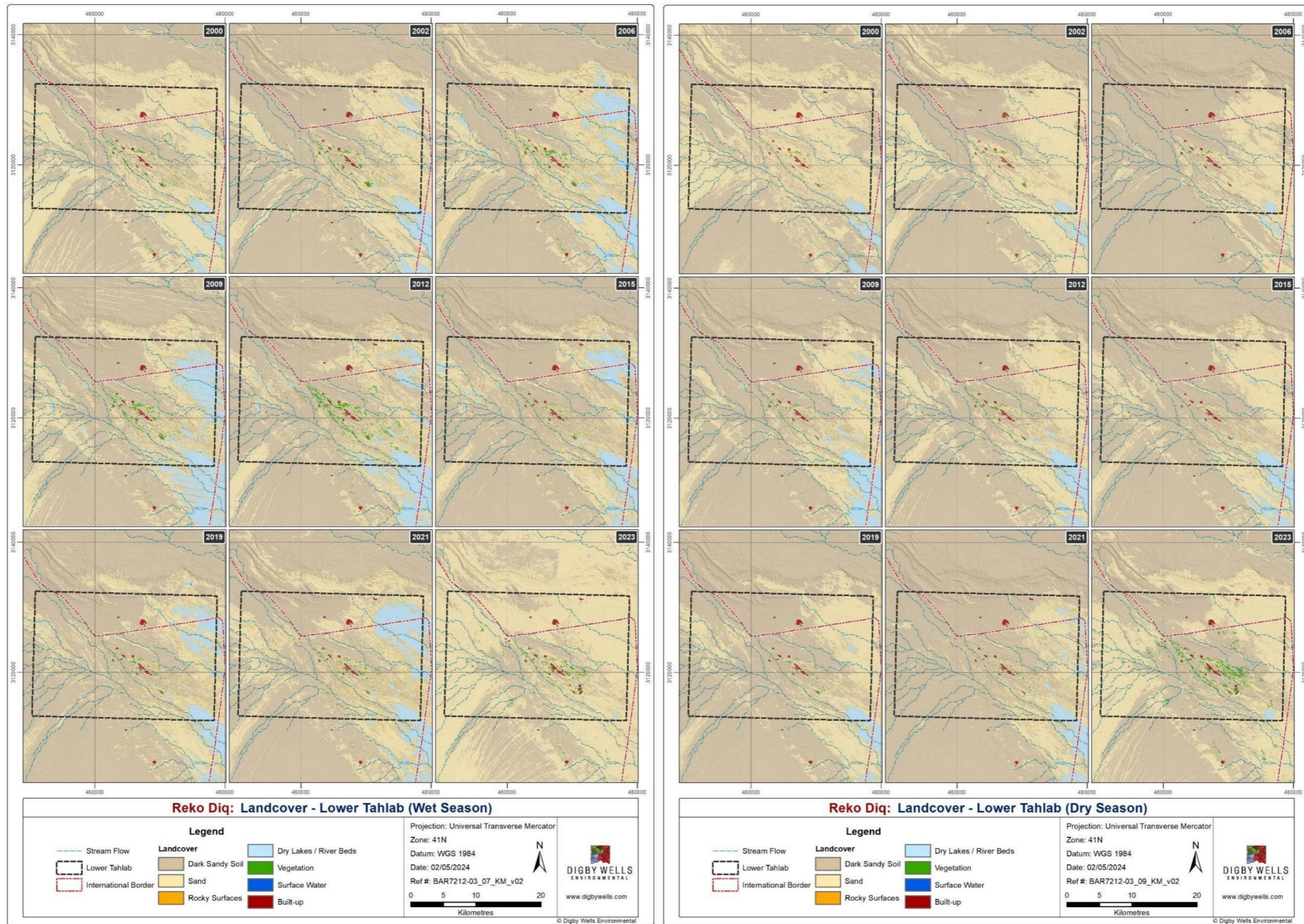


Figure 5-15 Landcover progression – Lower Tahlab, 2000 - 2023

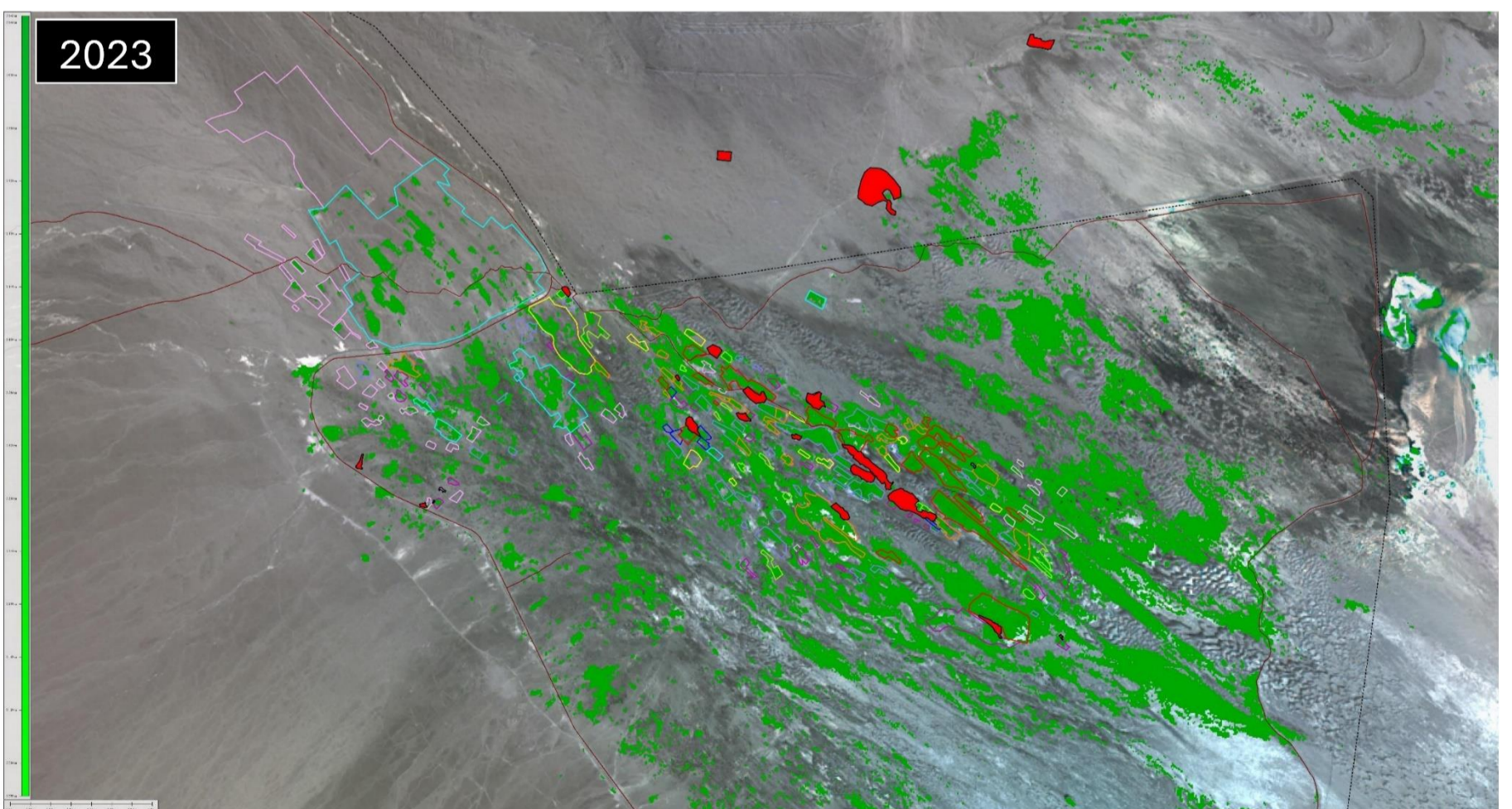
