CSTP

Commercial Space Technologies Prospecting

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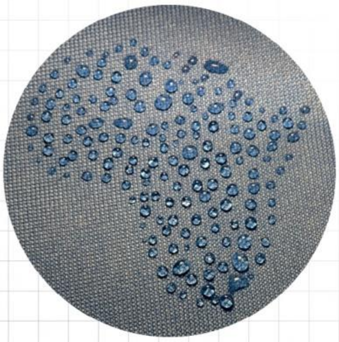
SATELLITE PROSPECTING FOR WATER IN SOUTH AFRICA



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Abbreviations

CST – Commercial Space Technologies

CSTP – Commercial Space Technologies Prospecting

DAC – Development Assistance Committee

DWS – Department of Water and Sanitation

EIA – Environmental Impact Assessment

EO – Earth Observation

GDP – Gross Domestic Product

GRIP – Groundwater Resource Information Project

IPP – International Partnership Programme

LESSA – Lineament Extraction and Stripe Statistical Analysis software

NGA – National Groundwater Archive

NGS – National Groundwater Strategy

OCHA – Office for the Coordination of Humanitarian Affairs

ODA – Official Development Assistance

SA – South Africa

SABI – South African Irrigation Institute

SANSA – South African National Space Agency

SAR – Synthetic Aperture Radar

SME – Small Medium Enterprise

UGEP – Utilisable Groundwater Exploitation Potential

UKSA – UK Space Agency

WMA – Water Management Area

WRC – Water Research Commission

WUL – Water Usage Licence

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Executive Summary

Commercial Space Technologies Prospecting (CSTP) has been researching the possibility of prospecting for groundwater in South Africa (SA) using expert analysis of satellite (remote sensing) imagery, the feasibility of which is confirmed in this study. This work has been funded by the 'Global Cooperation Feasibility Study' Innovate UK grant, which has enabled CSTP to travel to Pretoria and meet with collaborators who would be able to support future CSTP work in SA. This funding has also allowed CSTP to develop a project plan which targets areas of SA where CSTPs services could be in highest demand and could most effectively be applied. The end goal of this research is to develop a project concept that is viable for funding and can be implemented under the International Partnership Programme (IPP) grant, released by the UK Space Agency (UKSA).

The IPP is a £152M multi-year programme which uses expertise in space based solutions, applications and capability to provide a sustainable, economic or societal benefit to undeveloped nations and developing economies. The outputs of this study are therefore aimed at demonstrating how CSTP groundwater prospecting methods can socioeconomically benefit communities in SA.

The project designed in this study to answer the aims of the IPP has two proposed deliverables:

1. The first applies CSTPs methods to a region of SA to produce a prospecting model that upgrades the geological data of the region, and which CSTPs partners can use independently to efficiently locate novel groundwater sources.

2. The second follows on from the first, relying heavily on CSTP partner involvement to confirm CSTPs findings (by drilling exploratory boreholes), test for contaminants and design / build water supply systems (wells, irrigation and decontamination equipment, piping, etc.) to provide water to communities in need. This deliverable may however deviate too far from the interests of the IPP as it is less reliant on space based applications (with CSTP performing more of a higher level management role).

The three main partners identified by CSTP, where their support would be most important towards producing the two abovementioned deliverables are the South African National Space Agency (SANSA), the Department of Water and Sanitation (DWS) and the Council for Geoscience (CGS).

SANSA would be CSTPs primary contact for the IPP, as a government department it would be able to liaise with and apply management skills to coordinate the other SA collaborators. It could also potentially supply space data as an in-kind contribution to the project. DWS would be able to offer advice on any legislation that may influence the IPP project and coordinate with local communities. It also has an extensive network of contacts and experts CSTP could draw on if needed. CGS has access to the geological and geophysical data CSTP needs for its methods. It could also field local experts to confirm the presence of water and test for contaminants.

CSTP also made contact with the Water Research Commission (WRC), the SA Irrigation Institute (SABI) and the private company I-CAT, all of which proved to be useful contacts that could supply direct support on both deliverables or recommend other contacts that could.

As evidence of this partnership network and to clarify the nature of the collaborations thus far, CSTP has received MoUs from the three main partners and letters of support from the other useful three.

This commitment will also prove integral to CSTPs prospective IPP application because predetermined foreign partnerships in the country of interest are a necessity.

As further foundation work towards an IPP application, this study has attempted to identify a region within SA where its services could have maximum humanitarian benefit. This is partly because the land area of SA is too large for CSTP to survey within a reasonable period of time at the level of detail necessary for prospecting and also because there is a varied scale of drought severity across the country, with some drier and lower GDP regions being worse affected than others.

In this regard CSTP identified the Northern Cape Province as the most appropriate region to apply its methods under the IPP. This region receives some of the lowest rainfall and highest temperatures in the country, resulting in minimal surface water resources (rivers, lakes, reservoirs, etc.). It also has the largest land area of any SA Province, coupled with the smallest population. As a consequence the Northern Cape has some of the most isolated rural communities in SA. Most of these communities also rely on agriculture as their main source of income, which is the second largest industry in the Province and the most water intensive industry in the country. This makes these people some of the most reliant on groundwater of any in SA. However, there is little geological data on the region, including data relevant to locating groundwater resources. It also receives little government support or international attention because of its low population and national GDP contributions.

The number of lives CSTP aims to improve by focusing on the Northern Cape is small (relative to the population of SA), but the scale of this improvement to the individuals targeted (mostly in rural communities rather than cities like the Province's capital of Kimberly) should be significant. This potential for measurable and notable humanitarian benefit directly answers the objectives of the IPP and it is for this reason that CSTP (following its own research and the advice of its collaborators) will focus on the Northern Cape.

To further support a future IPP application, CSTP also performed a validation exercise in this study where it applied the preliminary stages of its analysis on an area of SA and compared its findings to existing groundwater data. CSTP chose the Limpopo Province as the focus of this work, this was once again recommended by its SA partners and supported by CSTPs own research. The main reason for choosing Limpopo was because of the wealth of groundwater data available, through national incentives like the Groundwater Resource Information Project (GRIP), compared to any other Province.

It was found that the geological features CSTP identified through the first stages of its space imagery analysis correlated with existing water well data on Limpopo, it also went so far as to suggest other features that may yield groundwater which were not identified in the datasets CSTP was comparing its results against. This therefore confirmed that there is potential for CSTPs methods revealing novel groundwater resources in the geological conditions of SA, especially in the Northern Cape where there is little groundwater data currently available.

This study has achieved all the objectives set for it, primarily in preparing CSTP as best as possible (within certain time and budget constraints) for the next IPP funding call. However, this study could also be used for other grant applications not yet considered by CSTP and will also undoubtedly prove useful as an example of work to refer to when in discussions with potential commercial customers.

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1. Introduction

Commercial Space Technologies Prospecting (CSTP) offers assistance in the exploration of oil, gas, groundwater and mineral resources, based on techniques involving the geological and geophysical interpretation of space imagery. These techniques originated from Russia in the 1980's (a country renowned for the application of space technology) and continue to be applied and perfected today. When added to Western methods they result in an increase in accuracy and cost effectiveness.

CSTP originated from a Commercial Space Technologies Ltd. (CST) project in 2006. This UK registered company has been managing advanced technical projects in the aerospace industry for over 30 years, with a representative Moscow office and native Russian speaking staff. CSTP is comprised of a team drawn from CST's contacts, with international experts in geology, geophysics, hydrogeology, remote sensing analysis and resource prospecting (primarily from Britain and Russia), and with collaborators from the aerospace and remote sensing industry, the oil & gas industry and related academic fields. The CSTP team have considerable and unique experience which can be flexibly applied to almost any prospecting or mapping project.

This study outlines a new line of business that CSTP is attempting to branch into, applying its methods to locate groundwater resources that its experts have developed and tested in jobs and academic exercises prior to joining CSTP. After discovering the International Partnership Programme (IPP) grant, released by the UK Space Agency (UKSA), which calls for space based applications to be used for humanitarian purposes in foreign countries on the Development Assistance Committee (DAC) list, CSTP has seen an opportunity to apply the skills of its experts to prospect for water in regions of the world severely affected by drought, thus developing a novel branch of its business and helping communities in the process.

The only problem however, is that CSTP has no prior work to draw on in this field, which could reduce its chances of successfully applying for the IPP grant (although the specialists working for CSTP are experienced in the field). Furthermore, as an SME working on narrow margins, it doesn't have the funds to trial its techniques ahead of its IPP application. Thanks to the Global Cooperation Feasibility Study released by Innovate UK, CSTP has been given the opportunity in this study, to test the feasibility of it techniques in a foreign DAC listed country and make local contacts in government, space and geology that it will need to work in conjunction with to most effectively apply its methods.

This study therefore defines the scope of a project that could appropriately answer the next IPP grant funding call. **Section 3** justifies CSTPs particular attention on South Africa (SA) over other African countries also gripped by drought, whilst **Section 6** narrows this focus still further to areas in SA where CSTP can maximise the humanitarian benefits of its methods.

Section 4 assesses the criteria required of an IPP application and designs a fitting CSTP project to answer them. This section also describes two potential project deliverables and shapes the collaboration network CSTP would need to have in place, with SA partners, to implement the project most effectively (established partnerships in the country of interest also being a prerequisite of the IPP).

Discussions were initiated in SA with prospective partners, the results of these face-to-face meetings are described in **Section 5**, along with signed letters of support and MoUs in **ANNEX A** which confirm their commitments to a future CSTP project under the IPP and summarise their roles.

Since the groundwater prospecting work being proposed is new to CSTP (although not to its team of experts), **Section 7** looks at a region of SA (pointed out in **Section 6**) to perform some preliminary space imagery analysis, the goal of this research being to demonstrate the potential for CSTPs groundwater prospecting services in the geological environment of SA.

Section 8 builds on the analysis of **Section 6** (which decided on the precise region of SA where CSTP would apply its IPP funded services) to define and breakdown the work, time and costs that CSTP would incur.

The objectives of this study are therefore:

- To define areas in Africa where CSTPs methods could most effectively be applied.
- To make necessary contacts in SA to aid CSTP's services and answer one of the main conditions of the IPP.
- To perform some preliminary analysis on a region of SA to demonstrate the potential benefits of applying CSTPs methods in SA under the IPP.
- To select an appropriate focal area within SA to implement the IPP project
- To structure a project plan appropriate for the IPP application.

The conclusions in **Section 9** summarise how this study achieved these objectives and describes future actions that need to be taken by CSTP in the lead-up to the next IPP grant release.

2. The Drought Problem in South Africa

Drought affects much of Africa. The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) has stated that the Horn of Africa is currently experiencing a drought, exacerbated by the El Niño weather system, which is threatening the food security of 24 million people. Ethiopia is worst affected with 10.2 million people requiring emergency food assistance[1]. OCHA additionally reports that Southern Africa is suffering its worst drought in 35 years, leaving 32 million people with food insecurity. Even with US$ 1.2 billion of foreign investment, only 12.3 million people will be helped[2].

Meanwhile news stories from around the world state that SA is experiencing its worst drought since 1982, with El Niño once again being pointed to for the lack of rain and surface water[3]. This extended dry spell (seen worst in the Northwest and Northeast of the country **Figure 2.1**)has reduced national dam levels to 55% in early 2017[4], making SA 148th out of 180 countries for water availability per capita[5]. Signs of the drought's severity include plans to kill 350 hippos and buffaloes in Kruger national park to ease the animals suffering, threats to food secutiry can also be seen as crops yeilds like maise decline nationally by ~30% and cattle by ~15% across the 2015/16 timeperiod[6]. To counter this, government spending was reprioritised in 2015/16, with R 268 million (~£17 m GBP) being put toward drought relief and R 173 million (~£11 m GBP) to assist farmers with animal feed and stock[7]. The SA government have also imposed water restrictions across the country, manifesting in several regional initiatives such as the closing of 29 municipal swimming pools in Cape Town[8] and the issuing of fines to people in the Gauteng Province who exceed the 25 m^3 monthly water allowance[9].

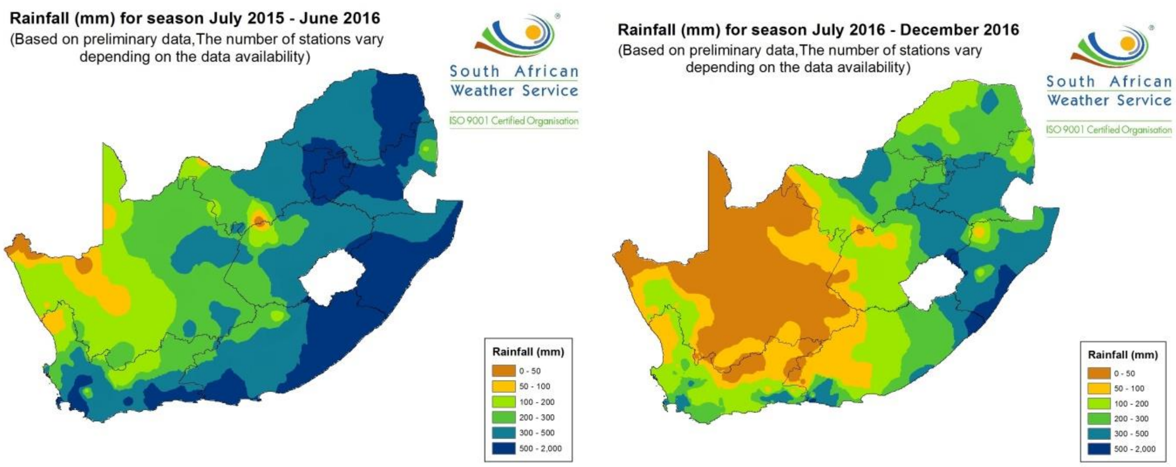

Fig. 2.1 Average precipitation in SA from July2015-June 2016 and from June 2016-December 2016[10]

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1 (2016) El Nino in East Africa, United Nations OCHA
2 (2016) El Nino: Southern Africa Faces its Worst Drought in 35 years, United Nations OCHA
3 (2015) South Africa Grapples with Worst Drought in 30 years, BBC
4 Weekly State of Reservoirs Report
5 (2014) South Africa's 20 Year Journey in Water and Sanitation Research, WRC
6 J. Burke (2016) South African National Park to Kill Animals in Response to Severe Drought, The Guardian
7 J. Joubert (2016) SA Drought Not Broken after Driest Year in History, Times Live
8 (2017) Cape Town Residents Urged to Use Groundwater as Drought Continues, SABC
9 D. Tsotetsi (2017) Water Restrictions Still Stand in Gauteng Despite Good Rains, SABC
10 Historical Rain Maps, South African Weather Service

Another issue is the inefficient useage of the country's existing water resources. Irrigiated Agrigculture is the largest single user of water in SA, accounting for over 60% of the usage but only adding ~3% to the country's GDP and ~7% to the formal employment. Despite this SA is still not self sufficient on its food production and relies on imports to feed its population. This is partly because the most irrigated crop is pasture (grassland) for grazing livestock, which offers one of the most inefficient water to calorie convervions. Water availablility is a major limiting factor to the growth of this sector, however the country's 'New Growth Path' still plans expansion by a further 145,000 new jobs by 2020 and has set a target to increase more than 50% of the irrigated land in SA, stating that the industry 'has a huge potential socio-economic impact in rural communities'[11].

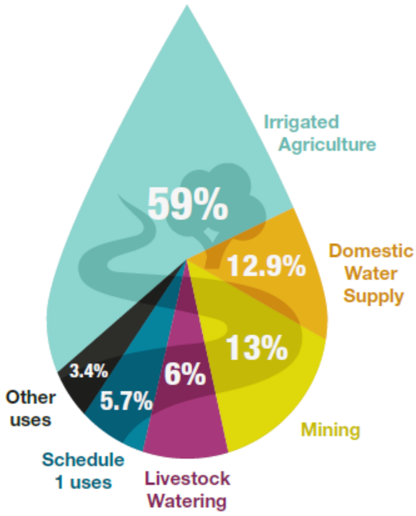


Fig. 2.2 Groundwater usage in SA [12]

One route towards the more sustained usage of water in sectors such as irrigated agrigculture is the exploitation of groundwater. SA already uses 59% of its groundwater for irrigated agrigculture (**Figure 2.2**) – with the people of SA being encouraged to use groundwater from boreholes to take pressure off dams and other surface water stores[13]. In recognition of the importance of groundwater, DWS has even produced a 'National Groundwater Strategy' (NGS) Document with one of the main aims being to 'let the full role/potential of groundwater towards water security in SA unfold'. This source of water isn't however without its own restrictions and government bodies warn residents to use groundwater sparingly[14].

This therefore demonstrates that the identification of new groundwater sources, as offered by CSTP's service, could greatly alleviate the pressure of drought on SA. Furthermore, in combination with more water efficient irrigation systems (such as drip, subsurface, micro-spray and micro sprinkler)[15], groundwater could better sustain irrigated agrigulture, SA's most water hungry sector which according to government plans aims to rapidly expand in the near future.

[11] (2016) National Groundwater Strategy, DWS & WRC
[12] (2014) South Africa's 20 Year Journey in Water and Sanitation Research, WRC
[13] (2017) Residents Encouraged to Use Boreholes Sparingly, South Africa News Today
[14] (2017) Residents Encouraged to Use Boreholes Sparingly, South Africa News Today
[15] I. Van der Stoep (2014) South African Irrigation Statistics: An Analysis of the 2014 WARMS Data, SABI

3. Overview of CSTP Groundwater Prospecting Service

CSTP offers services to assist in the exploration for groundwater as well as for oil, gas and mineral resources which are based on a technique involving the interpretation of space images. CSTP has assembled a team comprised of experts drawn from several organisations in the United Kingdom, Russia and Ukraine who have established collaborators from the remote sensing and oil & gas business and academic fields. The team have considerable, appropriate and unique experience which can be brought to bear on particular needs. The experts from which the team is composed are all at a senior level and have proven reputations in their fields.

The experts have a proven track record of successfully exploring and identifying of drilling targets through the interpretation of complimentary suites of satellite data and its full integration with the existing geochemical, seismic, gravity and magnetic data as available.

3.1. Technique

The interpretation of space images used by CSTP is mainly based on the extraction of data related to structural geology and the geomorphology of territories, and it represents the only method allowing one to have a view of geological objects as they are revealed on the surface as well as a view of their signatures in a landscape within natural boundaries and showing original relationships. In other words, the analysis of images at different levels of generalisation gives extra information on the geological structure. This is why it is expedient to use this method despite the fact that it is indirect. **Figure 3.1** illustrates the regional level of generalisation (approximately 500x500 km).

Groundwater reserves or any ore or oil and gas deposit is a geochemical anomaly which is always accompanied by tectonic, petrographic, geophysical and landscape anomalies. They display themselves in the landscape in different ways and are correspondingly reflected in aero- and space images in connection with their hierarchy rank, nature, climate, latest tectonic movements, intensity of anthropogenic transformation of the landscape and other factors.

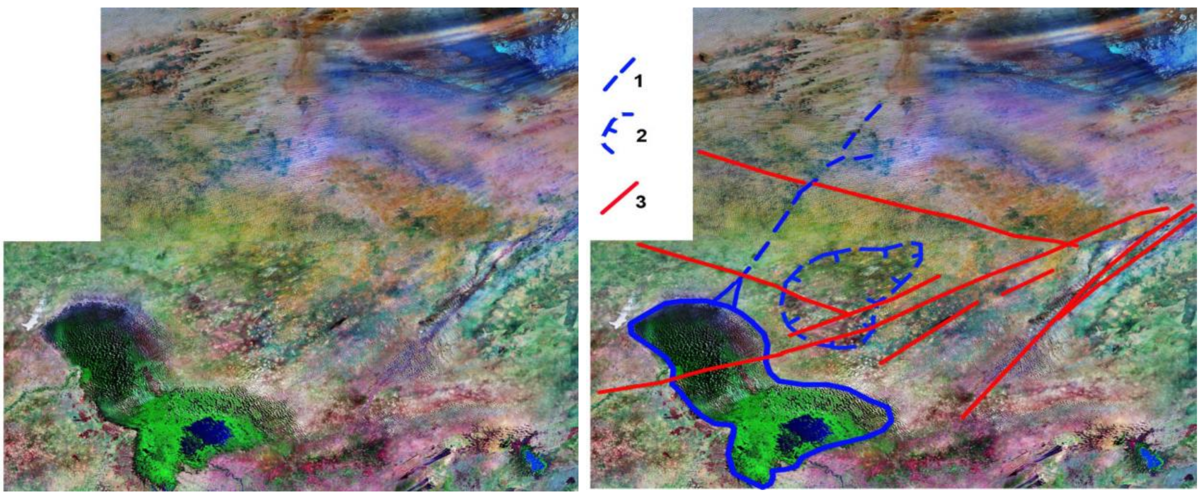


Fig. 3.1 Area between the Chad Lake and the Bodele basin. Its interpretation: 1 – underground influx from the Chad Lake; 2 – syncline; 3 – tectonic faults predicted by the analysis (Landsat).

The main objective of interpretation is the identification of areas on the Earth's surface which have specific indicants corresponding to various objects being prospected. These indicants are represented by respective signatures in space imagery. Depending on what we are looking for (ground water, oil and gas, mineral, etc.) and taking into account local geology and climate, we construct sets of images in necessary spectral bands and covering different areas at different resolutions for the interpretation with regard to known indicants. We use as many signatures and indicants as possible for any particular geological object being prospected.

It should be mentioned that since the late 1970's all Soviet and Russian geological explorations have applied a stage of space imagery analysis as an obligatory part of a survey. Space imagery is used for the construction of forecast-exploration models with the help of images of various spectrum bands and resolutions. Different levels (scales) of image overviews – global, regional, ore deposit field, etc. allow the identification of faults, lineaments, ring structures and other tectonic elements. Judging by the intensity of special features and their configuration the forecast is made (**Figure 3.2**).

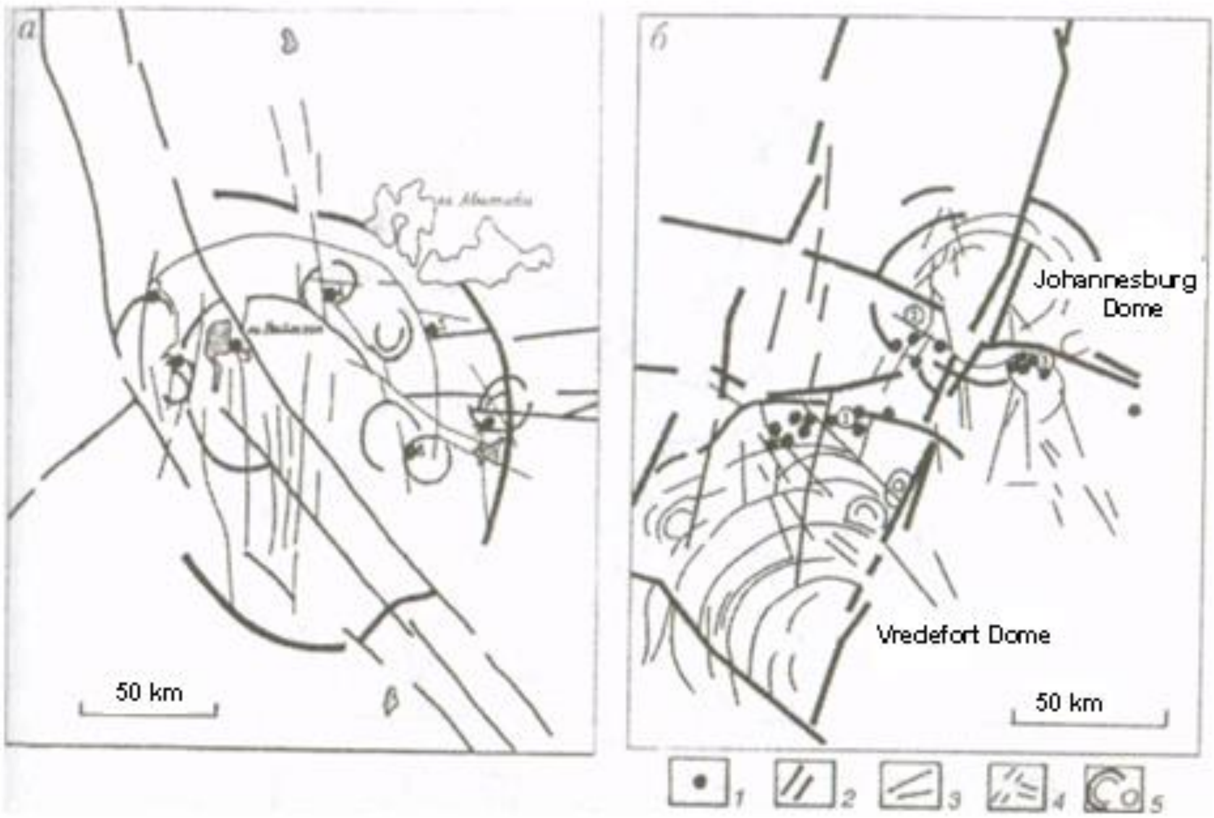


Fig. 3.2 Space structural models of a) — gold ore sub-province Abitibi (Canada), б) — gold ore basin Witwatersrand (South Africa)

Also, CSTP uses various methods of the processing of images, for instance, photometry, specialist software for the automatic identification of linear structures and other geological features. An example of photometry processing is given in **Figure 3.3** - usually dried waterways are hardly seen in deserts, but they become seen far better after the photometric processing of an image.

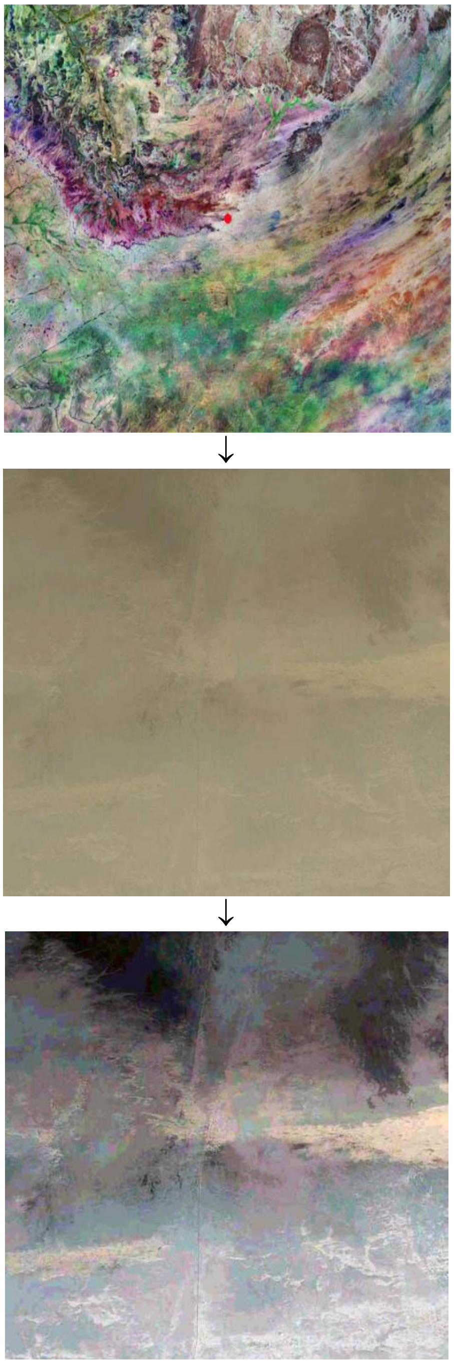


Fig. 3.3 A dried up riverbed in Niger.

The method used by CSTP has proved to be efficient for:

- The mapping of fault and block structures on the Earth's surface
- Identifying of the most promising areas for further, more detailed exploration in combination with traditional geological and geophysical data
- Quick educated assessment of plots having licenses for a customer wishing to buy them

Obviously, the more existing traditional geophysical and geochemical data that can be used in combination with the analysis of space imagery the more exact (accurate) the identification of areas for further detailed exploration is.

Compared to traditional methods of prospecting this technology allows one to reduce the costs and make the finding of water quicker. Most of the cost decrease is provided by the elimination of the need of large scale land-based exploration which is very expensive, limiting it to the most promising areas.

The novelty of the method compared to similar Western methods is in the CSTP specialists' knowledge and on-hand experience in the selection of the optimum hierarchy of satellite images (global, regional, local scales, etc.) with appropriate data (visible, infrared, radar, etc.). These specialists have an extensive database of signatures for various things being prospected (water, oil, mineral resources, etc.).

Territories explored by the members of CSTP include USSR areas (the Urals, areas to the east from the Caspian Sea, the Yamal peninsula, Ukraine), China and parts of Africa.

For water prospecting a model of the region of interest is implemented in the form of:

- A map of faults ranked by size and kinematics and dividing the region into a system of ranked 'blocks' nested within each other
- A map of permeable faults
- A map of modules of underground run-off
- A scheme of recommended areas of expected water intakes.

The generic plan of water prospecting survey activities based on space data is as follows:

- Detailed analysis of space images and existing geological, geophysical, geochemical, hydrological and hydrogeological data for a broad territory. The results are some geological maps + a map of prospective areas (ca. 5x5 miles) for detailed study.
- Detailed geochemical, hydrological and hydrogeological study of the prospective areas. The results are the recommended points for the location of water intakes.
- Drilling, chemical analysis of the waters obtained; construction of water intakes and water supply facilities.

Geochemichal analysis may involve emanation surveys (radon, thoron) for mapping of neo-tectonically active fractured zones; carbon dioxide gas survey - anomalies indicate rock permeability on the studied area; helium gas survey - formation of helium anomalies in near surface conditions is caused by ascending fluid and mass flows (through fractures); hydrogen gas survey - hydrogen is an indicator of depth of fractures depth and common for detachment faults but not found in compression zones.

3.2. Examples of the Use of CSTP Prospecting Methods

CSTPs method for groundwater prospecting can be illustrated by the work carried out in Ukraine. Combined research aiming at identifying fault zones of increased permeability (**Figure 3.4**) was done in the territory of Kiev, Zhytomyr, Cherkassy, Kirovograd and Dnepr regions. The obtained results provided an opportunity to identify areas of water intakes for drinking and industrial water supply to Fastiw, Bila Tserkva, Korosten, Korostyshiv, Nosachiv, Alexandria, Uman and other minor towns and industries. Combined research in this context means the use of hydrological, thermal and radon data together with space and aerial images. The unique feature of this case is the use of information on gases – measurements of Rn, Tn, He, CO_2, H_2 on the surface (emanation surveys) afterwards used in the integral map of geological & geochemical structure. (Thoron is the historical name for Radon 220)

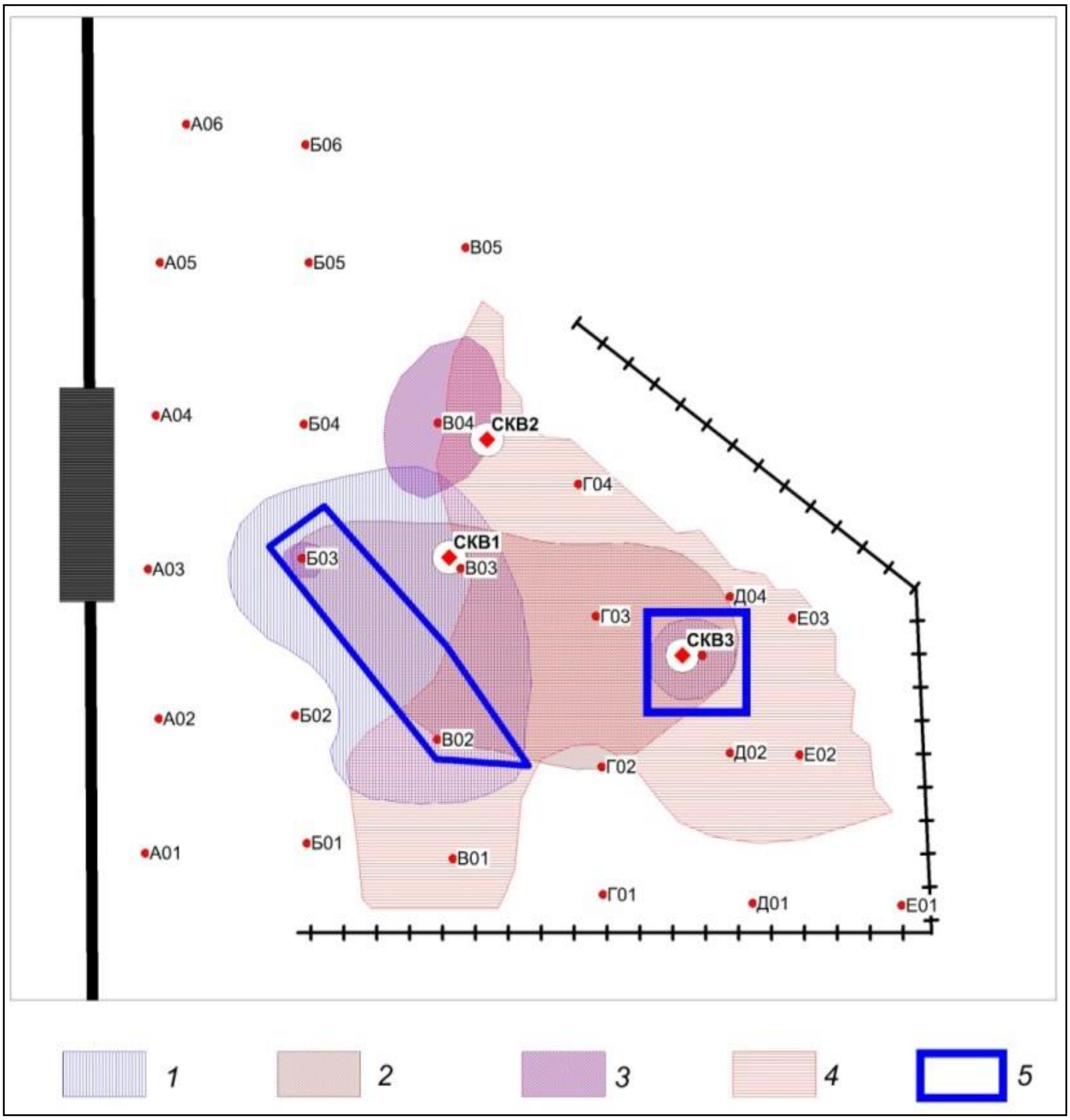


Fig. 3.4 The prediction of the most promising sites for drilling wells for groundwater withdrawals based on different characteristics: 1 – according to Rn; 2 – according to Tn; 3 - according to K_{Rn} = Rn/Tn; 4 - temperature; 5 - based on combined research (Rn=radon, Tn=thoron)

The next figure illustrates the results of the analysis for near-river water intakes which are situated in a zone of fractures of a special sort. One of the special characteristics of the fractures is their dynamics – there exist indications on the surface of the Earth which show whether the tectonics of the area are still changing (termed alive or "active" faults) or the faults are "inactive". According to contemporary hydrogeology, water cannot be found in zones with inactive fractures.

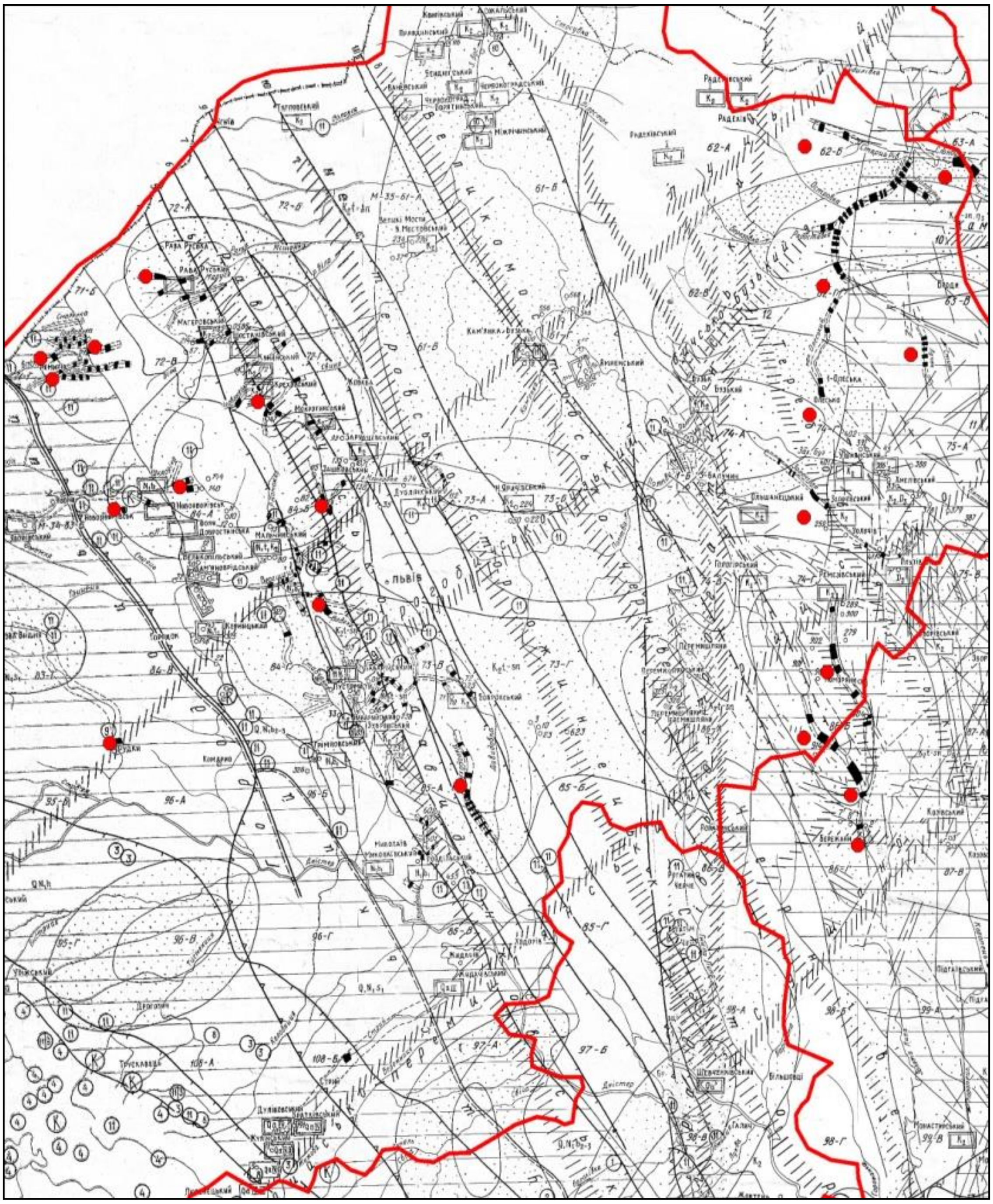


Fig.3.5 Validation of watery fracture zones for laying the near-river water intakes (Lviv region, Western Ukraine)

Another example is in prospecting for oil. CSTP used this method in Southern Sudan in the central part of Africa (the green square on the map of **Figure 3.6**, which is expanded in **Figure 3.7**). On space images the area looks like a single sublatitude submerging wedge which becomes narrower to the West. Space images assisted geologists to identify a huge graben there. Core samples from this area contain rocks dated from the Lower Cretaceous to Quaternary and oil bearing from Neocomian to Miocene. The cut is broken down by multiple faults which collectively form a complex graben. Sandstones are collectors and clays are traps. Most of these traps are tectonically shielded. The customer's licensed block of 120x120 km size is approximately in the centre of the square shown on the map in **Figure 3.6**.

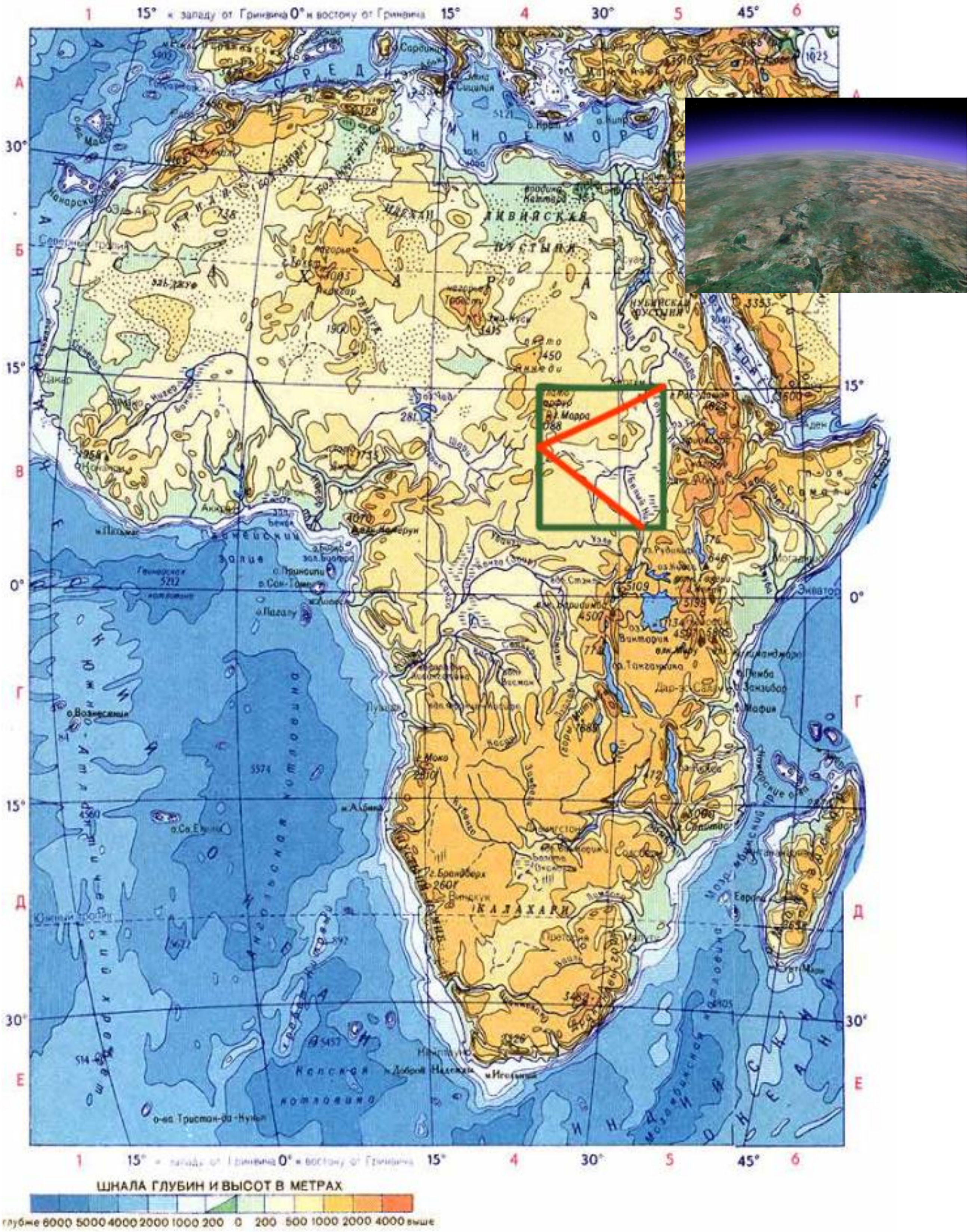


Fig. 3.6 Area in Southern Sudan in the central part of Africa (a green square on the map) where the work was done

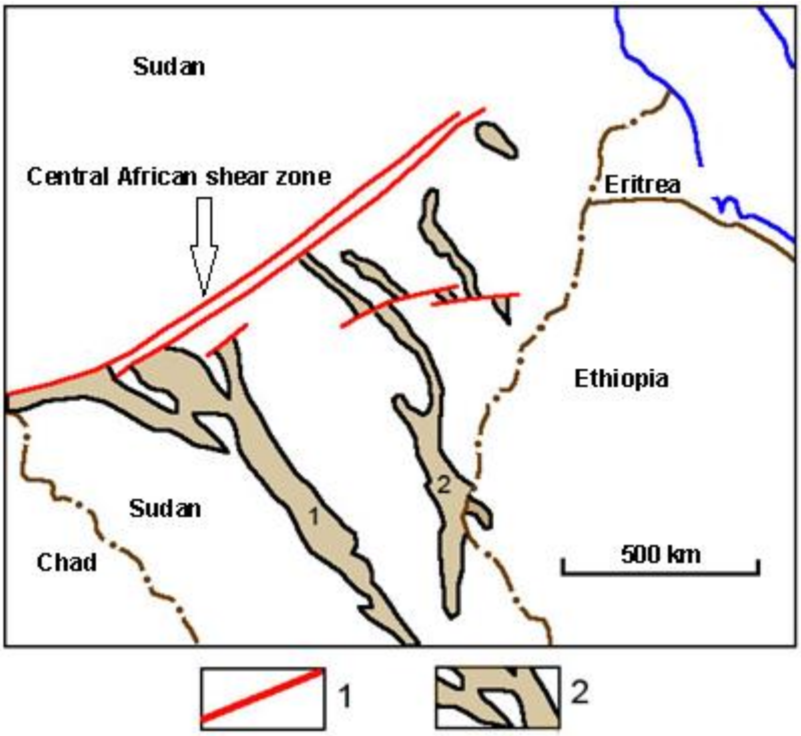
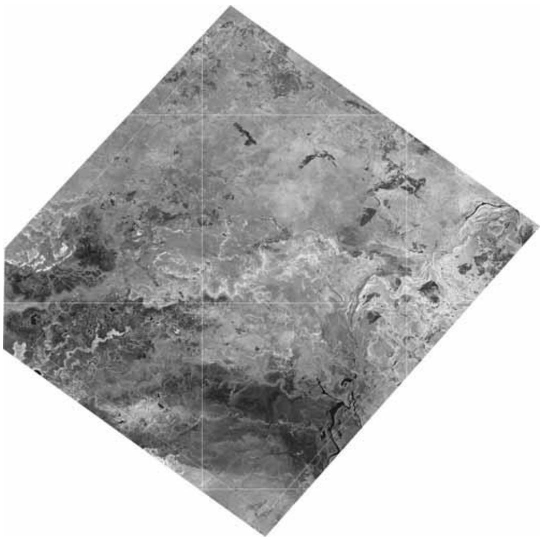


Fig. 3.7 The basins (existing regional data before the CSTP survey)

Oil and gas bearing here is connected with the two basins 1 – Melut and 2 – Muglat, which stretch mainly in a North-West direction adjoining the Central African shear zone in the South. Space images like that on the left hand side in **Figure 3.8** were interpreted and a map of the fault and block structure of the area was constructed (right):



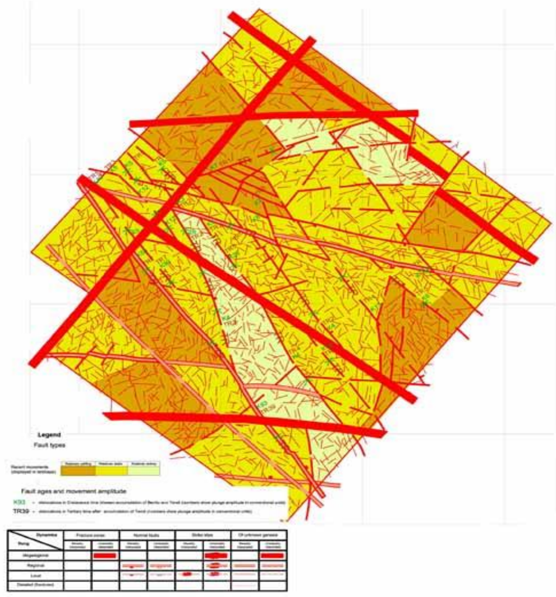


Fig. 3.8 Space image and the map of the fault and block structure.