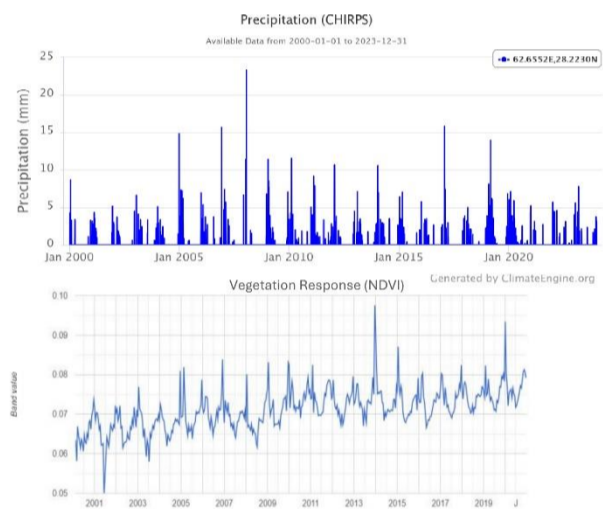
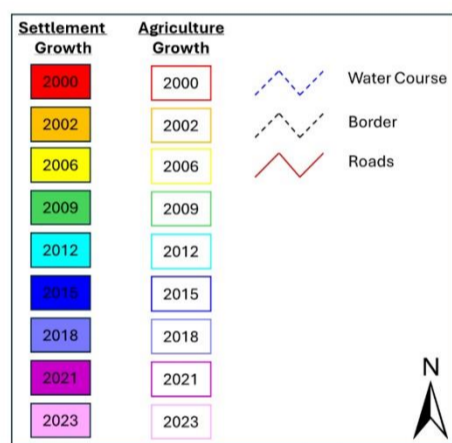