The interpretation of the space images together with already existing gravimetric, magnetic, and fragmental seismic data enabled the compilation of a map of the revealed graben (**Figure 3.9**). Certain locations were recommended for detailed seismic testing. One such point is characterised by several oil-bearing indications seen on space images and was qualified as the most promising one (circled in purple in **Figure 3.9**). The interpretation of the space images (combined with the analysis of conventional data) resulted in the choice of the locations for detailed seismic exploration limited to the areas of the size of 80 x 80 miles at 4 chosen points, the accuracy of the coordinates of which being within a diameter of 5 miles.

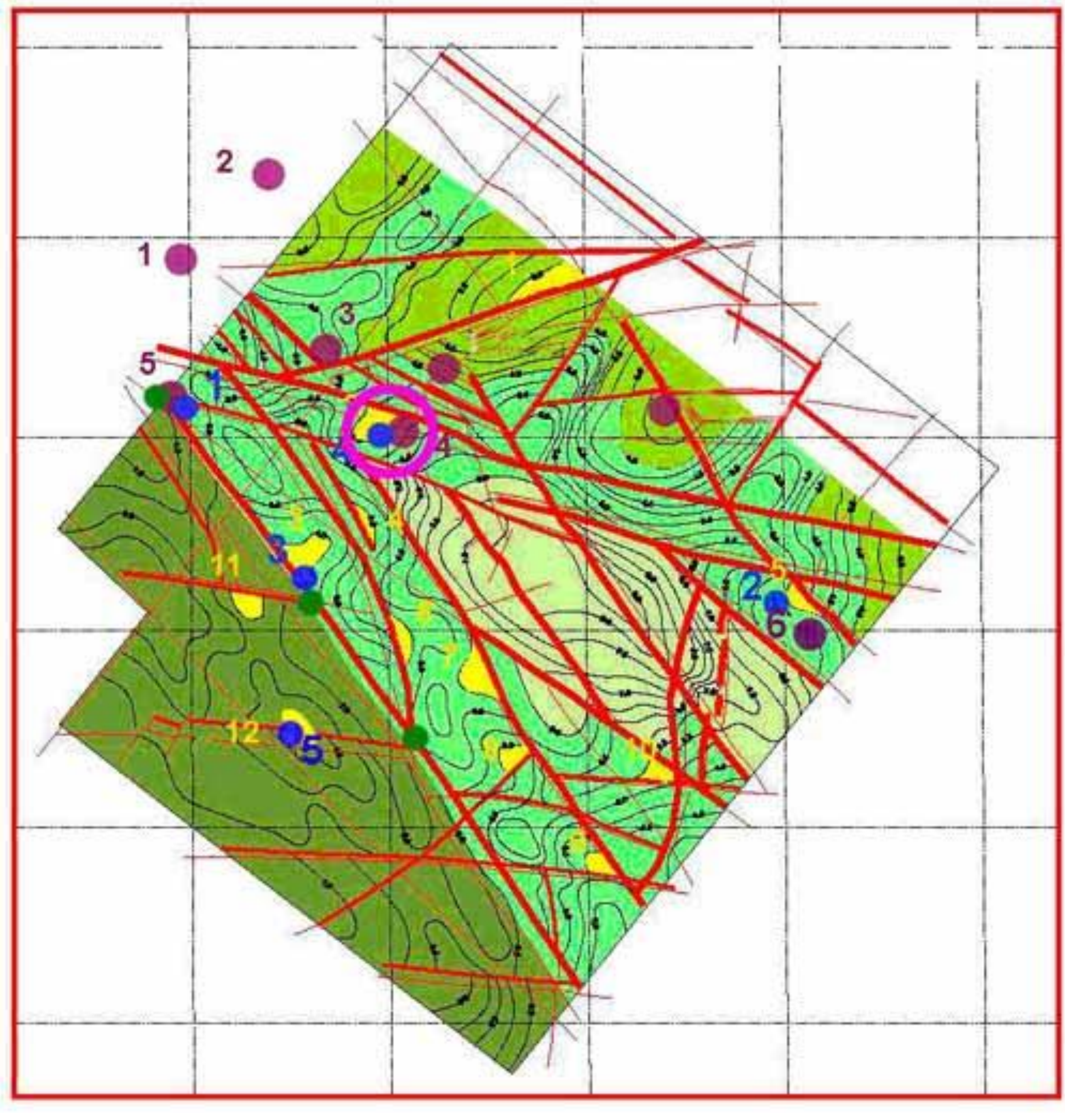


Fig. 3.9. A map of the graben which was revealed by the analysis

The results of the detailed seismic exploration confirmed the conclusions made from space images (**Figure 3.10**).

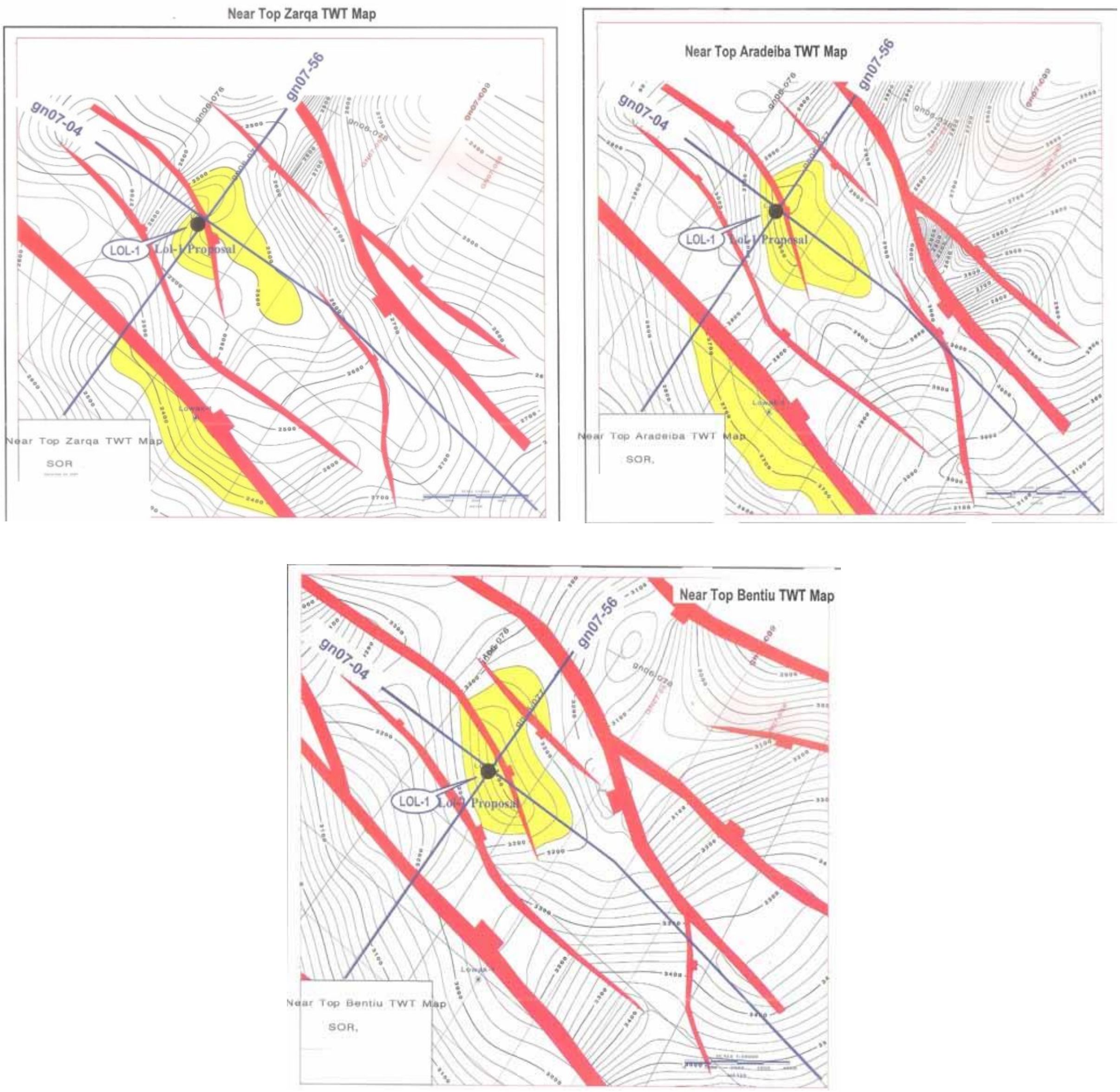


Fig. 3.10 Detailed seismic exploration confirmed the conclusions made from space images.

Later-on, drilling at 2 out of the four promising locations which CSTP identified was done by the Sudanese company The Greater Nile Petroleum Operating Company (GNPOC) and confirmed that oil was present in one of them.

CSTP is looking forward to applying this technology to the prospecting for groundwater in the Saouth African province Northern Cape, more details in **Section 8**.

4. Structuring a Project around the International Partnership Programme Grant

The UK Space Agency's International Partnership Programme (IPP) is a £152M multi-year programme which uses expertise in space based solutions, applications and capability to provide a sustainable, economic or societal benefit to undeveloped nations and developing economies. The fund originates from the UK's Official Development Assistance (ODA) fund which totals 0.7% of country's Gross National Income. To qualify for this grant applicants must therefore aim to partner with countries on the ODA list, of which SA is one.

It was confirmed in face-to-face discussions with UKSA that the IPP will be launching several calls. The first call for the IPP opened on June 28th 2016 and closed on September 27th 2016. 22 winning projects totalling over £70M have subsequently been announced, including a food security project in SA. There are however, no projects that overlap in either theme (groundwater prospecting) or technology (geological/geophysical analysis of Satellite EO images) therefore CSTP can propose a fully novel project the next time an IPP call is announced.

4.1. Defining and Answering the Aims

The goals for the IPP are as follows:

Primary Aim:

Using UKSA's expertise and capability delivered through Industry and Academia, deliver solutions whose outputs lead to a measurable and sustainable economic or societal benefit in chosen partner country or region

Secondary Aim:

- Develop valued and sustainable partnership arrangements which lead to growth opportunities for the Space community
- Show the additionality that space based solutions and applications have over terrestrial systems or can be added to bring benefit
- Use industries and Academia's unique expertise to complement existing effort or lead in areas where we have the expertise[16]

To answer the aims of the IPP CSTP will be applying for an Open Call that 'is open to any project which provides a sustainable, economic or societal benefit to an ODA country'. Constructing a project around an Open Call will allow CSTP the greatest flexibility to create a project that most appropriately answers the Primary and Secondary aims of the IPP.

4.1.1. Project Overview

The project proposed by CSTP will be to apply its geological/geophysical analysis of satellite derived Earth observation (EO) data (as described in **Section 3**) to prospect for novel groundwater sources in SA. As covered in **Section 2**, SA is currently in the grips of its most serious drought for over 30 years[17] and is turning to alternative forms of water, such as groundwater, to sustain its population and

[16] (2016) IPP Call 1: Application Guidance, UKSA
[17] (2015) South Africa Grapples with Worst Drought in 30 years, BBC

industries like Irrigated Agriculture[18]. As a cost effective and efficient means to survey the expansive SA land-area, CSTP's services would greatly assist in the search for novel and viable (non-contaminated) groundwater sources. Furthermore, as the exploitation of groundwater is seen as a priority in the SA government's strategy against drought, any assistance in this sector would have a clear humanitarian and economic benefit, as identified by the country itself[19].

The project would have one or even two deliveries, depending on the relevance to the grant. The **first delivery** would be a prospecting model created via CSTP methods, which displays the likely locations for novel groundwater sources in a specified region of SA. The **second delivery** could be a CSTP coordinated effort with local partners to confirm its findings by drilling exploratory boreholes, followed by the subsequent design and manufacture of necessary decontamination, pipe and irrigations systems to deliver useable groundwater to communities, thus providing a full 'end-to-end' service from the locating of groundwater – through to its delivery. Both project deliverables, and the partnerships required to achieve them, are outlined in **Figure 4.1**.

The necessary collaboration network to enable the first and (potentially) second delivery is described in **Section 4.2**. The first delivery is close to CSTP's field of expertise and is most related to the application of space technology and space-based methods; it is therefore more relevant to a grant released by UKSA that naturally has an emphasis on space. Whereas the further the project progresses towards the second delivery, the further it deviates from space. The second delivery may therefore hold less traction in an IPP application. However, the second delivery also has some strong positive additions; such as the provision of groundwater as a clear and more sustainable humanitarian outcome (local communities only care about receiving usable water). It also establishes a local partnership network and end-to-end service that can be more easily commercialised and exported to neighbouring African countries, where they may not have the local expertise and industry to properly utilise CSTP's first delivery only (a raw prospecting model).

The decision to focus on one or two deliveries for the project can only be made after consultation with the UKSA team that awards the IPP. This consultation will occur once the second IPP call is announced.

4.1.2. Answering the Aims

The focus of this proposed project complies with the main aims of the IPP. In meeting the **Primary Aim**, there is a clear socioeconomic benefit for SA in the efficient discovery of usable groundwater. The CSTP service can provide a sustainable benefit by locating multiple groundwater sources that would hopefully be utilised gradually for some time after the project's official end. The CSTP team also has experienced university level educators who could share some of their techniques with local experts so they can continue applying them to the benefit of SA after the project's end.

In meeting the **Secondary Aims** of the IPP, the planned partnerships described in **Section 4.2** would provide CSTP with African experts and a necessary footing to export its services to other countries on the African continent, starting with SA's neighbours (Namibia, Botswana, Zimbabwe and Mozambique) who are all also facing problems with drought. Meanwhile **Section 3** demonstrates the

[18] (2017) Residents Encouraged to Use Boreholes Sparingly, South Africa News Today
[19] (2016) National Groundwater Strategy, DWS & WRC

benefits of CSTP's space-based techniques over conventional on-ground counterparts. However, it also shows how CSTP's methods work in unison with existing on-ground SA prospecting methods, as geological and geophysical data is required by CSTP when creating its prospecting models, and conventional prospecting is needed for final validation of CSTP's findings.

As well as meeting the main aims of the IPP, the success of any application will depend on how well it addresses a number of **assessed criteria**. These criteria are listed below with descriptions of how CSTP intends to answer them:

- Clearly identified international partnership – *The collaboration network required for the project is outlined in **Section 4.2**.*
- Clear delivery aligned to the programme primary goal – *Two projects deliverables are described in **Section 4.1.1** and justified in the context of IPP main aims*
- Clearly able to show it meets ODA definitions and criteria – *ODA criteria include the following points:*
    - strengthening global peace, security and governance – *locating novel groundwater will reduce the need for water restrictions on the SA population and thus reduce public discontent and stabilise SA*
    - strengthening resilience and response to crises - *locating novel groundwater would relieve pressure on surface water stores and strengthen SA against the drought crisis*
    - promoting global prosperity – *a number of SA industries require regular access to water, assisting these sectors would promote prosperity in SA*
    - tackling extreme poverty and helping the world's most vulnerable – *Access to clean water is a humanitarian requirement that is under threat some of the more impoverished rural communities in SA, locating novel groundwater would directly help these people*
- Impact to Development Assistance Committee (DAC) list country – *SA is on the 'upper middle income countries' section of the DAC list, a previous SA project was also awarded a grant from the 1st IPP call, thus demonstrating that SA is an appropriate country to focus on.*
- Overall value for money – *As outlined in **Section 3** the CSTP service is aimed at reducing the cost of conventional prospecting and thus offering competitive value for money.*
- Project quality, including:
    - Whether the need for the project has been clearly established and potential for future impact – ***Section 2** and **Section 6** justify the need and potential for the project*
    - Excellence, novelty and appropriateness of the proposed activities – ***Section 3** explains the novelty of CSTP's services in comparison to similar Western methods*
    - Suitability of the applicants and partners – *the proficiency of CSTP and its partners is covered in **Section 3** and **Section 4.2** respectively*
    - Strength of user involvement – *User involvement will be key throughout the project and is covered in **Section 4.2***
    - Demonstrable and measurable success criteria – *the physical confirmation of the findings on CSTP's prospecting model, though exploratory borehole drilling, is a demonstrable and measurable result*
    - Strength and experience of the project consortia – *the experience of CSTP and its partners is covered in **Section 3** and **Section 4.2** respectively*
- Applicability to UN sustainability goals – *the project covers a number of UN sustainability goals, including: clean water and sanitation, zero hunger and economic growth.*
- Sustainability of the project benefits beyond the period of any funding including a sustainability plan – *project sustainability is a main IPP aim and is covered in **Section 4.1.2.***

4.2. Required Collaboration Network

CSTP
Task – Identify required remote sensing data and perform initial prospecting analysis. Apply general project management, coordination of partners and marketing.
Applied Expertise – General management, geophysics and geology specialising EO analysis for prospecting

Council for Geoscience (CGS)
Task – To provide existing geological and geophysical data on identified regions of interest (e.g. maps, seismic, gravimetric, etc.)
Applied Expertise – Conventional geology and geophysics, local geology knowledge

SANSA
Task – Prime Partner – To provide EO data and coordinate with government departments regarding licensing and legislation to project activities
Applied Expertise – Intergovernmental discussion, EO data sourcing and processing, public outreach

Department of Water and Sanitation (DWS)
Task – To coordinate with government departments and local communities to find areas most in need of clean groundwater, provide permission to build infrastructure
Applied Expertise – Intergovernmental discussion, public out reach

FIRST DELIVERABLE – CSTP Prospecting Model revealing new potential groundwater sources

Conventional Prospecting Company (CPC)
Task – To apply conventional exploration drilling to confirm CSTP analysis
Applied Expertise – Conventional geology and geophysics, local geology knowledge

Water Contamination Analyst (WCA)
Task – To perform chemical analysis on water found by CPC and identify contaminants
Applied Expertise – Chemistry, knowledge of clean water requirements

Water Purification Company (WPC)
Task – WPC will be selected depending on WCA results to build appropriate purification equipment
Applied Expertise – General engineering, knowledge of water purification methods

SECOND DELIVERABLE – Clean groundwater to SA communities in need.

Water Utilities Company
Task – To manage and maintain water distribution to the SA public
Applied Expertise – Waste water treatment, water distribution management, public engagement

Irrigation/plumbing/water-well Company
Task – To design, engineer and build water provision infrastructure, incorporating purification measures if needed
Applied Expertise – Civil engineering

Fig. 4.1 *Collaboration Network – The partnerships required for CSTP's proposed IPP project are outlined in this graphic. Each box represents a partnering organisation (this could be a government department, private company or independent commercial contractor), the blue arrows represent the communication channels between partners. All boxes with bolded black titles which are above the green dashed line represent partners required for the first deliverable, described in* ***Section 4.1.1.*** *Meanwhile all boxes with red titles below the dashed green line represent unidentified or unspecified partners required for the second deliverable, described in* ***Section 4.1.1.***

The collaboration network displayed in **Figure 4.1** outlines the SA partnerships CSTP needs to make to conduct its IPP project. CSTP set out to acquire this network through a series of meetings during a visit to Pretoria, the topics discussed and outcomes of these meetings are described in **Section 5**. Justifications for the partnerships highlighted in **Figure 4.1** are as follows:

- **The South African National Space Agency (SANSA) –** is an SA government department, established in 2010, which is directly responsible for space related affairs. As the IPP grant is managed by UKSA and therefore has an emphasis on space-based applications, it is logical to have a space related entity as the **lead SA partner** in the collaboration network. SANSA would be able to assist CSTP in a number of ways. Firstly, it has an extensive repository of EO satellite data and has access to international EO datasets (like the European Sentinel Database), all of which can be made available to CSTP as an in-kind project contribution. Secondly, one of SANSA's assigned roles is in the facilitation of intragovernmental discussions and general project management; it could therefore coordinate work between other SA partners, whilst subsidising its own work as another in-kind contribution. Thirdly, SANSA has worked with UKSA in the past for the construction of an IPP tactical call; it therefore has experience to bear in the application and management process for the IPP.
- **The Department of Water and Sanitation (DWS) –** is an important partner to engage with early-on because as stated on their website, DWS is the 'custodian of South Africa's water resources' and is 'responsible for the formulation and implementation of policy governing this sector'. Therefore any CSTP groundwater project would have to comply with the policy that is constructed and enforced by this department. DWS are also involved in several out-reach programs with local communities, and continually survey the distribution of water resources to regions of SA and assess the resulting economic and societal impact this may have. So when determining which areas SA (from a humanitarian and economic standpoint) most require CSTP's services, DWS can supply CST with the necessary information to make this decision. Like SANSA, DWS can also manage intragovernmental discussions and have contacts that could assist in achieving the second project deliverable (these contacts could cover some of the boxes titled in red text in **Figure 4.1**).
- **The Council for Geoscience (CGS) –** is the SA equivalent of the British Geological Survey. As explained in **Section 3**, CSTP's methods need to be supplemented with existing geological (geological maps/surveys) and geophysical (seismic, gravimetric, etc.) data, related to whatever region it might be surveying. The more existing data CSTP has the more precise and effective its final prospecting models are. CGS is the government department with access to this data, and like SANSA, it could supply its data to CSTP as an in-kind project contribution. CGS could also supply the project with on-ground hydrogeology experts who could drill boreholes to confirm CSP's findings, and perform the necessary chemical analysis to determine if and what contaminants could be in any newly discovered groundwater. This means that CGS could also fill the roles of 'conventional prospecting company' and 'water contamination analyst', as displayed in **Figure 4.1** these roles would represent the first steps towards CSTP's second deliverable.

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5. Meeting Collaborators in South Africa

From January 24th – 26th 2016, a CSTP team (Alan Perera-Webb, Kostya Milyayev and Natalia Maloushina) met with a series of potential collaborators in Pretoria. The purpose of the trip was to:

- Introduce CSTP – its team and services
- Discuss the study for Innovate UK
- Describe the IPP grant and its potential to assist SA
- Describe the envisaged CSTP led project to answer the IPP
- Discuss the desired contribution of each partner
- Engage in a general discussion and exchange ideas

The results/conclusions of these meetings and their implications for CSTP's proposed IPP project are listed in this section in the chronological order of their occurrence.