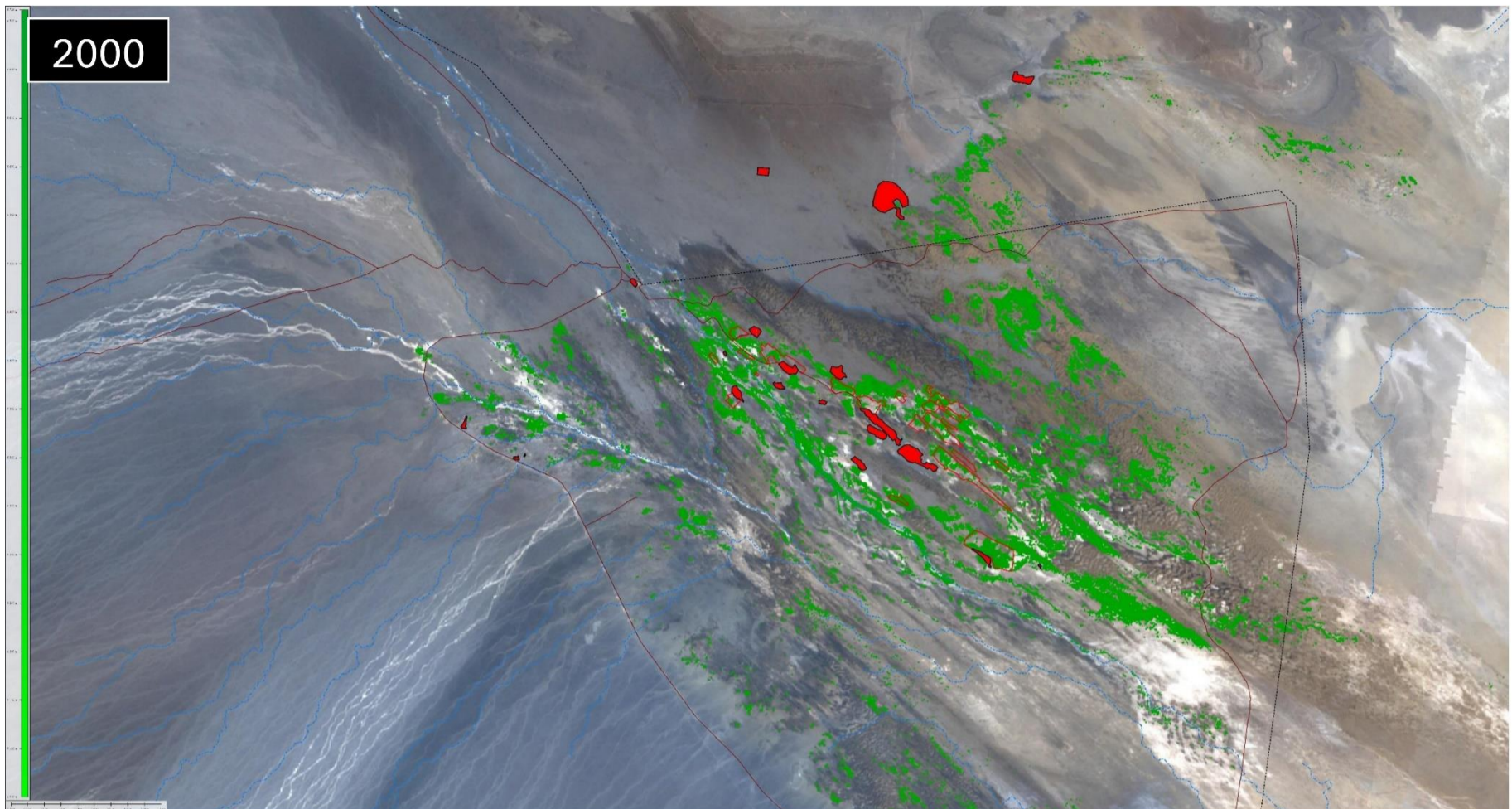
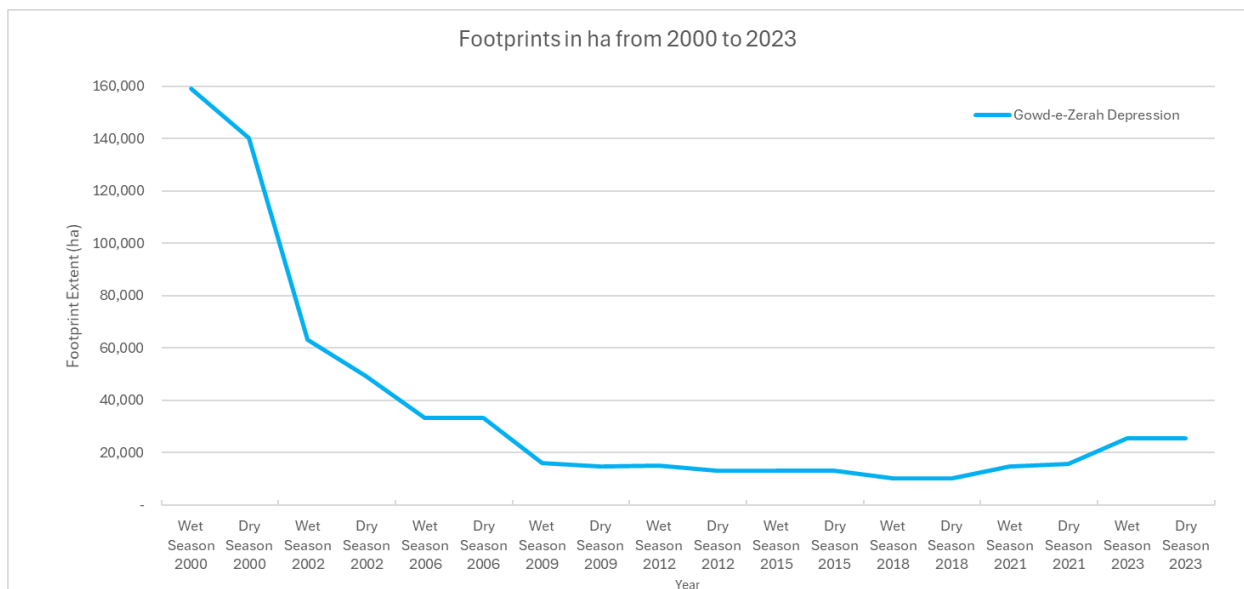


Figure 5-16 Lower Tahlab region comparison from 2000 to 2023 – Changes in agriculture and settlements

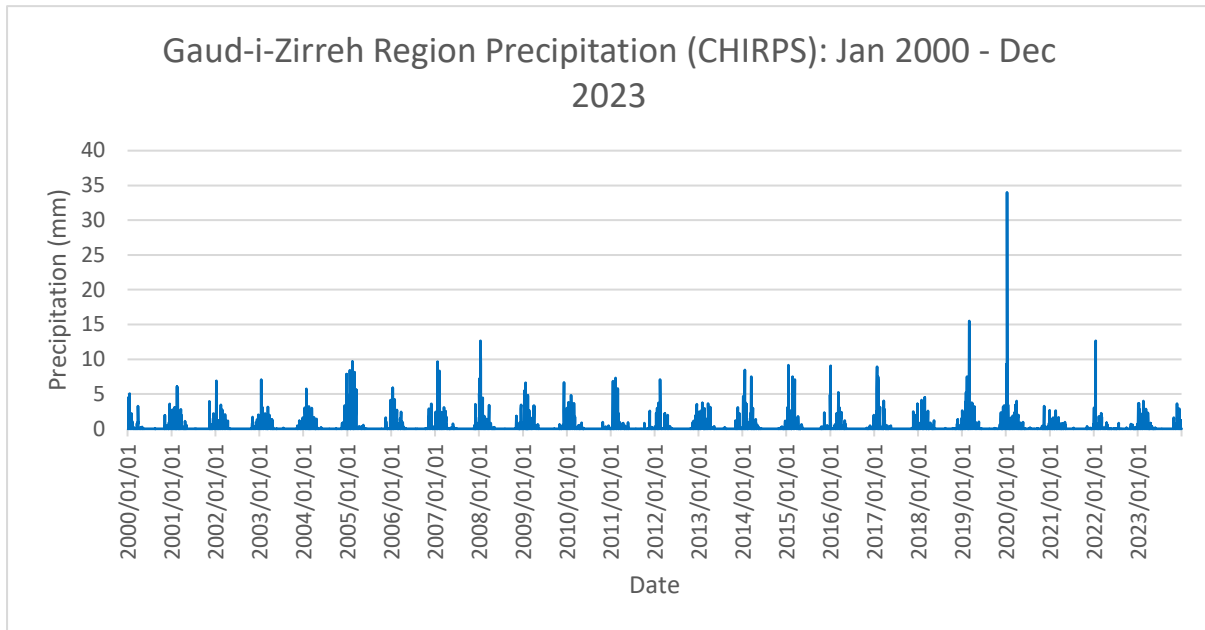
### 5.3.4. Area Analytics – Gaud-i-Zirreh Depression

The Gaud-i-Zirreh depression area analytics from the year 2000 to 2023 indicate an overall decline of approximately 83% (82% decline observed in dry season, 84% decline observed in the wet season). The period from 2000 to 2009 saw an average decrease of 52% for each assessment period. The rate of decrease slowed down in 2012 (9% decrease compared to 2009) and 2015 (6% decrease compared to 2012) which was followed by another decrease in extent for 2018 averaging 22.87% when compared to 2015. Increases in the water extent have observed for 2021, with an increase in the water area’s extent of 48% when compared to 2018, followed by another increase of 69% in 2023 when compared to 2021. Cumulatively, the loss of water however far outweighs the gains seen in the last two periods. Figure 5-17 provides a graphical depiction of the surface water extent changes observed over the Gaud-i-Zirreh depression.