5.1 The Department of Water and Sanitation

CSTP first met with DWS during its trip to Pretoria, the DWS team that attended the meeting were as follows:

- Chris Moseki (academic training in hydrogeology and initial contact at DWS, organiser of meeting, works in research base for Climate Change – Modelling and Interpreting)(Email: MosekiC@dws.gov.za ; +27 (0) 12 336 8164)
- Zachariah Maswuma (Director of Hydrological Services) on groundwater monitoring data and information management (Email: maswumaz@dws.gov.za ; +27 (0) 12 336 8784)
- Sakhile Mndaweni (Scientific Manager – Geohydrology) on groundwater planning (Email: mndawenis@dws.gov.za ; +27 (0) 12 336 8764)
- Two members of the DWS Climate Change division and the overall Department boss were also in attendance but they didn't have business cards and so their contact information was not exchanged.

The proposed IPP project presented by CSTP was well received by DWS and they confirmed their willingness to be involved. As evidence of their commitment to participate and to outline the nature of the future partnership, DWS signed a MoU with CSTP (**Annex A)**. The following participation points were agreed:

- To facilitate communications with other government departments
- To advise on potential legislation that may need to be considered at various stages of the IPP project
- To assist in acquiring necessary industrial and academic contacts either during the IPP application process or during the IPP project
- To help obtain and process population and drought statistics either during the IPP application process or during the IPP project, so that CSTP can appropriately determine the socioeconomic impact of its services on SA regions of interest.

The majority of the meeting involved assessing which areas of SA could most socioeconomically benefit from CSTP's services. The conclusions from this discussion greatly assisted CSTP in focusing its proposed IPP project, thus maximising the potential humanitarian and economic value of its services, as fitting with the objectives of the IPP grant.

It was recommended that the Limpopo Province would be an ideal region for CSTP to validate its methods (as discussed in **Section 7**), whilst the Northern Cape Province would stand to benefit the most from CSTP's applied services through the IPP grant (as discussed in **Section 8**).

According to DWS, Limpopo is one of the worst drought affected Provinces in SA, caused by a combination of high water usage from large population centres, and some of the lowest rainfall in the country. As a consequence it receives a lot of financial relief and there are several on-going national and international water-aid and research projects (German, Swiss, etc.). DWS therefore suggested that all this existing attention would dilute the impact CSTP's services could have on the Province. However, DWS then went on to suggest that Limpopo would, for two reasons, be ideal for the validation study outlined in **Section 7** of this report.

Firstly, the extensive work in Limpopo has generated a lot of readily available geological, geophysical and other relevant data on the region. As stated in **Section 3**, CSTP's methods are improved by including as much existing data as possible. The accessibility and abundance of this data would therefore make it easier, faster and cheaper for CSTP to perform a cursory survey of Limpopo, compared to other SA Provinces. Such a survey would not be precise enough to indicate borehole targets, but given the abundance of available data, it could have high potential for revealing geological features that may not have previously been linked to groundwater.

Secondly, there was a previous German project using similar satellite-based methods that was unsuccessful in Limpopo, therefore any novel findings by CSTP would validate the potential for its services in SA over other competing techniques.

DWS and CSTP therefore agreed that because of the abovementioned points, Limpopo would be an ideal focus for the validation work performed in **Section 7** of this report.

The reason DWS suggested Northern Cape as the target Province for the main IPP project was more subtle. The region represents the largest Province by land area in the country (approximately one third) whilst being the most sparsely populated. There is minimal industry and the Province contributes little to the GDP of SA. Furthermore, there is only a small amount of existing geological / geophysical data, which would make it more of a challenge for CSTP to survey.

However, the Northern Cape experiences some of the lowest rainfall averages in the country, when coupled with some of the highest temperatures this results in minimal surface water and confirmed problems with drought. As a consequence, the population of Northern Cape is one of the most heavily reliant on groundwater and because of the Province's small population and GDP; it receives little national or international support (either in research or financial aid) to find new groundwater sources. DWS therefore concluded that CSTP's services would have the greatest humanitarian impact on individuals and communities if applied to the Northern Cape. The main industry in the Province is also agriculture, one of the most water intensive, therefore any new groundwater discoveries would have a proportionately greater impact on the economy of Northern Cape, compared to other SA Provinces.

5.2 South African Irrigation Institute

The South African Irrigation Institute (SABI) was approached because of its potential to assist with irrigation, plumbing and water-well activities (as highlighted in one of the red texted boxes in **Figure 4.1)**. CSTP met with the following SABI representative:

- Isobel van der Stoep Pr Eng (SABI Technical Executive Officer, contact for Pretoria and Gauteng region) – Irrigation engineer involved in industrial training (Email: isobel@sabi.co.za ; +27 (0) 80 331 4987)

SABI was introduced to CSTP as a committee of irrigation experts that is used as a forum to exchange business opportunities and perform industrial training for company staff. It was recognised early on that SABI may not be able to offer direct assistance in CSTP's IPP project, but could recommend irrigation experts from its extensive membership and contact base. As a consequence it was agreed that a MoU would not be necessary, but SABI would be prepared to offer a letter of support as evidence of its willingness to offer future assistance (**Annex A**).

The majority of the meeting involved an exchange of relevant facts related to irrigation:

- 1000mm of rainfall per year is required to economically irrigate crops
- The cost of an irrigation system is very approximately 50,000 RND per hectare
- There is a major problem in SA with the over-allocation of water
- There are roughly 270-300 irrigation companies in SA – NETAFIM SA was mentioned as a company that produces efficient drip irrigation systems
- SA is one of the most mechanically irrigated countries in the world
- SA irrigation systems use ~60% of the water used in SA
- Approximately 1.2 million hectares of land is irrigated in SA each year – Pastures (grass for farm animals) are the most irrigated crop, which is a very inefficient agricultural use for water

The meeting concluded with a few final recommendations from SABI. Firstly, there are some strict legislation points that CSTP should consider. When performing any irrigation work (even drilling a borehole to validate findings), an Environmental Impact Assessment (EIA) would need to be performed. The EIA is then fed into an application for a Water Usage License (WUL); this process sometimes takes years to conclude. However, CSTP's on-going interaction with DWS (who issue the licence) should smooth the whole process when this stage is reached during the IPP project.

Secondly, some of the soil in the Northern Cape might not be suitable for irrigation and CSTP should also consider the issue of drainage, as well as irrigation, which can be more expensive:

- Surface drainage could be ~100,000 RND per hectare
- Sub-surface drainage could be ~25,000 RND per hectare

These final points are mostly relevant to the second deliverable of the IPP project (outlined in **Figure 4.1** and **Section 4.1.1**), and may have to be factored when deciding which deliverables the IPP project should focus on.

5.3 Water Research Commission

The Water Research Commission (WRC) was established by DWS as a technology incubator; because of their close affiliation it was recommended by DWS that CSTP visit them. WRC conducts funding into water research areas (waste water management, agriculture, water resources, etc.) and works closely with university researchers to incubate research ideas and provide funding. CSTP met with the following representative from WRC:

- Dr Manjusha Sunil (Works in Business and Development as part of Innovation and Impact branch of WRC) – Innovation and Impact is a new branch at WRC (Email: manjushas@wrc.org.sa ; +27 (0) 12 761 9300)

CSTP's presentation was well received by WRC, because of their interest in niche technologies and techniques. It was therefore agreed that WRC could assist in linking CSTP with appropriate partners specialising in cutting-edge water purification and supply technologies (activities that are needed for the second deliverable of CSTP's IPP project, **Figure 4.1**) and a MoU would be signed to this effect (**Annex A**).

It was finally noted that WRC organises funding calls for research proposals in SA water-related areas; they are mainly targeted at SA entities but foreign companies like CSTP could apply and participate if their research/work focus is for the benefit of SA.

5.4 The South African National Space Agency

CSTP met with the following SANSA representatives:

- Nosiseko Mashiyi (Remote Sensing Scientist, SANSA EO Department – Training in Geology, ore mining, mainly gold) primary contact (Email: nmashiyi@sansa.org.za ; +27 (0) 82 624 6928)
- Oupa Malahlela (Remote Sensing Scientist, SANSA EO Department – Training in Geology) (Email: omalahlela@sansa.org.za ; +27 (0) 61 468 7728)

SANSA were the first SA contact CSTP had remotely engaged with since uncovering the IPP grant and they had assisted CSTP in preparing its trip to Pretoria by recommending contacts to meet. The conversation with SANSA was at their headquarters in Pretoria, it was very positive and helped CSTP better structure its proposed IPP project.

Before the meeting, SANSA had recommended CSTP consider the Limpopo Province as an appropriate beneficiary of its services. The socioeconomic and environmental reasoning to focus on Limpopo was later confirmed to CSTP through consultations with other contacts (such as DWS **Section 5.1**) and further research into the drought situation in Limpopo compared to other Provinces of SA, discussed in **Sections 6 and 7** of this report.

SANSA confirmed during the meeting that it was willing to operate as CSTP's lead partner for the IPP project. The details of this collaboration included the potential in-kind contribution of EO data, IPP project management support and the facilitation of information exchange with other SA partners and government departments. As evidence of their commitment to participate and to outline the nature of the future partnership, SANSA signed a MoU with CSTP (**Annex A)**.

The final items of conversation were more directed towards strategizing for the IPP grant, when it was revealed that SANSA was already engaged on a food security IPP project with Airbus Defence and Space and is familiar with the IPP application process. It was the suggestion of SANSA to plan two potential project routes with separate deliverables (as discussed in **Section 4.1.1**). A back-up plan was also considered, if CSTP's application to the IPP was unsuccessful SANSA could request a 'tactical IPP call' from UKSA that CSTP could potentially be better equipped at addressing compared to other applicants.

5.5 Council for Geoscience

The final meeting of CSTP's trip to Pretoria was with CGS at their headquarters, the representatives who attended from CGS were:

- Dr Abraham Thomas (Manager, Remote Sensing) primary contact – PhD from Birmingham University UK, originally from Kerala India (Email: athomas@geoscience.org.za ; +27 (0) 12 841 1142)
- Henk Coetzee (position unknown) Works on acid water contamination from mining (Email: henkc@geoscience.org.za)
- Janine Cole (Geophysicist, Remote Sensing Competency) – in regular contact with Henk (Email: jcole@geoscience.org.za ; +27 (0) 12 841 1195)
- Patrick Cole (position unknown) (Email: pcole@geoscience.org.za)
- Christo Craill (Manager, Geophysics Competency) – Part-time farmer (Email: ccraill@geoscience.org.za ; +27 (0) 12 841 1193)

Considering the relevance of expertise fielded by CGS for the meeting, the CSTP presentation (including the more technical sections) was well received. The reasoning behind CSTP's choice to look at Limpopo for the validation study (in **Section 6** of this report) and the Northern Cape Province for the IPP project was also corroborated by CGS.

The idea of having SANSA as the IPP project lead was explained to CGS and the reasons understood. It was also revealed that CGS had almost completed a signed MoU with SANSA that would assist the exchange of information between the two entities.

The initial IPP project contribution that was discussed for CGS was in sharing geological and geophysical data as an in-kind contribution. This idea was accepted but it was also stated that it might not be possible for all of CGS data. For instance, 30% of SA's land-area is covered by very new 200m line spacing data which might need to be paid for or might not be made available at all. If this or other specialised data is required as an in-kind contribution for the project, it would need the 'correct approach' from SANSA, as lead collaborator, to CGS. CGS also stated that it has experts who could cover the role of 'Conventional Prospecting Company' (CPC) and 'Water Contamination Analyst' (WCA) (described in **Figure 4.1**). It was therefore agreed that CGS would sign a MoU as evidence of their interest to participate in CSTP's IPP project and to outline their willingness to share data (if possible as an in-kind contribution) and assist in the role of CPC and WCA if required (**Annex A**).

5.6 Conclusions from Meetings

The results from all of CSTP's meetings were positive. It was confirmed that the contacts CSTP made during its visit to Pretoria could either directly cover the roles outlined in the required collaboration network (**Figure 4.1**), or recommend other effective contacts who could. All the contacts CSTP met also agreed to sign either MoUs or letters of support as evidence of their desire for future cooperation in the IPP project, which will greatly support CSTP's IPP grant application (**Annex A**).

CSTP also made a coincidental contact during its trip to Pretoria, who happened to be staying in the same hotel. The contact, who works in a company called 'I-CAT Water Solutions', was:

- Lin (One of the 3 original founders of I-CAT) – 78 year old with life experience across large parts of African continent (Email: lin@i-cat.co.za ; +27 (0) 83 445 1671)

I-CAT is a company that commercially conducts several environmental solutions across SA; it employs roughly 80 people and has been established for over 10 years. It is currently engaged in a 250 million RAND project to build a desalination plant in Cape Town that can process over 10,000 litres of water a day.

However, the activity most of interest is the company's ability to perform Environmental Impact Assessments (EIAs) and assist in Water Usage Licence (WUL) applications, something that was mentioned in CSTP's meeting with SABI (**Section 5.2**) as potentially troublesome for CSTP's first and second deliverables (**Figure 4.1**). I-CAT stated that it would be keen to offer contractor work in this capacity for the IPP project and would be prepared to offer a letter of support as evidence of its willingness to offer future assistance (**Annex A**).

A contact was also recommended from I-CAT that could offer direct assistance on the EIA and WUL:

- Rachelle Stoffberg (I-CAT specialist in Environmental Impact Assessments) (Email: rachelle@i-cat.co.za ; +27 (0) 79 889 6275)

It was finally agreed with all the contacts CSTP made during its trip (including I-CAT), that once complete, this feasibility study would be made available to aid their understanding of CSTP's IPP project, clarify their roles in the collaboration network and ease future coordination.

6. Deciding Focal Areas for CSTP Services in South Africa

SA is the 25th largest country by land area in the world, totalling 1,214,470 sq km[20], because of the country's immense size CSTP decided early-on that directing its services to smaller areas within SA would offer greater humanitarian and economic value to individuals and communities most in need.

SA is divided into 9 governing Provinces, which are in turn comprised of a number of smaller Municipalities. The SA national census and most of the data on the country's water reserves are presented by Province; therefore for simplicity and to most reliably compare data sets, CSTP will refine the focus of its service down to Province level. The population dynamics, economics and environmental conditions of these Provinces can differ greatly, therefore varying the socioeconomic impact drought may have on them. It is all of these considerations, alongside the suggestions of SA collaborators, which have been factored into the decision of which Provinces CSTP will focus its attention on.

As covered in **Section 5**, the collaborators CSTP met in Pretoria recommended focusing its validation work for this study on the Limpopo Province, whilst focusing its applied services through the future IPP project on the Northern Cape Province. This suggestion originated from DWS and SANSA, but all other collaborators when consulted agreed with the idea. Considering the high level experience held by these collaborators in relevant fields such as: SA water research and statistics, local socioeconomics and geology, their suggestions hold a significant credence that cannot be ignored.

This section of the report will therefore review census and drought statistics across all of SA's Provinces, noting how communities within Limpopo and Northern Cape could benefit socioeconomically from CSTP's services compared to SA's other Provinces. It will then balance these findings with the reasoning of its contacts suggestions, to justify the focus of the 'Validation Study' performed in **Section 7** and future work under the IPP outlined in **Section 8**.

6.1 Comparison of Physical Drought Indicators by Province

The administration of South Africa's water resources is split between 9 'Water Management Areas' (WMA) (**Figure. 6.1**). The boundaries of these WMAs take into account catchment and aquifer boundaries, financial viability, stakeholder participation, and equity considerations and are, as a result, not aligned with Province boundaries[21]. This means that CSTP may have to deal with different WMAs and their affiliates when focusing its services on a particular Province. The overlaps between Province and WMA borders can be seen by comparing **Figures 6.1** and **6.2**.

DWS asses three indicators to reflect the 'water status' of the country, 'river flow', 'dam levels' and 'groundwater storage'. Comparing all three should give a rough idea of the most physically drought affected regions of SA[22]. However, there are other more human factors, such as water wastage, population density, poverty, etc. that also require consideration when gauging the full severity of drought, which will be discussed later-on in this section.

[20] The World Fact Book, Central Intelligence Agency
[21] M. N. Nkondo, F. C. van Zyl, H. Keuris, B. Schreiner, (2012) National Water Research Strategy 2
[22] National Integrated Water Information System (DWS)

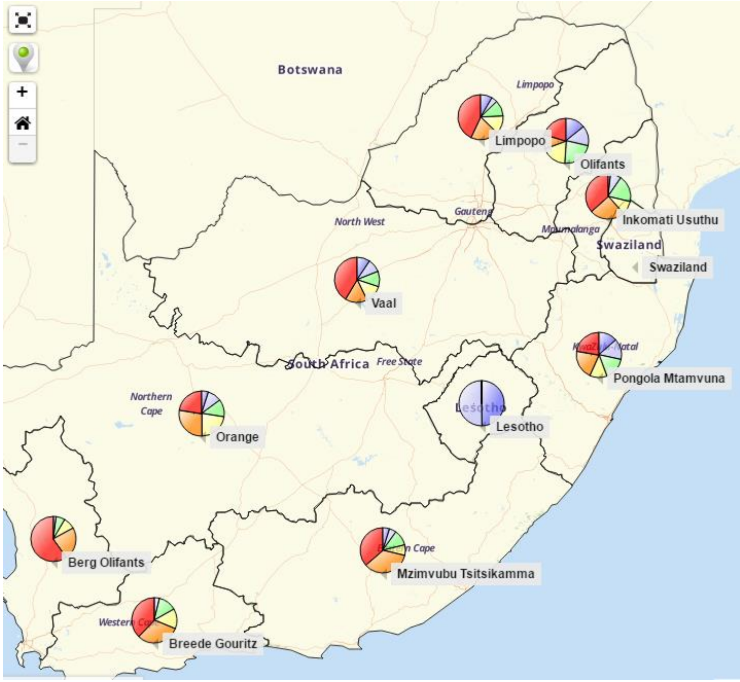


Fig. 6.1 River flow of SA – WMAs are outlined in black (Limpopo, Olifants, Inkomati Usuthu, Pongola Mtamvuna, Mzimvubu Tsitsikamma, Breede Gouritz, Berg Olifants, Orange, Vaal). The pie charts in each WMA denote river flow level (red = very low, orange = low, yellow = moderately low, green = normal, light blue = moderately high, dark blue = high) measured at a series of weirs[23].

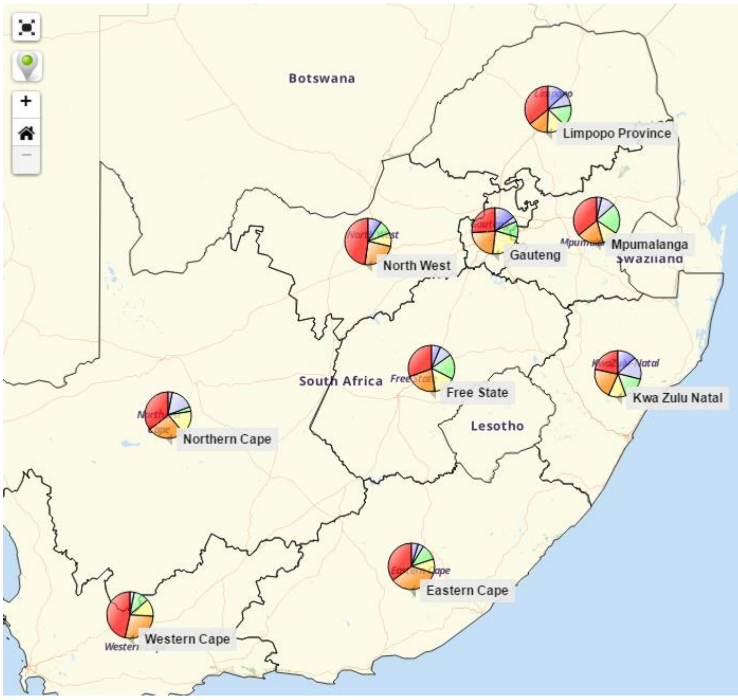


Fig. 6.2 River Flow of SA – Provinces are outlined in black (Limpopo, Northern Cape, Eastern Cape, Western Cape, Free State, North West, Gauteng, Kwa Zulu Nata, Mpumalanga). The pie charts in each Province denote river flow level (red = very low, orange = low, yellow = moderately low, green = normal, light blue = moderately high, dark blue = high) measured at a series of weirs[24].

[23] National Integrated Water Information System, Operational, Water Status, River Flows (DWS)
[24] National Integrated Water Information System, Operational, Water Status, River Flows (DWS)

Figures 6.1 and **6.2** denote river flow as a physical indicator of drought, which partly reflects the problems SA is facing when assessed by either WMA or Province. When looking at river flow by Province, **Figure 6.2** suggests that Western Cape, North West and Limpopo are the worst affected.

According to DWS, five of SA's nine Provinces are severely affected by drought and declared as disaster areas, with KwaZulu-Natal as the Province worst affected. Other Provinces include Free State, Limpopo, Mpumalanga and North West. DWS has committed R 352.6 million to initial drought intervention projects in Kwazulu-Natal. Some of the emergency relief measures that are currently being implemented with the allocated funds are water tankering, borehole drilling and rehabilitation, water conservation, demand management and water source augmentations[25]. Any services like CSTP's, which support the targeting and efficiency of borehole drilling, could help stretch the government money in Kwazulu-Natal more effectively to assist a greater number of individuals in need.

Despite the serious situation emerging in certain Provinces, the message from DWS is somewhat positive, stating that 'SA experienced its worst drought in 1983 with the national average dam level at 34.0%. By comparison the national average dam level sits at 63.3%, meaning that regional water supply dams and schemes remain water secure, sitting with a positive water balance.'

This situation has however appeared to worsen, according to **Table 6.1** from the Weekly State of Reservoirs Report (displayed on the DWS website), the SA average national dam level now sits at 55%, with Western Cape not KwaZulu-Natal as the worst affected Province with only 37.9% of its dam capacity full. (National dam levels roughly denote the status of SA's surface water storage[26], and like river flow, are another physical indicator of drought severity.) This suggests that the drought problem is not only deteriorating but also changing in relative severity across SA's Provinces.

Summary Provinces	Full Supply Capacity 10^6M^3	Water in Storage 10^6M^3	Last Year %Full	Last Week %Full	This Week %Full
EC Eastern Cape	1832.4	1057.2	73.5	58.3	57.7
FS Free State	15971.2	9062.5	54.6	55.9	56.7
G Gauteng	114.8	99.4	83.1	86.4	86.6
KN Kwazulu-Natal	4668.7	2195.0	52.3	45.9	47.0
L Lesotho	2376.2	1059.2	47.4	44.0	44.6
LP Limpopo	1508.1	960.2	61.7	60.9	63.7
M Mpumalanga	2538.8	1672.8	61.4	65.4	65.9
NC Northern Cape	145.5	136.3	67.6	90.6	93.7
NW North West	886.7	648.8	46.0	67.3	73.2
S Swaziland	333.8	138.2	35.7	41.4	41.4
WCo Western Cape - Other rainfall	272.9	72.7	56.9	26.8	26.6
WCw Western Cape - Winter rainfall	1597.5	636.7	44.9	41.6	39.9
WC Western Cape - Total	1870.4	709.4	46.6	39.5	37.9
GRAND TOTAL	32246.5	17738.8	55.4	54.2	55.0

Table 6.1 Dam water levels denoting above-ground water reserves for SA[27]

[25] Drought Interventions (DWS)
[26] National Integrated Water Information System, Operational, Water Status, Surface Water Storage (DWS)
[27] Weekly State of Reservoirs Report

Another physical indicator that DWS uses to measure the 'water status' of SA is 'groundwater status', **Figure 6.3** suggests that the Gauteng Province is worst affected in this regard, with 37.5% of its groundwater being over allocated. The Western Cape and Limpopo Provinces are not far behind Gauteng, with 36.1% and 35.6% over allocation respectively. The SA government see groundwater as an important resource to alleviate drought pressures and assist water security. Hence the formation of the NGS which prioritises appropriate management, future exploration and the sustainable use of groundwater, therefore the over allocation of groundwater goes directly against this national agenda[28].