**Figure 5-17 Gaud-i-Zirreh Depression - Water extent area changes observed from 2000 to 2023**

The precipitation records as derived from the CHIRPS platform is presented in Figure 5-18, which indicates the region received higher volumes of rainfall in 2008, 2019, 2020 and 2022, which is also associated with an increases in water extent observed with the satellite imagery for the respective periods. In 2022, the Kamal Khan Dam was observed as fully filled with water being diverted into the Kushk Rud which flows into the Gaud-i-Zirreh depression as shown in Figure 2-4. Where increases in water for the Gaud-i-Zirreh depression were observed across the assessment period, the indications are that this is associated with increased rainfall and upstream flow.



**Figure 5-18 Gaud-i-Zirreh region precipitation (2000 - 2023)**

Figure 5-19 shows the Landsat based satellite imagery of the Gaud-i-Zirreh depression from 2000 to 2023. No receptors (in terms of settlements and agricultural activity) were identified in the Gaud-i-Zirreh depression region through the Phase 1 and Phase 2 components of the assessment.

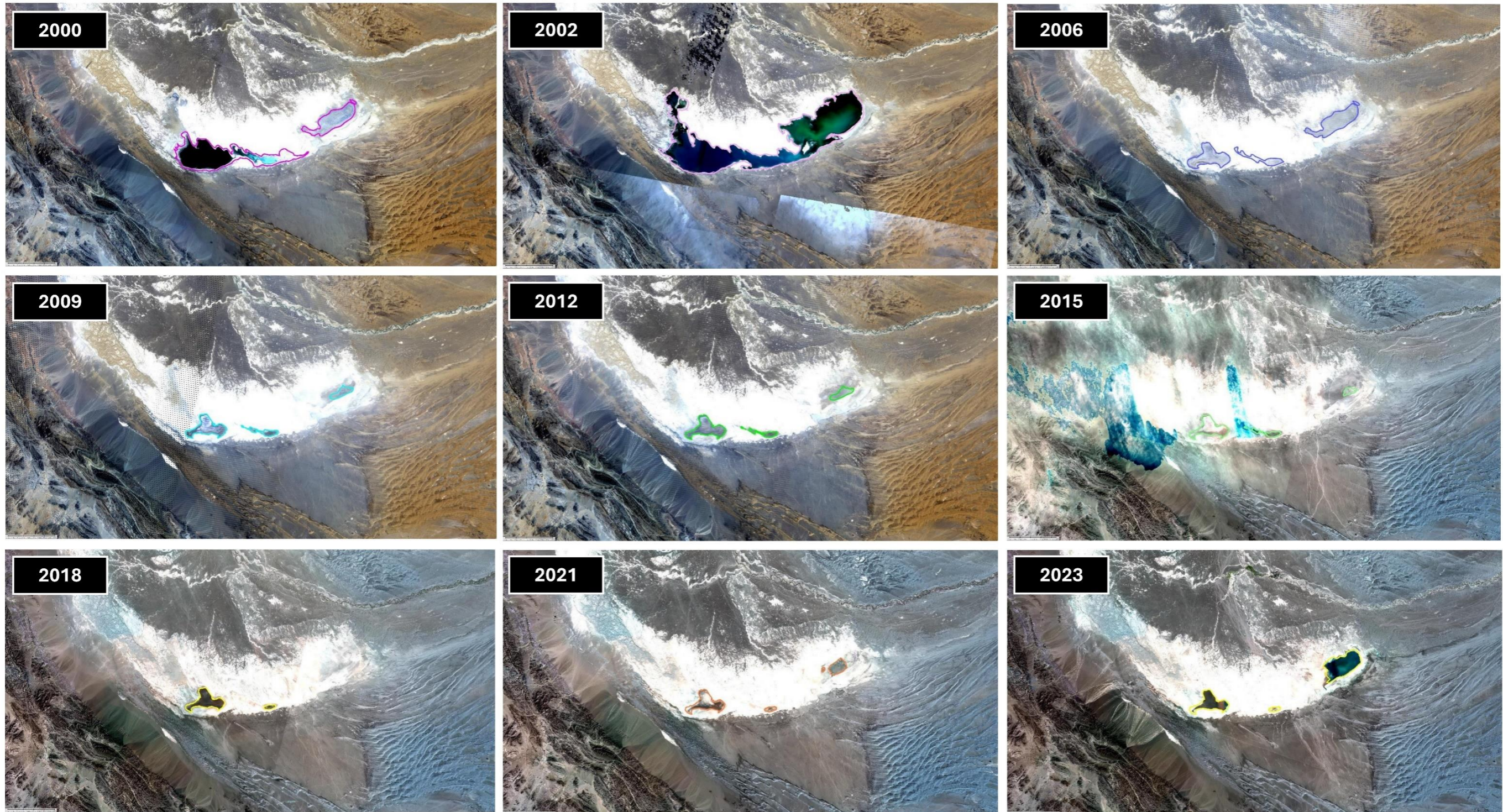


Figure 5-19 Gaud-i-Zirreh depression - Landsat imagery progression from the year 2000 to 2023

## 5.4. Data Synthesis

This component of the assessment aims at holistically incorporating the outcomes from the remote sensing assessment. The landcover analytics and vegetation assessment statistics in comparison to the baseline precipitation data and its derived trends have been used to provide a quantitative representation of each focus area.

The following key findings are derived from the analysis –

- Settlement growth in the identified focus assessment areas (Lavar Ab / Rig Chah, Upper & Lower Tahlab) is steady, where the growth of the agricultural footprints in the same areas far outweighing the growth in settlement footprints. This indicates that these areas are primarily focused on agricultural production;
- When compared to the regional area regression output that compared vegetation to precipitation, all focus assessment  $R^2$  values have significantly weaker relationships than the regional baseline output. The key difference between the regional regression analysis and the focus areas are the occurrence of isolated areas of natural vegetation (where natural vegetation is included in the regional assessment areas, while the focus areas are dominated by agricultural activity and human settlements). Natural vegetation is expected to have a seasonal positive relationship with the regional precipitation patterns. The generally low relationship seen in the majority of assessment areas indicates that these areas are not dependent on surface water for water supply for the plantations. Vegetation growth and expansion, as shown by the area analytics, are largely driven by groundwater irrigation-based methods. This is consistent with the existing literature for the Chagai region; and
- Each focus assessment area that has significant amounts of agricultural activity have large growth spikes in vegetation response and agricultural extent growth in 2012. This coincides with a large drop observed over the same period in the GRACE gravity data, indicating a loss of water mass from the region.

## 6. Recommendations

The reporting approach utilised cross referenced multiple sources of reputable remote sensing data sources and techniques. The incorporation of ground-truth data for specific receptor regions can add an additional layer of depth to the findings thus far. Recommendations are also made towards future considerations in the region in the form of a periodic monitoring programme. The recommendations include:

- Historical borehole depths observed in the focus areas – particularly in the areas around the dry lake classifications;
- Should the area of anticipated influence extend to the agricultural areas identified, it is recommended that higher resolution imagery be utilised for the identification and quantification of agricultural plots, along with field based biomass estimates to infer potential water usage per plot;
- The incorporation of evaporative studies and assessments conducted in the area to understand the losses in the Gaud-i-Zirreh depression from evaporation;
- A more representative and inclusive range of GRACE data to understand the gravity and water mass movement changes in the time period post 2016; and
- A periodic assessment that forms part of the monitoring programme to identify changes in the region compared against the baseline results obtained in this assessment.



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