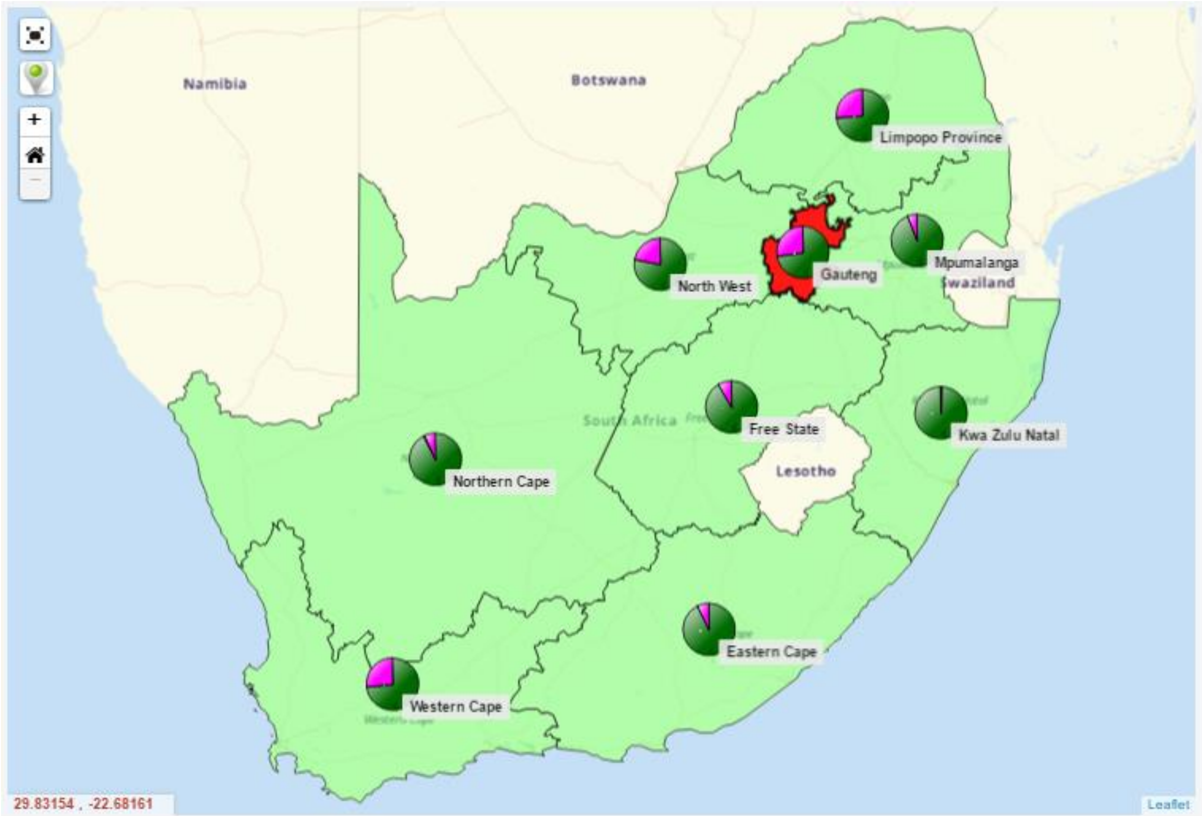


Fig. 6.3 Groundwater Status of SA - Provinces are outlined in black (Limpopo, Northern Cape, Eastern Cape, Western Cape, Free State, North West, Gauteng, Kwa Zulu Nata, Mpumalanga). The pie charts in each Province denote the over allocation (purple) or under allocation (green) of groundwater. The Gauteng Province is highlighted in red as it has the highest over allocation of groundwater.[29]

When comparing the physical indicators of drought to find the worst affected Province, one appears pronounced at the top of the severity list, Western Cape. The Western Cape appears significantly worse in terms of dam levels and river flow, and despite Gauteng having a worse groundwater status, Western Cape follows close behind. However, despite this Western Cape doesn't even feature in the Provinces announced by DWS as 'disaster areas'. Instead the only Province to rank consistently high in severity across all physical drought indicators, and be named by DWS as a 'disaster area', is the Limpopo province.

[28] (2016) National Groundwater Strategy, DWS & WRC
[29] National Integrated Water Information System, Operational, Water Status, Groundwater Status (DWS)

These results demonstrate that there are other (possibly socioeconomic) factors that need to be considered when assessing how severely drought effects a region. Western Cape and Gauteng may have the worst 'water status' according to DWS figures, but they are also the two wealthiest provinces by GDP per capita, which may explain why they are not classed as 'disaster areas' by DWS in relation to drought. Whereas Kwazulu-Natal and Limpopo have the 7th and 8th (out of a total of 9 Provinces) lowest GDP's per capita in SA[30] , which would make them higher priorities in the context of the IPP that emphasises maximal socioeconomic benefit. By contrast, Western Cape and Gauteng could be a target for CSTP to offer its services commercially, following the IPP.

6.2 National Census Statistics and their Implications for Drought

The population of SA is not evenly distributed, as shown in **Figure 6.4**. Like most nations of the world, there is a high clustering of people around the country's capital of Pretoria, which is situated in the Gauteng Province, alongside other major population centres such as Johannesburg. Gauteng therefore has the highest population of any Province in SA (~12.3 million people)[31]. It is also the smallest Province by land area, which gives it the highest population density. A large population would naturally increase water usage, which could explain why Gauteng has the highest over allocation of groundwater according to **Figure 6.3**.

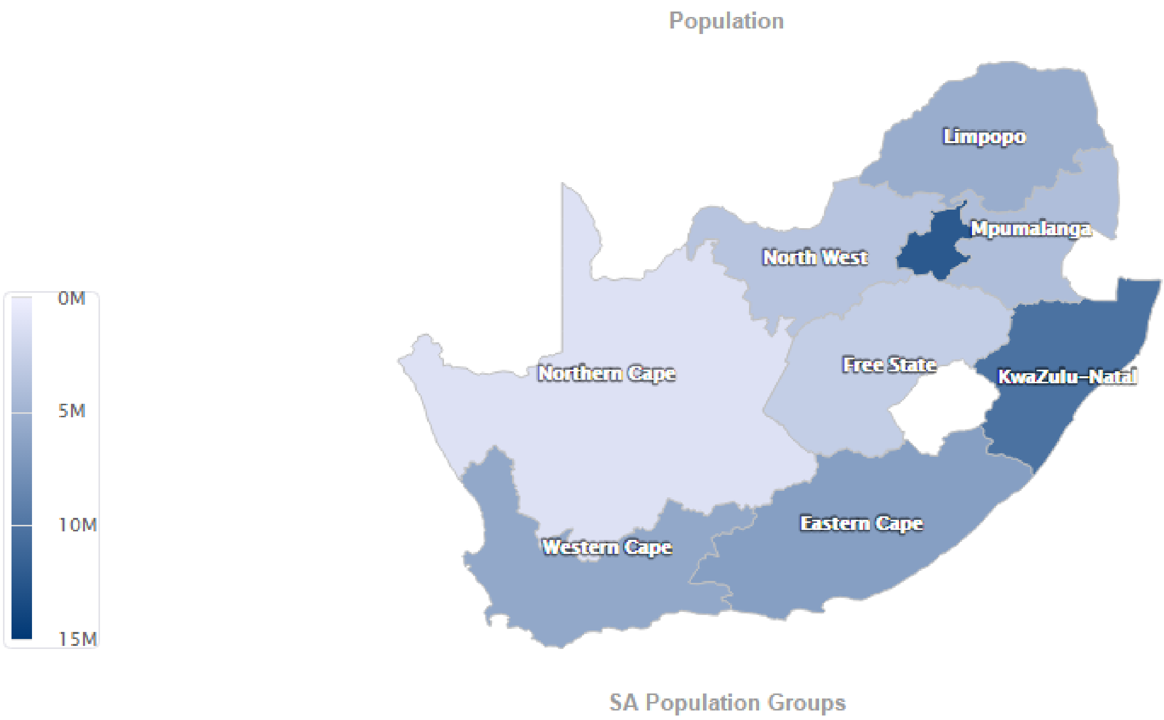


Fig. 6.4 SA Population Groups – Population sizes by Province, the darker the shade of blue for the Province the larger the inhabiting population size.[32]

The second highest populated Province is Kwazulu-Natal (~10.3 million people)[33], which would again imply a high water usage that could have contributed to DWS declaring it the prime drought disaster area of SA and committing R 352.6 million (~£23m GBP) to initial drought intervention projects.

[30] (2014) Stats SA, Provincial GDP Figures
[31] Stats SA, Statistics by Place, Population, Census 2011
[32] Stats SA, Statistics by Place, Population, Census 2011

By contrast the Northern Cape Province contains the smallest population in the country, amounting to ~1.15 million people[34].

There are also some potential connections to be made with drought severity when looking at particular features within the population of SA. **Figure 6.5** allows one to compare education and unemployment levels across the population, both of which are indicators of poverty[35]; in this regard Limpopo is the worst affected Province with 17% of its population lacking schooling and 38.9% unemployed.

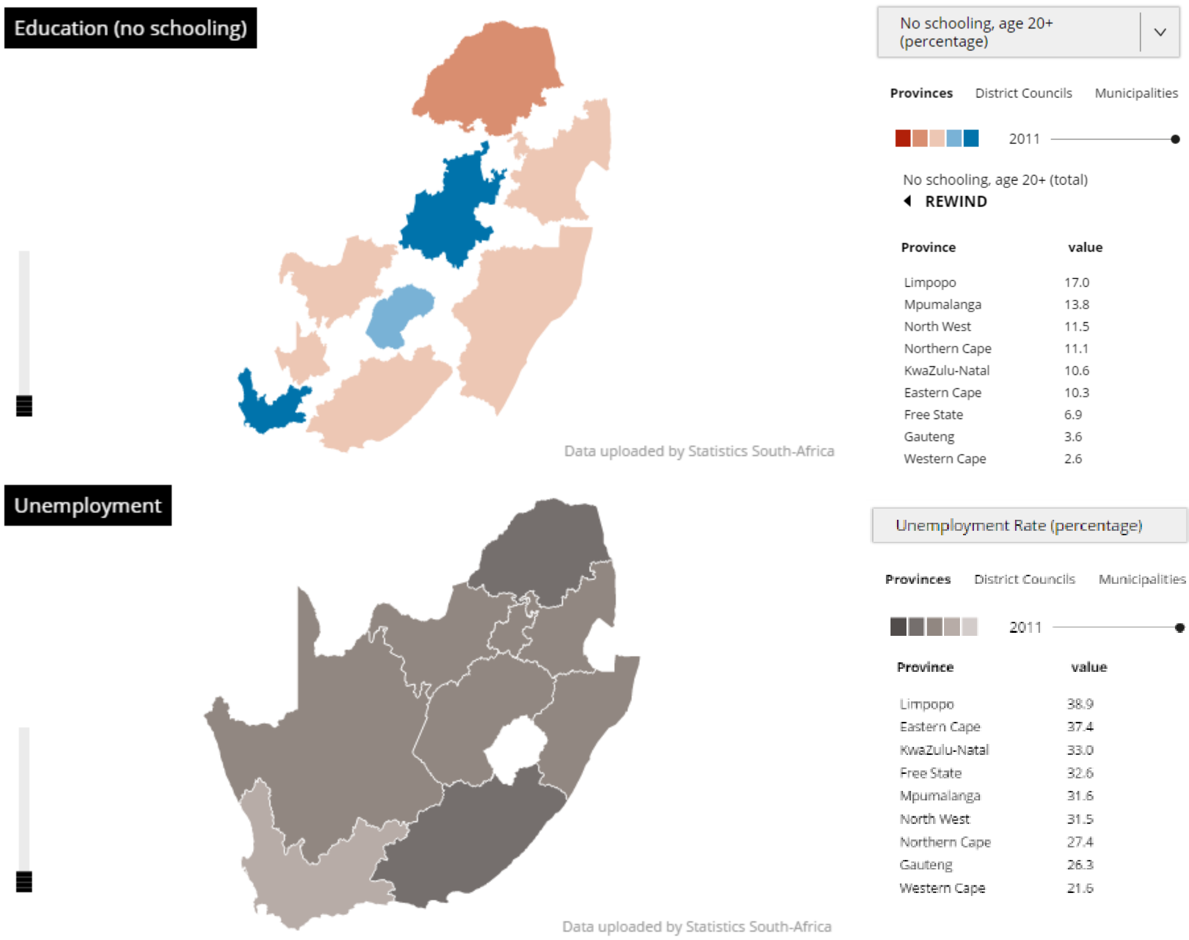


Fig. 6.5 Education and Employment in SA – The top map of SA displays the size of each province in relation to the percentage level of its population that has no schooling, this value is also reflected by a colour coding scheme which is explained in a key to the right of the map. The bottom map shows the percentage level of unemployment in each Province as a shade of grey, the darker the shade the higher the level of unemployment. The percentage figures for both maps a displayed in the keys to their right.[36]

Measuring the level of poverty in a population is important because it is one way of estimating the areas and communities that most need humanitarian assistance; one of the prerequisites of any IPP project. Furthermore, the level of poverty in a population could be a contributing factor to the severity of drought, as it may increase the likelihood of misappropriation and mismanagement of

[33] Stats SA, Statistics by Place, Population, Census 2011
[34] Stats SA, Statistics by Place, Population, Census 2011
[35] Oxford Poverty & Human Development Initiative, Policy – A Multidimensional Approach
[36] Stats SA, Statistics by Place, Population, Census 2011

water resources; however it could also be a symptom of drought. A correlation point between these two factors is access to clean drinking water, which is another indicator of poverty but also a sign of drought severity. In this regard Eastern Cape and Limpopo are the worst affected Provinces, with only 72.7% and 75.7% respectively of their populations having access to clean drinking water. This is quite a contrast when compared to Western Cape and Gauteng, SAs wealthiest Provinces, where 93.2% and 92.9% respectively of their populations have access to clean water (the two best figures for the country).

Another potential contributing factor to drought could be the amount of households that have adopted agriculture as an activity, which is quite a water intensive exercise. **Figure 6.6** reveals that once again Eastern Cape and Limpopo are at the top of the list with 35% and 33% respectively of households engaged in agriculture. This is in direct contrast to additional data in **Figure 6.6** that also shows these Provinces have the highest proportion of households without access to piped water, with only 49.4% of households in Eastern Cape having piped water and 52.3% in Limpopo.

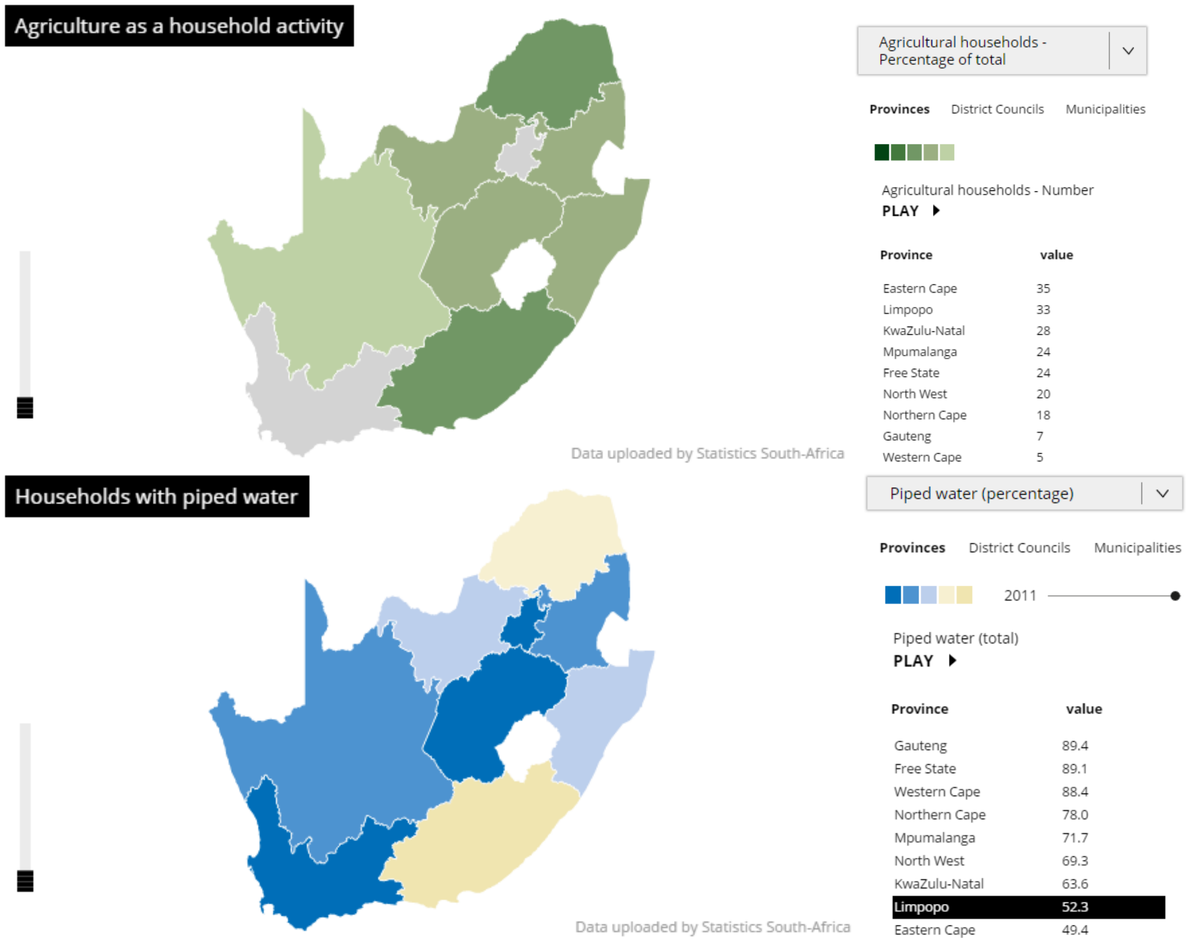


Fig. 6.6 Agriculture as a Household Activity and Households with Piped Water in SA – The top map reflects the number of households in each Province which have agriculture as an activity; the darker the shade of green the higher this value. The bottom map shows the number of households in each Province with piped water, the lighter the shade of blue the lower this vale, until beige which is the lowest of the values.[37]

[37] Stats SA, Statistics by Place, Population, Census 2011

The number of agricultural households should however not be mistaken for industrial agriculture, which would normally be more likely to contribute to a household's main source employment and income, rather than additional food and income from selling home-grown produce. The distinction between the two can be made by comparing **Table 6.2** and **6.3**.

Province	Back yard	Farm land	Communal land	School, church or other organisational land	Other	Total
Western Cape	80.9	15.2	0.9	0.4	2.6	**100.0**
Eastern Cape	80.8	6.8	9.5	1.1	1.8	**100.0**
Northern Cape	61.9	24.0	11.1	0.7	2.3	**100.0**
Free State	84.2	11.4	2.1	0.9	1.4	**100.0**
KwaZulu-Natal	84.0	8.1	5.8	0.8	1.4	**100.0**
North West	78.9	13.9	3.9	0.6	2.7	**100.0**
Gauteng	89.5	6.7	1.1	1.1	1.6	**100.0**
Mpumalanga	86.1	8.6	2.9	1.2	1.2	**100.0**
Limpopo	86.7	7.2	4.5	0.5	1.0	**100.0**
South Africa	**83.8**	**8.7**	**5.0**	**0.9**	**1.6**	**100.0**

Table 6.2 Distribution of agricultural households by main place of agricultural activities and Province[38]

By assessing **Table 6.2** it is clear that most of the agricultural households (83.8%), displayed by Province in **Figure 6.6,** are small scale operations using their backyard, the only exception is the Northern Cape which has a significantly higher proportion of its agricultural households engaged in commercial agriculture using farm land (24%) and communal land (11.1%). This is further supported by **Table 6.3** which shows Northern Cape as having the most agricultural households using the activity as a main or extra source of income (18.4% and 12.1% respectively).

Province	Main source of household food	Main source of household income	Extra source of household income	Extra source of household food	For leisure/ hobby	Other	Total
Western Cape	25.4	8.9	4.6	31.8	26.9	2.4	100.0
Eastern Cape	52.7	4.2	5.2	33.7	3.1	1.2	100.0
Northern Cape	29.9	18.4	12.1	25.0	11.0	3.6	100.0
Free State	45.2	7.4	5.1	36.3	5.0	1.1	100.0
KwaZulu-Natal	40.8	4.1	3.6	44.0	6.1	1.4	100.0
North West	44.1	13.5	8.5	26.5	5.3	2.1	100.0
Gauteng	43.5	3.6	3.4	36.6	11.0	1.9	100.0
Mpumalanga	48.0	5.2	4.0	36.1	4.8	1.9	100.0
Limpopo	38.6	5.4	4.5	43.2	6.8	1.5	100.0
South Africa	**43.7**	**5.7**	**4.7**	**37.5**	**6.8**	**1.6**	**100.0**

Table 6.3 Distribution of agricultural households by main purpose of involvement in agricultural activities and Province[39]

When looking at **Table 6.3** the Western Cape Province has a significantly higher percentage of households with agriculture as a leisure activity; 26.9%, which partly reflects the wealth of the area. It also however has the second highest number of agricultural households (after the Northern Cape)

[38] (2016) Stats SA, Community Survey 2016, Statistical Release
[39] (2016) Stats SA, Community Survey 2016, Statistical Release

using farm land (15.2%) rather than their back yard, and a fairly high proportion see agriculture as their main source of income (8.9% which is 3rd highest).

These figures make sense as the Western Cape is one of the more prolific wine producing regions of SA and agriculture is Northern Cape's second largest industry (after mining), contributing 7.1% to the Province's total GDP in 2014[40]. Almost 81% of the land area in the Northern Cape is dedicated to agriculture, totalling a vast 29.5 million hectares; by contrast the Eastern Cape has the second largest land area dedicated to agriculture at just 14.8 million hectares. However, only 1.3% of the land in the Northern Cape is arable, the smallest ratio of any Province. Meanwhile the remaining 80% of its land is dedicated to pasture for grazing animals (the highest ratio of any Province)[41], which as mentioned in **Section 2** is the most inefficient agricultural practice regarding water usage. The value of each grazing animal is also very high compared to crops and their transfer to market is usually critical to the livelihood of the farmer. So unlike crops, grazing farm animals are less likely to be a food source for the household raising them as well as a source of income. This could explain why agricultural most households in the Northern Cape do not use the activity as a main (or even extra) source of food (**Table 6.3**).

Inefficient farming practices and a dependence on grazing livestock could also explain why the Northern Cape had the second highest proportion of households skipping a meal in 2016; 17.5% with the Eastern Cape just ahead on 17.6% (**Table 6.4**).

	GHS 2015					CS 2016				
	Yes		No		Total	Yes		No		Total
Province	N	%	N	%		N	%	N	%	
Western Cape	311 654	17,6	1 462 911	82,4	1 774 565	161 692	8,4	1 766 632	91,6	**1 928 324**
Eastern Cape	296 773	17,2	1 430 424	82,8	1 727 197	311 263	17,6	1 457 967	82,4	**1 769 230**
Northern Cape	87 752	27,4	232 273	72,6	320 025	61 810	17,5	291 105	82,5	**352 915**
Free State	171 226	18,9	734 394	81,1	905 620	148 697	15,7	796 251	84,3	**944 948**
KwaZulu-Natal	529 493	19,3	2 217 008	80,7	2 746 500	425 660	14,8	2 444 362	85,2	**2 870 022**
North West	370 897	30,5	844 484	69,5	1 215 382	216 088	17,4	1 028 223	82,6	**1 244 311**
Gauteng	587 939	12,5	4 101 566	87,5	4 689 506	534 340	10,8	4 392 339	89,2	**4 926 679**
Mpumalanga	256 300	21,2	954 525	78,8	1 210 825	182 519	14,8	1 049 961	85,2	**1 232 480**
Limpopo	81 858	5,3	1 450 512	94,7	1 532 371	205 432	12,9	1 389 854	87,1	**1 595 286**
South Africa	**2 693 893**	**16,7**	**13 428 096**	**83,3**	**16 121 989**	**2 247 501**	**13,3**	**14 616 694**	**86,7**	**16 864 195**

Table 6.4 Households who skipped a meal in the past 12 months by province[42]

The values in **Table 6.4** can therefore be another indicator of poverty, on which Northern Cape and Eastern Cape score highest.

In conclusion to this subsection, it appears that Limpopo ranks consistently high on several poverty indicators, when combined with its consistently high ranking in physical drought indicators (**Section 6.1**) it is clear that CSTP's services could benefit the Province. However, as previously stated, CSTP's SA contacts have suggested its focus as a validation exercise; the reasons for this will be explained further in **Section 6.3**.

[40] (2016) Stats SA, GDP Annual and Regional Table
[41] (2016) Department of Agriculture, Forestry and Fisheries, Abstract of Agricultural Statistics, Table 5
[42] (2016) Stats SA, Community Survey 2016, Statistical Release

Another Province which scored consistently high on poverty indicators was the Eastern Cape. It also had the highest proportion of agricultural households at 35% (**Figure 6.6**) and despite the majority of these households only having backyard agricultural activity (80.8% according to **Table 6.2**), most of the activity contributes to the main source of food for the household (52.7% according to Table 6.3, which is in fact the highest of any Province). Considering agriculture (even in the backyard) is quite water intensive, and that it contributes to the food security of a notable portion of the Eastern Cape population, any services that better assure the availability of water could be especially beneficial.

For these reasons Eastern Cape could benefit from the services of CSTP following the IPP, or it could be aided by locals trained in CSTPs services during the IPP. Either way the potential for CSTP services in the Eastern Cape demonstrates prospects for future sustainable benefits to SA after the end of CSTPs IPP project (sustainability being one of the main criteria for the IPP grant).

The other Province that stood out in this subsection was Northern Cape, despite being fairly average on poverty indicators (apart from some issue with food security, as noted in **Table 6.4**). This Province has a distinctively high dependence on its agricultural industry, as can be seen when comparing **Table 6.2** and **6.3**, whilst also noting figures from the SA Department of Agriculture, Forestry and Fisheries. Better access to water would certainly help the Northern Cape agricultural industry, but on its own is hard to justify CSTP focusing its services for the IPP project. CSTP's SA contacts had more subtle reasons for suggesting Northern Cape as the focus of CSTPs IPP project, which will be explained in more detail in **Section 6.4**.

6.3 Justifying Limpopo for CSTPs Validation Study

The Limpopo Province has already proven to be an area of interest for CSTP's services when assessed in **Section 6.1** and **6.2**. It ranked consistently high (compared to other Provinces) on the physical indicators of drought (river flow, dam levels and groundwater status) and on some of the poverty indicators for its population (education, unemployment and access to clean water). These poverty indicators demonstrate that there could be a need for humanitarian and economic support, which is one of the intentions of CSTPs service under the IPP. When factoring for the high ranking in physical drought indicators, it is clear that one way to socioeconomically assist the province would be through drought relief services, which is once again the focus of CSTPs IPP services.

The situation with Limpopo has not gone unnoticed however, both nationally and internationally. As stated in **Section 6.1**, Limpopo has already been declared a drought disaster area by DWS, leading to the attention of national projects such as the 'Groundwater Resource Information Project' (GRIP).

As explained in the NGS, "GRIP is a national Department of Water Affairs project to improve data holdings by accessing unpublished or "private" data as well as "new" groundwater data collected by visiting existing boreholes in the field – particularly in priority areas. The project has also been used to develop systems and procedures for the collection and verification of unpublished data.

GRIP was started in the Limpopo Province, and extended to KwaZulu-Natal, the Eastern Cape and Mpumalanga and is planned to extend it to the Free State. To date, GRIP has been most fully implemented in the Limpopo Province, where it began in 2002 and is still underway. More than 2,500 villages have been visited in Limpopo Province, in excesses of 31,000 drill sites have been verified, and 1 500 additional pumping tests have been added to the Provincial database. Limpopo

Province now has probably the most extensive and best verified dataset on rural groundwater resources in the country, and enough is known about groundwater in the province to allow it to be much better integrated into general water resource management. The extra data has led to a higher borehole drilling success rate in the province, saving a considerable amount of money. The GRIP data for Eastern-Cape is currently available via the National Groundwater Archive (NGA). The GRIP data for Limpopo and KwaZulu-Natal is in the process of being migrated to NGA"[43].

The above paragraphs from NGS aptly clarify the main reason DWS recommended Limpopo for CSTPs validation exercise, as opposed to being the main target of its prospective IPP project. Thanks to projects like GRIP, Limpopo has more data on groundwater compared to any other Province, thus reducing the potential beneficial impact of novel groundwater prospecting services like CSTPs. The detail of this information gathering can be partly visualised in **Figure 6.7**, where a distinct clustering of groundwater quality monitoring stations can be seen in the Limpopo Province.

Fig 6.7 Distribution of National Groundwater Monitoring Stations as stored in the WMS – Red triangles represent active stations whilst black stations represent inactive stations, WMAs are outlined in blue [44]

This abundance of data does however pose a good opportunity for CSTP to validate the component of its methods that purely involves the analysis of satellite derived data. If the findings of CSTPs

[43] (2016) National Groundwater Strategy, DWS & WRC
[44] (2017)Surface and Groundwater Information, DWS

analysis correlate with existing groundwater data on Limpopo, then it would demonstrate in some way that its methods work. Furthermore, if CSTPs techniques also uncover geological indicators that could lead to new groundwater discoveries, it could also display the potential of CSTPs services over groundwater prospecting methods currently being applied in SA.

6.4 Justifying Northern Cape for the IPP Project

From earlier analysis in this section, Northern Cape may not seem like an obvious choice for CSTP to try and assist through the IPP. As already mentioned in **Section 6.2**, the Province ranked fairly average on poverty and physical drought indicators. So on face value it would appear that there is little socioeconomic impact to be made in the region from CSTPs services. However, one has to look a little deeper to see the reasons why DWS and the rest of CSTPs SA contacts recommended the focus of the IPP project to be on this Province.

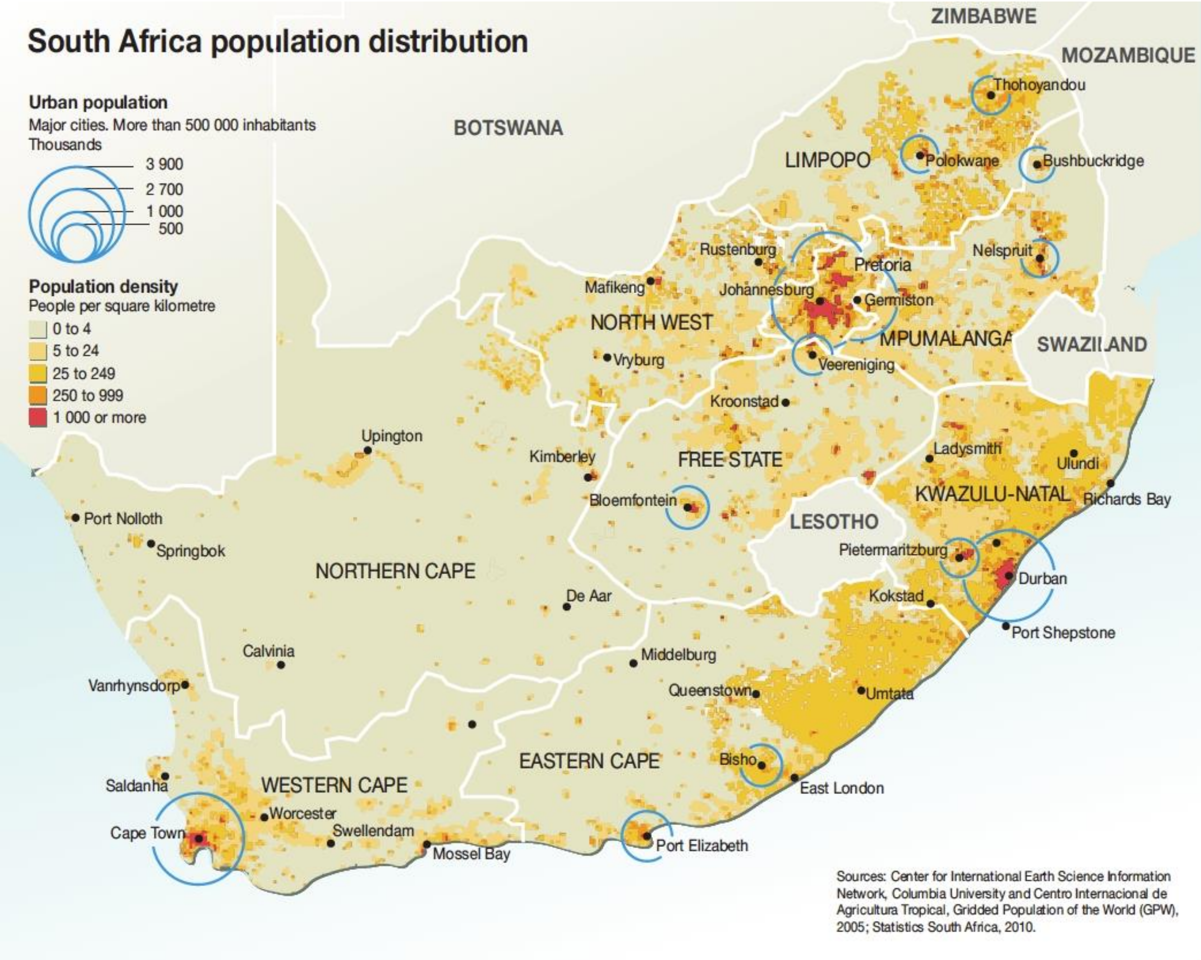


Fig. 6.8 Population Density of SA – Northern Cape has a distinctly low population density in relation to any other Province, with most of its population confined to the Provincial capital of Kimberly and along the banks of the Orange River, upon which Upington is situated[45]

Aboveground water resources in the Northern Cape are limited to the perennial Vaal and Orange rivers[46]. An interesting figure to note in **Table 6.1** is the dam capacity of the Northern Cape, which

[45] R. Pravettoni (2011) Working for the Environment, South Africa, Department of Environmental Affairs

despite the Province totalling 30.5%[47] of the land area of SA, can hold only 145.5 million cubic meters of water, the second smallest dam capacity after Gauteng (SA's smallest Province by land area). This means that Northern Cape has the lowest dam-water storage in relation to its land area, whilst also having the lowest population density (**Figure 6.8**). As a result, a proportion of its rural inhabitants are some of the most isolated from over-ground water sources (such as rivers and dams) in the country, theoretically making them some of the most reliant on groundwater of any in SA (this was also stated by DWS during face-to-face consultations).

According to the NGS, assisting communities like these is top priority for the SA government – 'the focus is on supplying water mainly for household use in remote rural areas, where levels of water services are often unacceptable'[48]. It could therefore be argued that CSTP's focus on the Northern Cape Province directly aligns with the national strategy of SA. Although despite this, national projects like GRIP and relief aid (like the R 352.6 million (~£23m GBP) DWS committed to Kwazulu-Natal) seems to bypass the Northern Cape. Part of the reason for this is the small GDP contribution it makes to the country; only 2.1% as of 2014, which is by far the lowest of any Province[49].

This means that Northern Cape is naturally placed further down the national priorities list, and what attention it does receive is mostly directed to its main population centre, the Province's capital of Kimberley. This could turn into a hard to break cycle, where lack of national support stifles the growth potential of the Province, which would lead to a continued lack of support.

Supporting the agricultural industry in Northern Cape could be an answer to this problem. It is the second largest industry in the Province and totals a significantly higher amount of land area (~29.5 million hectares) compared to any other Province. One limiting factor however, is that most of this land is non-arable and dry for several months of the year (the precipitation maps of **Figure 2.1**, **Section 2**, clearly show this)[50].

A more assured source of water to reduce the impact of these 'dry spells' could therefore greatly lift the potential of this farm land, theoretically contributing to a significant boost in the Province's GDP output, thus encouraging population growth in some of the more remote rural areas and attracting greater national and international attention. Considering the reduced rainfall in the region, groundwater would be the most logical source of this water. However, in fitting with the reduced attention placed on this area, available geological data on groundwater in the Northern Cape is limited, as partly shown in **Figure 6.7** and by the fact that projects like GRIP have so far not been focused on the Province. This lack of data was also confirmed in consultations with CGS.

The current understanding (from what little data is available) is that that the potential for groundwater resources in the Northern Cape is: 1) limited (**Figure 6.9**), 2) deep /hard to reach (**Figure 6.10**) and 3) with a high likelihood of contamination (**Figure 6.11**). All three of these issues

[46] G.S. Van Dyk, *et al*., (2008) Groundwater Resources in The Northern Cape Province (Combined), Department of Water Affairs and Forestry

[47] www.gov.za, Home, About SA, South Africa's Provinces

[48] (2016) National Groundwater Strategy, DWS & WRC

[49] (2016) The Real Economy Bulletin, Trends Developments and Data, Provincial Review 2016: Northern Cape

[50] G.S. Van Dyk, *et al*., (2008) Groundwater Resources in The Northern Cape Province (Combined), Department of Water Affairs and Forestry

most strongly overlap in the central, north and northwest of the Province, which is incidentally where the sparsest population figures can be seen (throughout the Province and country).

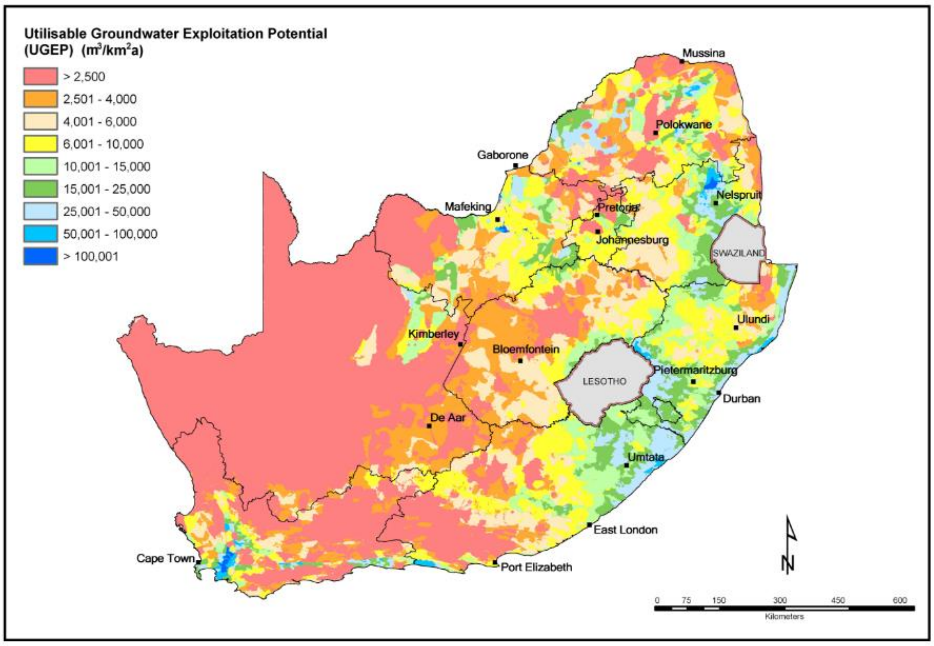


Fig 6.9 Utilisable Groundwater Exploitation Potential (UGEP) – "The Utilisable Groundwater Exploitation Potential takes into account limits imposed by recharge (including its variability due to drought), variations imposed by borehole yield which affect the practicality of abstraction ("exploitation factor"), groundwater contribution to river base flow, and ecological Reserve." With this in mind, red signifies the lowest potential for exploitable groundwater (which encompasses most of the Northern Cape Province) and blue the highest.[51]

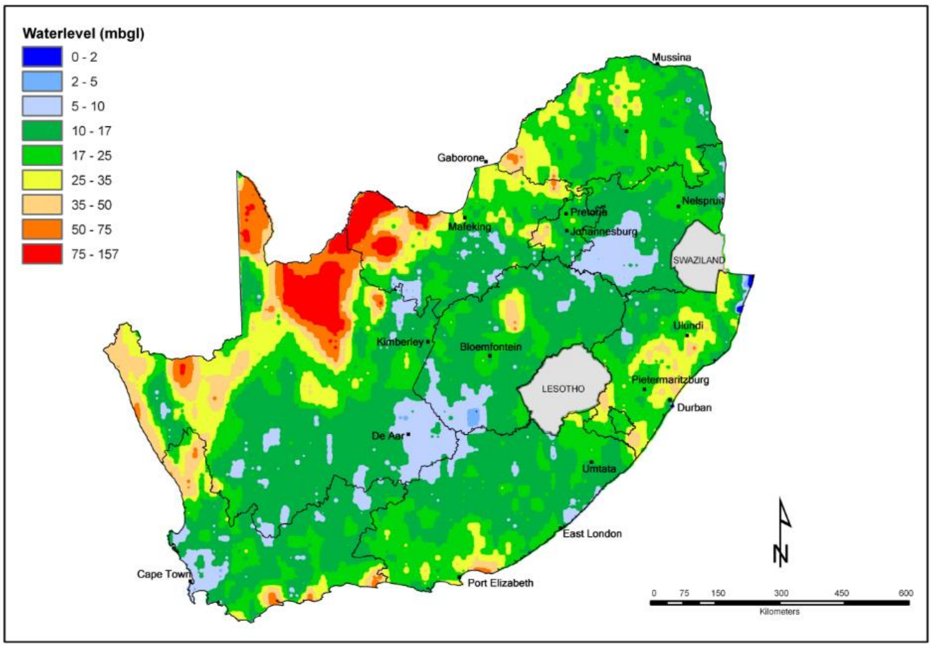


Fig 6.10 Groundwater Levels of SA – Red indicates the deepest levels of groundwater and blue the highest[52]

[51] (2010) Groundwater Strategy 2010, Department of Water Affairs
[52] (2010) Groundwater Strategy 2010, Department of Water Affairs

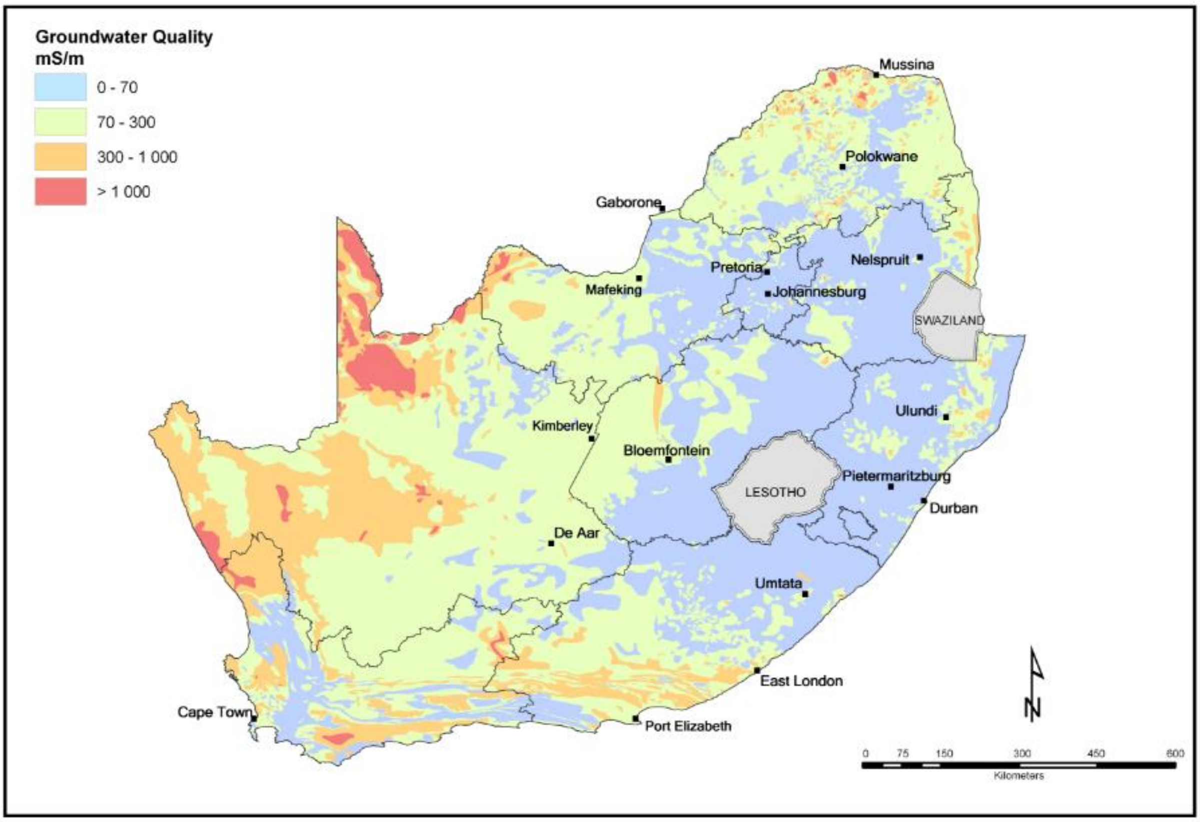


Fig 6.11 Groundwater Quality – "Groundwater contains dissolved "minerals" such as chloride, sodium, iron and others, in the same way as surface water. The natural dissolved mineral content of groundwater depends on a number of factors, including the aquifer material and the groundwater residence time. This map indicates natural groundwater electrical conductivity (mS/m). In some cases, high levels of dissolved minerals cause groundwater to be brackish or even saline. In some (relatively rare) cases, naturally high levels of dissolved constituents like fluoride, arsenic or nitrate render groundwater unfit to drink, even though it may taste perfectly fresh." Red indicates the most potentially contaminated groundwater and blue the least.[53]

The groundwater prospecting services CSTP plans to implement through the IPP have the highest chance of adding notable benefit under these extreme conditions. The first stage of the service is to consolidate all existing regional data and add to it with CSTPs own findings to produce more detailed prospecting models and therefore improve the original data. It is clear that Northern Cape would benefit from this part of the service, as existing data on its groundwater resources is limited. Another aspect of CSTP's services is the detailed survey of potential contaminants though gas analysis techniques (described in **Section 3**), which would improve the understanding of groundwater availability and quality in the Northern Cape. With more overall groundwater data and a better understanding of the contaminants, the level of utilisable groundwater exploitation potential (UGEP) (as described in **Figure 6.9**) would inevitably improve. If the UGEP of the Province improves, so (ultimately) would its agricultural output, and considering the immense scale of agricultural land available in the Northern Cape, this output could potentially add a significant contribution to the GDP of the Province and the whole of SA.

In conclusion, the number of lives CSTP aims to improve by focusing on the Northern Cape is small (relative to the population of SA), but the scale of this improvement to the individuals targeted

[53] (2010) Groundwater Strategy 2010, Department of Water Affairs

(mostly in rural communities rather than cities like Kimberly) should be significant. This potential for humanitarian improvement directly answers the objectives of the IPP and it is for this reason that DWS suggested CSTP focus on the Northern Cape.

6.5 Conclusions from Assessing Focal Areas in South Africa

It was suggested by CSTPs contacts that it directs it attention to Limpopo to validate the technical potential of its methods in SA, whilst focusing its full service under the IPP to support communities in the Northern Cape. When assessing the drought situation in SA, it became clear that Limpopo and Northern Cape are not the only Provinces affected. It could even be argued that other Provinces have been and are currently worse affected, such as Kwazulu-Natal and Eastern Cape. However, this has not gone unnoticed either nationally or internationally, and a number of these Provinces have since received relief aid in the form of grant funding and directed water research projects.

This is already having a positive impact in these Provinces, one example being the vastly improved groundwater datasets from the GRIP project in Limpopo, KwaZulu-Natal, the Eastern Cape and Mpumalanga. The GRIP research started in Limpopo in 2002 and as a consequence this region has the most publically available data on groundwater resources in SA. It was for this reason that CSTPs contacts suggested its focus for the validation study. With more available data, CSTP can quickly apply its methods to survey the province and have plenty on information to compare its own findings against. Any correlation would therefore demonstrate the ability of CSTPs methods to uncover groundwater sources in SA, whilst any new findings could suggest some advantages of CSTPs methods for groundwater prospecting over those already being applied in SA.

The reasons behind choosing Limpopo for the validation study were completely the reverse when selecting Northern Cape for CSTPs eventual IPP project. Initial research into poverty and physical drought indicators didn’t reveal anything exceptional about this Province, unlike Limpopo and other Provinces assisted by projects like GRIP. The majority of its population appeared to be reasonably well educated, employed and have access to clean water. However, this majority is mostly situated around the Province’s few population centres (like its capital city of Kimberly), thus skewing the statistics. When looking away from these cities and towns at the more forgotten rural areas of Northern Cape, the situation appeared quite different. These areas contribute to almost a third of SA’s land area, but contain sparsely populated communities, some of which are extremely isolated from above ground water supplies because of extremely low rainfall. As a consequence, individuals in these areas are some of the most reliant on groundwater for their livelihood (mostly involving agriculture which is extremely water intensive) and survival. However, because the status of most of the Northern Cape’s small population appears satisfactory on paper, little attempt has been made to gather data on groundwater resources, and what information is available suggests that there is little potential for usable groundwater discovery. Therefore any service like CSTPs, which can improve groundwater datasets and increase the likelihood of novel groundwater discoveries, would have a notable socioeconomic impact on these rural communities. Focusing on the Northern Cape therefore directly aligns with the humanitarian focus of the IPP.

Some of the other Province’s like the Western Cape and Gauteng, which scored highly on drought indicators but receive little additional support on account of their relative wealth, could also be a commercial target for CSTPs services following-on from the IPP (commercial return to the UK being a lesser IPP requirement)

7. Limpopo Validation Study

The main objectives of this research carried out for the Limpopo Province is to check if the methods used by CSTP may be applied for water exploration in other areas of SA. Limpopo is one of the most geologically documented Provinces in SA, particularly for water (because of international and national incentives like GRIP). It is for this reason that CSTP is conducting its validation study here; firstly the wealth of available data on the region will allow CSTP to perform its survey quickly within the limited timeframe of this feasibility study. Secondly, there are plenty of identified water resources in the region which CSTP can compare its own findings against for validation. Finally, considering the amount of existing data on the region, if CSTP can suggest anything possibly novel, it would demonstrate the potential of CSTPs methods over those currently being applied in SA.

7.1 Applied Methods

From a geological perspective, the main peculiarity of the aquifers in the Limpopo Province is how they are mainly confined to fractured and faulted zones; with only an insignificant number associated with alluvial deposits of low thickness.

Traditional exploration methods that were mainly developed for layered reservoirs cannot be used for fractured aquifers. As a basis for exploration we used the lineament-geomorphologic analysis of space images modified from known CSTP techniques.

It should be noted that attempts to compile and analyse space images [54, 55] for hydrogeological needs have been carried out in SA before, in particular in the Karoo Basin. One example is the compilation of imagery data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (an imaging instrument onboard NASA's Terra satellite) in SA's GRIP project. CSTP's research has not revealed that these space based attempts have had a big impact. The main reason for this lack of future work was (as mentioned by the authors who conducted this research) because of the low reproducibility of the results. It should be pointed out that CSTP's team have always emphasised the importance being able to reproduce the results of their interpretation[56, 57, 58, 59, 60]. Indeed, the lineaments revealed by the authors applying a competing space imagery analysis to CSTP had even confirmed some results through 3D seismic[61]. By comparison, CSTP controls the

[54] Miloserdova L.V. (1982) Dependency of mega-fracturing parameters on scale of interpreted images. - Izvestia VUZov, Geologia i razvedka, No.3, pp.156-158 (*in Russian*)
[55] Miloserdova L.V. (1982) On influence of the scale factor on the dominant orientation of mega-fracturing. – Vestnik Moskovskogo Universiteta, Ser.4 Geology, No.4,pp.93-95 (*in Russian*)
[56] Miloserdova L.V., Ryabikina E.V. Related the method of quantitative examination of lineament network orientation. - Izvestia VUZov, Geologia i razvedka, 1982, No.9, 1989, pp.123-127 (*in Russian*)
[57] Boyarchuk K.A., *et al*,. (2007) Informativeness of space images of various spectral bands for oil & gas geological interpretation. – International Space Forum 'Cosmos: Science and Problems of the XXI Century', section 'Remote sensing of the Earth from Cosmos', Moscow (*in Russian*)
[58] Makridenko L.A., *et al*,. (2008) Informativeness of space images of various spectral bands for oil & gas geological interpretation. – Voprosy electromekhaniki, vol.105, pp.63-81 (*in Russian*)
[59] Boyarchuk K.A., *et al*,. (2010) Geological informativeness of the images Meteor-M No.1 (case study for Central Africa) -Voprosy electromekhaniki, vol.118, No.5, pp.23-30 (*in Russian*)
[60] Boyarchuk K.A., *et al*., (2012) Reflection of geological structures in space images with different resolutions. Issledovania Zemli iz kosmosa, No.6, pp. 29-34 (*in Russian*)
[61] Yantsevich A.A., *et al*,. (2011) Complex interpretation of seismic space survey data, case study for Western Siberia. – First Scientific & Practical conference of geologists and geophysicists (*in Russian*)

reproducibility and reliability of the results of interpretation by using two or three overlapping methods, including: expert interpretation, extensive use of computer software, landscape control of detected lineaments and ranking the subordination of the sizes of revealed lineaments through a course of statistical processing.

CSTP's modification of its usual geological interpretation methods for hydrogeological tasks is based on lineament and structural analysis. The lineaments [♣]revealed in space images determine the structural skeleton of territories that control features of its geological structure and geological development, as well as hydrogeological conditions. This way, the schemes of the lineaments revealed by the interpretation of space images represent the structural neotectonic planes of territories in which the geological structures are revealed in their natural occurrence and in their interconnections and interdependencies with surrounding, enclosed and insertion geological bodies. Such an approach proved highly effective for revealing fractured aquifers (such surveys had been previously carried out mostly for the 'Ukrainian shield') and for the detection of fracture waters, for which these specially modified techniques were originally developed [62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72].

[♣] It is needed to mention that the term 'lineament' means a linear landscape anomaly displayed in an image and supposedly caused by a disjunctive dislocation; 'fault' and a 'disjunctive dislocation' is a lineament in which the fault structure is proved by geological (displacements) or any other independent data.

[62] Yantsevich A.A and Veselov V.M. (1985) Case record: use of space images for mid-scale hydrogeological mapping. – Razvedka i okhrana nadr, No.8, pp.51-54 (*in Russian*)

[63] Yantsevich A.A. The use of thematic interpretation of space images for forecast of manifestations of exogenous geological processes/ Case study for Ukrainian shield. – Geological Problems and their Solutions. Abstracts, All-Russian scientific and technical conference, 26-30 April 1990, Part 3: Engineering-geological and geocryological problems of environment. – Moscow, 1991, pp.93-94 (*in Russian*)

[64] Yantsevich A.A. Tectonic break as a factor influencing on appearance and development of exogenous geological processes. – Scientific & practical seminar: Theoretical and methodical grounds of environmental monitoring in Ukraine. 28-30 November, Kiev, 1990, pp. 16-17 (*in Russian*)

[65] Yantsevich A.A. Water saturation of crystalline rocks of the Ukrainian shield by space image data. – Geologichesky zhurnal, 1991, No.1, pp.26-31 (*in Russian*)

[66] Yantsevich A.A. Influence of active disjunctive dislocations on the speed of radionuclides' migration in underground waters. – Geological and environmental problems of Ukraine. Scientific and practical conference, 22 October 1991, Abstracts, Dnepropetrovsk, 1991, pp. 21-22 (*in Russian*)

[67] Yantsevich A.A., Woolfson L.D. Complex use of remote sensing data in IR and SHF bands and interpretation of aerial and space images for revealing and evaluation of opening degree of active fractured zones. – Aerospace methods in Geology, Kiev, Naukova Dumka, 1992, pp. 131-137 (*in Russian*)

[68] Yantsevich A.A. Influence of disjunctive tectonics on speed of radionuclides' migration in an alluvial aquifer. – Geologichesky zhurnal, 1993, No.1, pp. 88-96 (*in Russian*)

[69] Nikolaenko B.A.,Yantsevich A.A. Method of evaluation of an aquifer protection based on the factor of tectonic break determined by space image data. - In: Principles and methods of mapping of geological media for environmental evaluations (abstracts). Kiev, 1994, pp. 45-46 (*in Russian*)

[70] Veselov V.M., Lesnoy D.A., Nikolaenko B.A., Yantsevich A.A. Disjunctive neotectonics of 30-km zone of the Chernobyl nuclear power station and the speed of radionuclides' migration. – In: Fifth International scientific & practical conference Chernobyl-96, Zeleny Mys, 1996, p.46 (*in Russian*)

[71] Yantsevich O.O., Nikolaenko B.O. Forecast of alterations of anthropogenic landscapes by the 'Markov circuits' method based on retrospective interpretation of space imeges. – In: New methods of aerospace land researched (Methodical data for thematic interpretation of space-born data) TsAKDZ IGN Nat.Acad.Sci., Kiev, 1999, pp. 133-138 (*In Ukrainian*)

[72] Nikolaenko B.O., Yantsevich O.O. Lineament analysis based on interpretation of space images for solution of problems of environmental mapping and forecasting - In: New methods of aerospace land researched

The technique of space imagery interpretation used by CSTP as grounds for forecasting water saturation involves the examination of territories in different scales, starting with the analysis of large areas of land displaying large geological features and focusing down to smaller areas and features. This technique is based on an understanding of the Earth's crust as a system-ranked object and the use of this fundamental feature for the analysis of images at various scales. Such a fact is especially important for the investigation of water saturation in fractures and fissured bodies, since systems of disjunctive dislocation of different scales in crystalline rocks and sedimentary deposits differently influence the degrees of water saturation and physical and mechanical properties.

It is known that geological objects of different dimensions require examination in images at different scales (resolutions). It is also known that new information appears in images when the resolution changes from 3 times to 5 times higher (some authors suppose 10 times higher). The choice of the initial scale of the survey and the rules of transition from one scale grade to another in a manner when the examined scale reveals the order of the structure under study is an important feature of our surveys. This is especially important for the statistical examination of lineaments in cases where they are revealed by computer programmes.

The required scale of images is determined by the scale of the survey carried out and it relates to the level of generalisation (the size and detail of geological features displayed) and resolution of the images.

In general, high-resolution space data is characterised by a lower amount of generalisation and land area covered, compared to data of medium or low resolution.

To provide an optimal solution for the geological challenges posed in a project, it is needed to use images with different levels of generalisation at the same time: the 'overview level' for the analysis of general features or processes under study; the 'working level' that is mainly used for the survey, and the 'detailed level' that is needed for elaboration in some complicated cases.

In **Figure7.1** it is shown that the same territory looks differently when studied in different scales and that principally different objects can be distinguished in such cases.

In the 'overview level' (a) of **Figure 7.1** we see a lineament that probably reflects in the landscape an ancient deep fault. The northern periphery of the Bushveld lopolith is confined to the visible seam, and to the east of it various intrusions are seen via the red line in **Figure 7.1** (c). This line is more clearly seen in the filtered image (b). In (c) the same lineament (the contours of the Limpopo Province for reference) and the location of detailed areas for the working (2) and detailed (3) levels is shown.

In the 'working level' (scale) of **Figure 7.1**, a fragment of the lineament is shown. According to all indications, it may be diagnosed as a concordant fault (f) located at the south-west edge and the south-west continuation of the Strydport mountains, along which the Achaean formations (Rwo - shales, quartzites, conglomerates, basalts) underlying the Bushveld lopolith contacts with biotite granites (Rtu). This is seen even better after image filtration (e).

(Methodical data for thematic interpretation of space-born data) TsAKDZ IGN Nat.Acad.Sci., Kiev, 1999, pp. 129-132 (*In Ukrainian*)

In the ‘detailed level’ (image g in **Figure 7.1**) a fragment of the river valley is shown; at its flanks layers of triangles are seen that reflect the dips of layers, the rectifiable boundary of the valley floor and a slope indicating the presence of a fault.

Such effect is seen far more clearly, if we will use images having initially different resolutions.

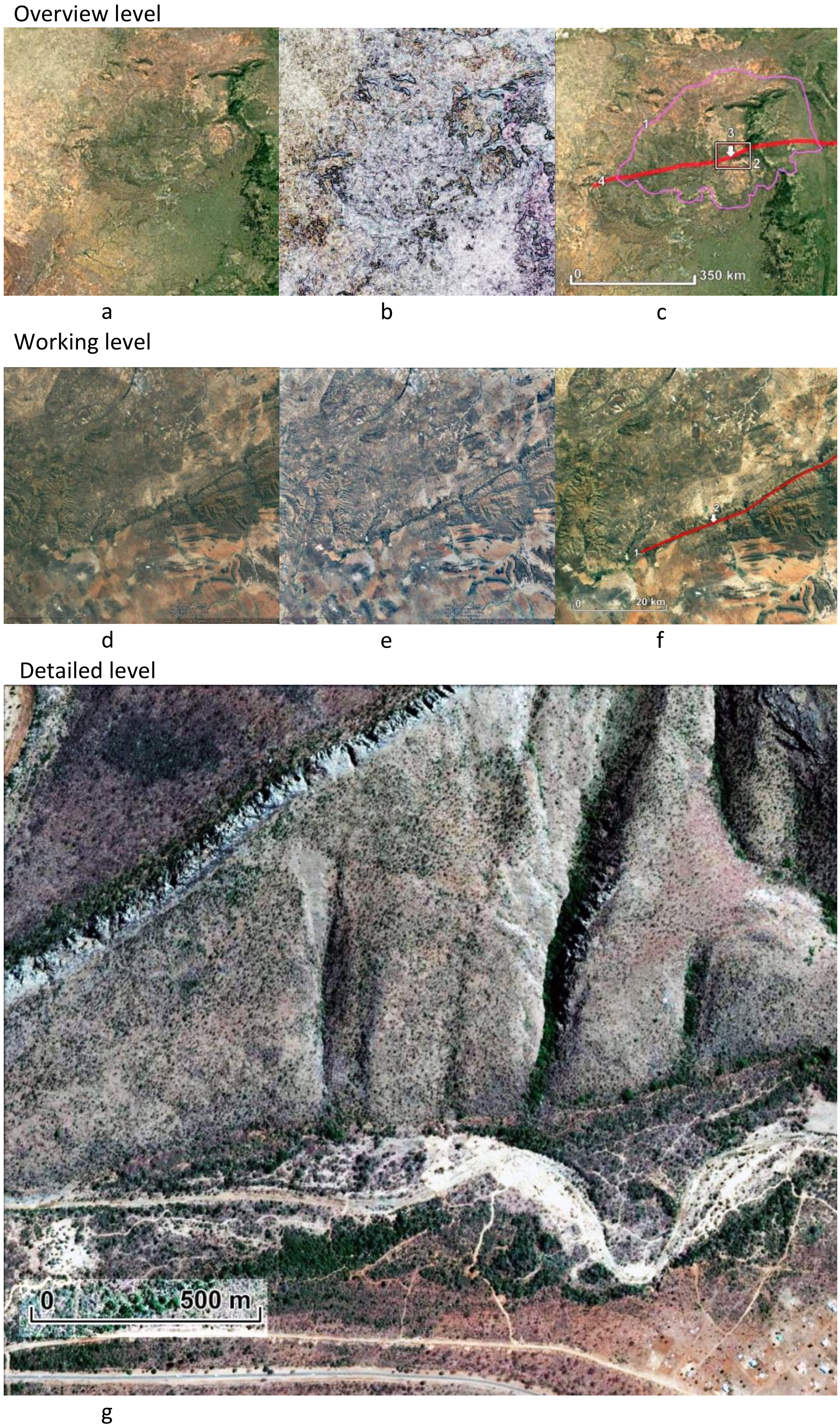
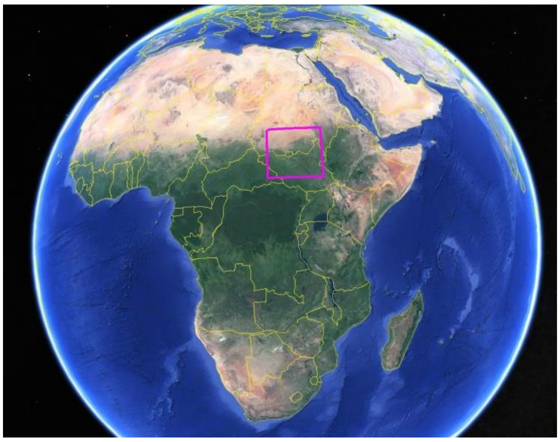


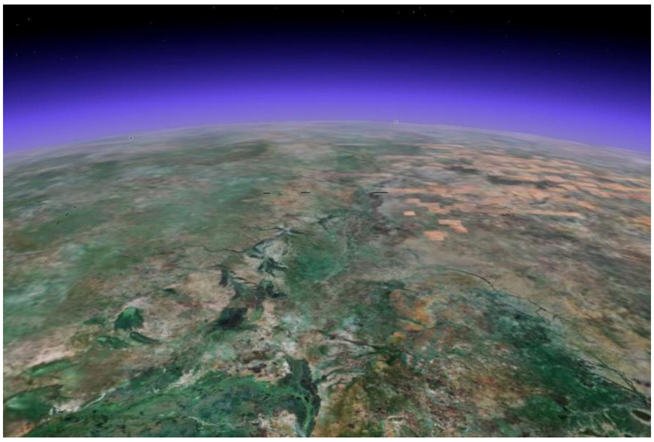
Fig. 7.1 Survey of the detailed plots and determination of priorities for land-based prospecting - Manifestation of the same lineament (fault) and its fragments with different levels of detail (Explanations of a-g in the text).

One more important peculiarity of the technique is its ability to be adapted to completely different tectonic and landscape cases. When adapted the general exploration criteria and indicants slightly differ depending on the site conditions, and new local exploration criteria and indicants are required.

The technique used by CSTP for Limpopo involves the following sequence of operations:

- Examination of existing data for the territory, and the selection of appropriate space images.
- Survey of the territory in the 'overview level' when the area under study is presented as an integral whole in the context of a large scale geological system. As a result, the territory can then be broken into blocks that are more or less comparable from point of their geological (tectonic) structure, modern tectonics and by conditions of interpretation, and this gives the possibility to consider the revealed blocks differently.
- Examination of each revealed block with revealed areas of potential assessed at a more 'detailed level' (for water prospecting, a scale 1:200,000 is appropriate, but for demonstration purposes we have used a simplified variant of 1:500,000). The most prospective plots shall be revealed and then considered in more detailed scale.


a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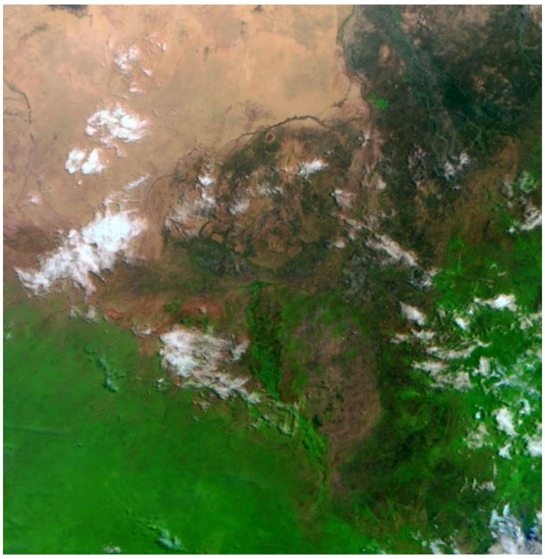
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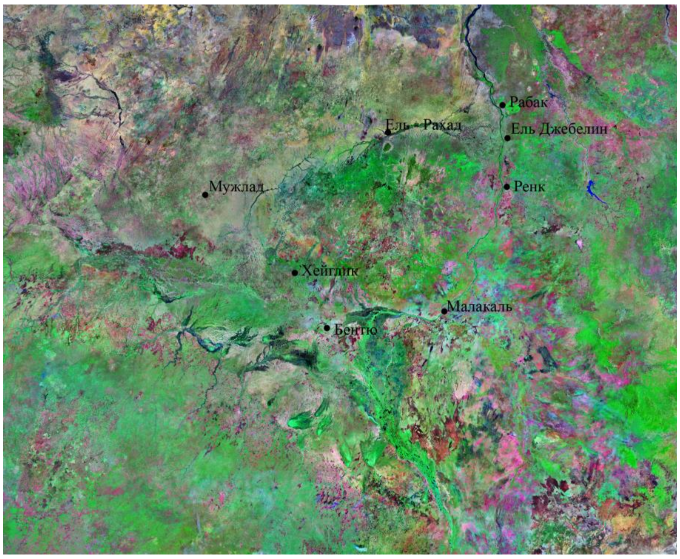


d

Fig. 7.2 Images from CSTP's Sudan case study, detailing the same structures at different resolutiona: a – location of an area under study (South Sudan); b – oblique view, Google Earth; c – image from the Russian Meteor-M No.1 spacecraft, resolution 1 km; d – mosaics of synthesized Landsat images, resolution 30 m.

In this report, the application of CSTP's techniques are shown in the case of the Limpopo Province. As mentioned above, the aquifers in Limpopo are almost exclusively confined to fractures, fissures, and faults of basement rocks, and therefore the main object of the study was the identification and analysis of fracturing that can be clearly seen in space images (over other forms of data). For the study LESSA software (Lineament Extraction and Stripe Statistical Analysis) was used, which represents an automated method for revealing the linear elements of images and computing their statistical characteristics, orientations and locations. For further ease of demonstration, Landsat space images (the most easily attainable of satellite images) were used.

7.2 Results of the Limpopo Province Survey

Overview level

For examination at the overview level of the Limpopo Province territory (the dimensions of the area under consideration are 4º in latitude and 5º in longitude) a scale ca. 1:2,500,000 is appropriate. At such a scale we are able to view the entire territory as an integral whole in the context of larger geological features connected to the surrounding area.

General characteristics of the territory in terms of hydrogeology

From a hydrogeological perspective, the Limpopo Province belongs to the hydrogeological massifs characterised by the basement outcropping at the daylight surface or the basement overlapped by thin Quaternary deposits. The basement rocks are sectioned by tectonic faults into blocks (see **Figure 7.17** on page 67). The peculiarities of the basement structure is determined by the fact that the waters are mainly of fracture and vein types. In the upper structural levels of the basement, fracture-layered waters occur sporadically. The hydrogeological massif represents a discharge system of fracture waters and waters of alluvial deposits.

As we have mentioned already, the lineaments seen in space images reflect as a rule at the daylight surface (since they are taken in the visual spectrum), disjunctive dislocations. These dislocations can be considered as peculiar individual hydrogeological structures that are usually characterised by significant outstretches, low widths related to the lengths, and by significant depths that in some cases may reach several kilometres, i.e. it is far deeper than the depth of the exogenous fracturing of rocks (the active water exchange zone) that is usually determined for the Limpopo Province as 100-150 m. However, in areas of intensive neotectonic movements the thickness of the sweet water zone is increased up to 600-700 m and even to 1500 m. Evidently, among all forms of disjunctive dislocations, the vertical ones inside dense easily fracturable rocks are most favorable for the accumulation of groundwater. Such disjunctives are often accompanied by zones of increased fracturing. Even in cases where there is an absence of significant underground resources, the rocks in zones of tectonic dislocations are more water-saturated than ones outside such dislocations.

Recharge of groundwater in areas of disjunctive dislocations is provided by atmospheric precipitation (rain), drainage of rocks sectioned by faults, by surface water streams and polls, and in some areas probably by condensed moisture. Participation of such recharge sources differs due to the complicated natural resources in Africa. Within the Limpopo Province, for the dry arid zone, the main source of renewal of underground water resources will be the water inflow from water-saturated rocks sectioned by faults and surface streams, especially in the areas where their directions match to fault zones or where fault zones are crossed by waterways.

The presence of weathered materials overlapping crystalline rocks is often critically important for fractured basement waters, and this is especially important for the stability of water resources since it may represent a zone where the water is preserved. Even in the areas where the basement is significantly fractured but the weathering zone absents, the water resources will be most probably low and unreliable if there is no alternative recharge source like a river or a link to alluvial deposits. River sand may play the role of groundwater deposit in the majority of arid areas.

The groundwater of disjunctive dislocation zones discharge by springs and also more subtly to phreatic waters or other aquifers that may be met along their movement path.

The natural quality of water in basement conditions is generally good, with low salinity and neutral pH. The increased salinity is common in areas with low recharge, discharge and/or in cases when waters stagnate underground for a long period of time. However, the natural quality of water in a basement may be harmful for human health due to high levels of trace elements like fluorine. Metals like aluminium are mobile under low pH values. A high content of iron caused by lateritic soils is not harmful but unpleasant. The complicated geology and absence of continuity means that the water quality may be changed at very short distances both laterally and in depths.

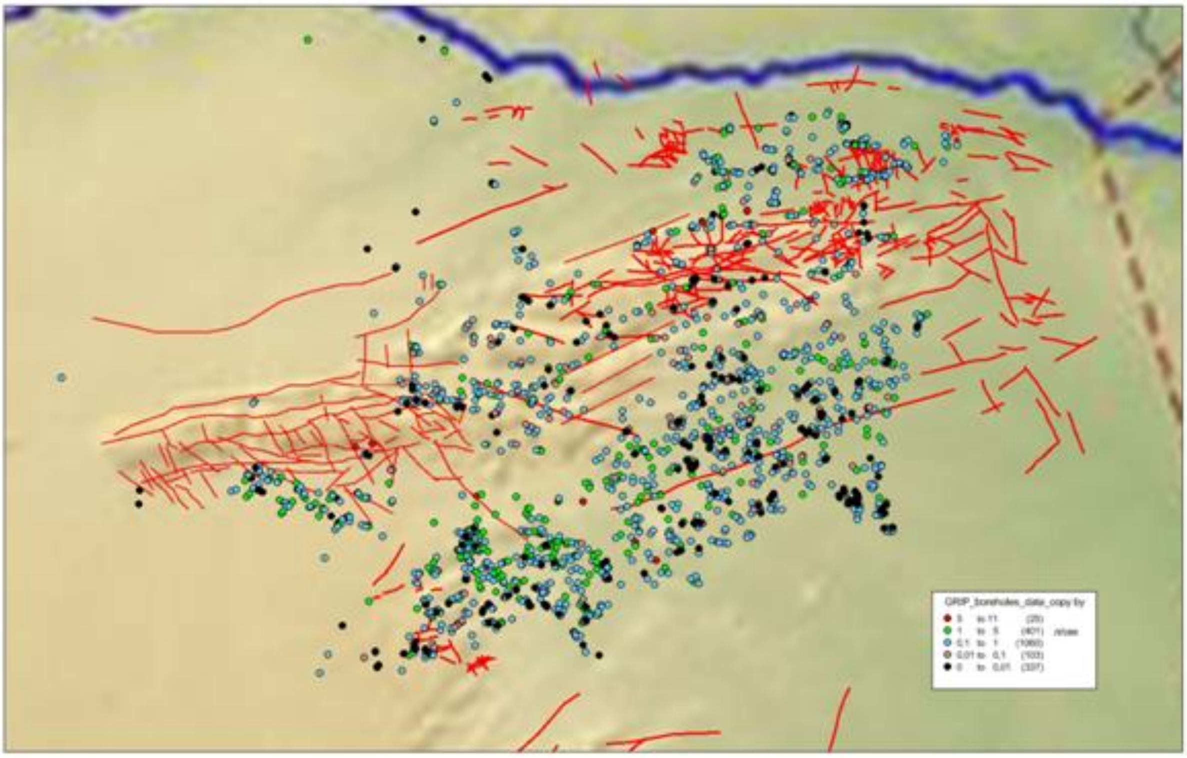


Fig. 7.3 Collation of hydrogeological wells in the western part of the Limpopo Province with relief and lineaments; prepared for scale 1:500,000. Blue line – the Limpopo River; red lines – lineaments; the dots show hydrogeological wells with the yields shown by different colours.[73]

[73] Limpopo hydrogeological wells, GRIP data, WRC and DWS - http://griplimpopo.co.za

For the examination of links between water abundance of fissure waters with disjunctive dislocations, topography and geology, the database of Limpopo hydrogeological wells (http://griplimpopo.co.za) was used. The examination of the influence of relief on well yields shows that, in general, the wells located in valleys and on flat areas show higher yields compared to wells located on slopes or heights.

The yields of basement aquifers are usually low, less than 5 l/s, often less than 1 l/s. While the water saturation of fractured basement rocks may be at most predicted at the regional level, whereas at the local level the saturations may differ significantly and it is quite complicated to predict the yield and the water quality at a specific point.

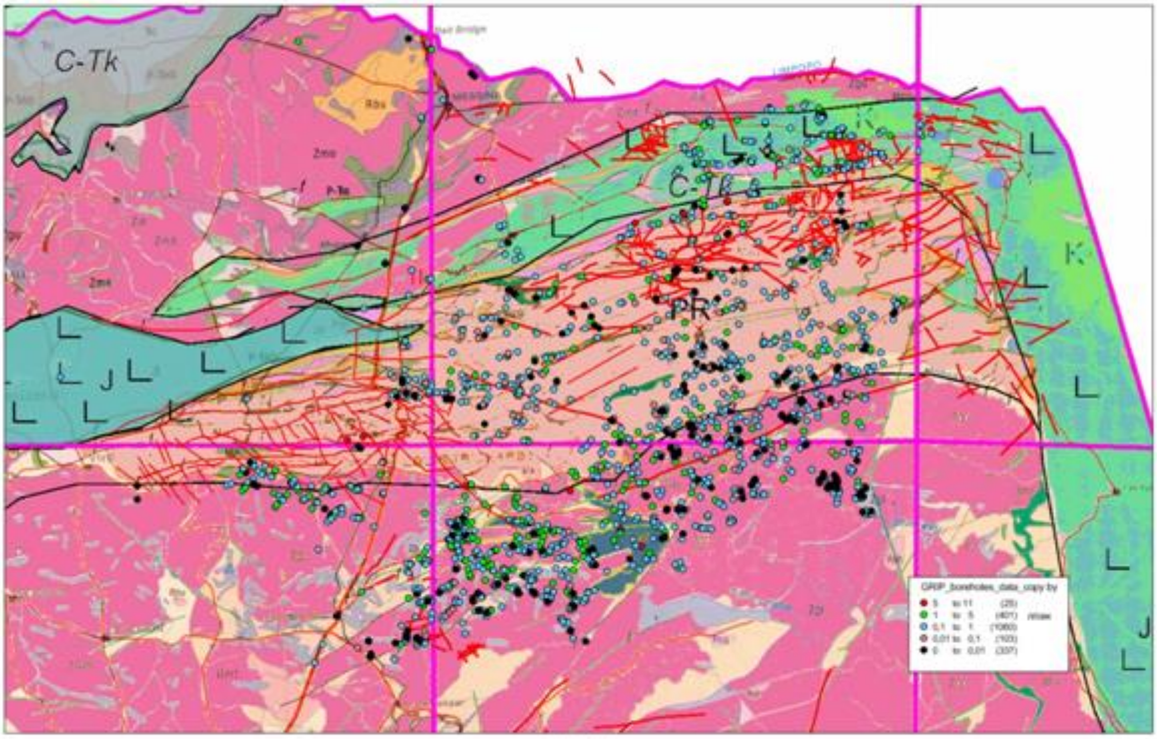


Fig. 7.4 Collation of hydrogeological wells in western part of the Limpopo Province with lineaments and geology. As a background of the map, a quick-look transformation of the official geological map was taken, where the colours were changed to conventions of the traditional international geochronological scale.[74] *Other conventions see* ***Figure 7.3****.*

In general, there is benefit to be had from the interpretation of space images in Limpopo (**Figure 7.4** outlines the geological structures), including ones that could potentially be water-bearing. The main features of the geological structures are seen well in different variants of space images, including generally available ones (**Figure 7.5** and **7.6**).

[74] Limpopo hydrogeological wells, GRIP data, WRC and DWS - http://griplimpopo.co.za

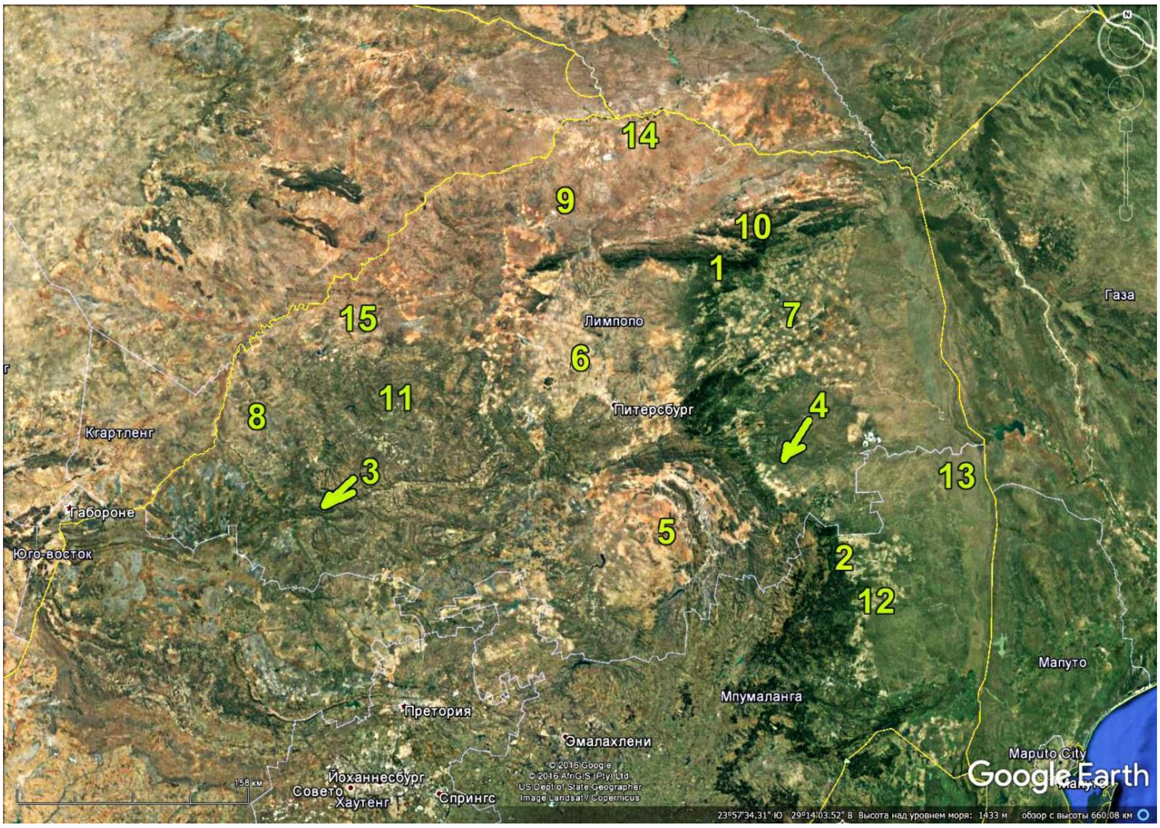


Fig. 7.5. The Limpopo Province seen from Google Earth (numbers 1-15 define blocks)

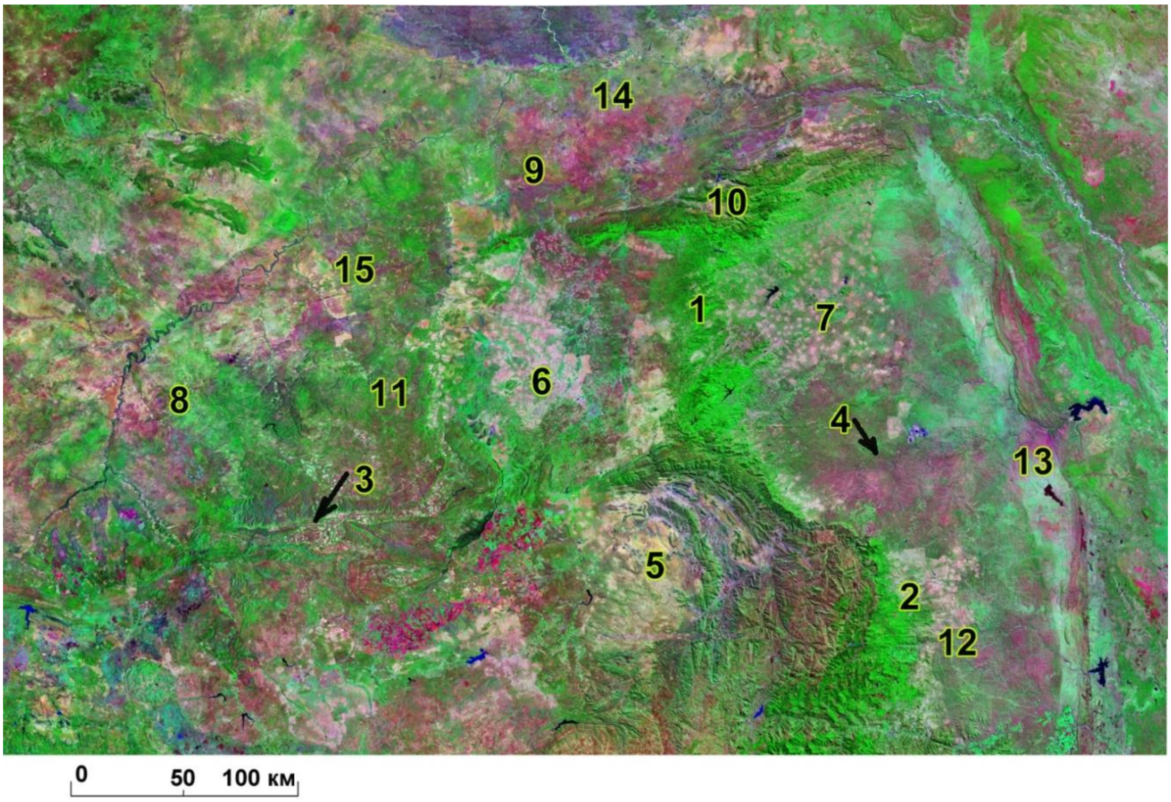


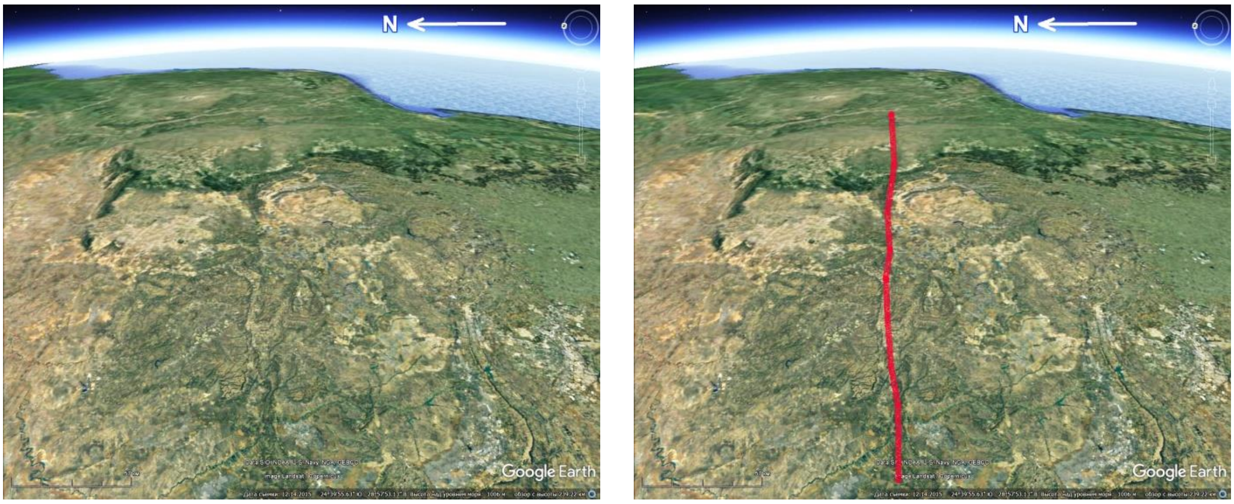
Fig. 7.6.The Limpopo Province. Fragment of mosaics (ETM+ a sensor on-board Landsat 7)[75] *(numbers 1-15 define blocks)*

[75] http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

CSTP

Primarily, attention may be drawn to the relatively abundant development of vegetation cover, especially within the S-form meridian band stretching from the outcrops of the Jurassic basalts to the eastern border of the Bushveld lopolith (blocks 1 and 2 in **Figure 7.5**). This band that is more or less manifested in different images and most probably reflects the increased moisture of the territory. This band relates only partly to known geological boundaries and it may probably be related to the differences in the modern tectonic activities of the rising central block (block 6 in **Figure 7.5**) and the condensation of water coming from the Indian Ocean or other reasons.

Another clearly seen visual object is the sub-latitudinal lineament stretching across the entire territory of the Limpopo Province (blocks 3 and 4 in **Figure 7.5**). This lineament is manifested in lowered relief that is seen in the perspective image (**Figure 7.7**) and in the increased moisture of the area. Such objects are usually caused by large fault zones.



a b

Fig. 7.7. Latitudinal lineament. Perspective image by Google Earth. a –initial image, b – interpreted image.

The most notable object on the territory of Limpopo is the Bushveld lopolith located in the southern part of the province (block 5 in **Figure 7.5**).

Other geological objects are manifested in the overview images to a lesser extent. For example, Archaean rocks in the central part of the Limpopo Province may be revealed by a light colour and vaguely-spotted photo pattern (block 6 in **Figure 7.5**); to the east, the same rocks are seen by the finely sparse photo pattern that is caused by the land-use character. The light spots are linked to supressed vegetation colour in settlements (block 7 in **Figure 7.5**); in the west they form a ring structure drawing outside Limpopo, and they are there practically undistinguishable from outcrops of Proterozoic deposits (block 8 in **Figure7.5**); in the north this is again an area of downtrodden vegetation, but in that case most probably due to a deficit of moisture.

The Proterozoic deposits also appear differently. The basalts may be distinguished well; they are stretched as a latitudinal strip in the northern part of Limpopo. To the east and to the west of the Bushveld lopolith the Proterozoic outcrops are mainly seen by various cuts of small waterways that most probably reflects the differences in intensities of the modern tectonic movements that are higher in the west (block 11 **Figure 7.5**) than in the east (block 12 in **Figure 7.5**).

In the east, a strip of Jurassic basalts is clearly seen (block 13 in **Figure 7.5**), but the same basalts overlying the Bushveld lopolith and mapped in the north of the area appear differently.

Thus, in the overview images objects may be revealed that are not shown in the official geological maps and that may be important for water content. Apart from that, some geological bodies having similar geological structures and composition have different appearances in space images. That is most probably caused by different modern tectonic activity that forms the relief to a large extent. It is possible to suppose on the base of the space images that the territory of the Limpopo Province like many other territories of the Earth is broken by a system of faults of various sizes into separate blocks that are move along each other in the modern era like piano keys. It means that the separated parts of the territory shall be considered separately. This way raises the task to section the territory into blocks for maximum effectiveness.

Apart from that, it is known that fractures play a very important role for water content. This is why it is very important to understand which faults and fractures relate to stretching (ruptures and throws) and which ones relate to compression. For these purposes the images were processed by the LESSA software package. This software reveals the linear elements of images and computes the statistical characteristics of their location and orientation.

Examination of the territory with LESSA software

With help of LESSA software, images of size 1140x867 pixels were examined (**Figure 7.8**).

Fig. 7.8 Initial image (Landsat), with processing

As a first step, the software reveals short strokes answering minimal rectilinear drops of the photo tint in a sliding window of 9x9 pixels, with help from a rotating mask that scans the image[76] (**Figure 7.9**). The sizes of the strokes are 2 - 5 pixels. In the landscape, these are small linear seams, settlings or rises displaying layering, foliation, cleavage, fractures, etc.

For convenience of referencing, the strokes are overlaid on the initial image. The directions of the strokes are shown by different colours, and this way the dominating direction of the strokes will influence the overall colour of the image. The dominating orientation of the strokes is shown in the rose diagram – these are north and north-west, but the orientation of the strokes is in general isotropic.

For greater clarity, a blown-up fragment of **Figure 7.9** (shown in the black rectangle) is shown for the area of development of the Proterozoic basalts, as shown in **Figure 7.10**.

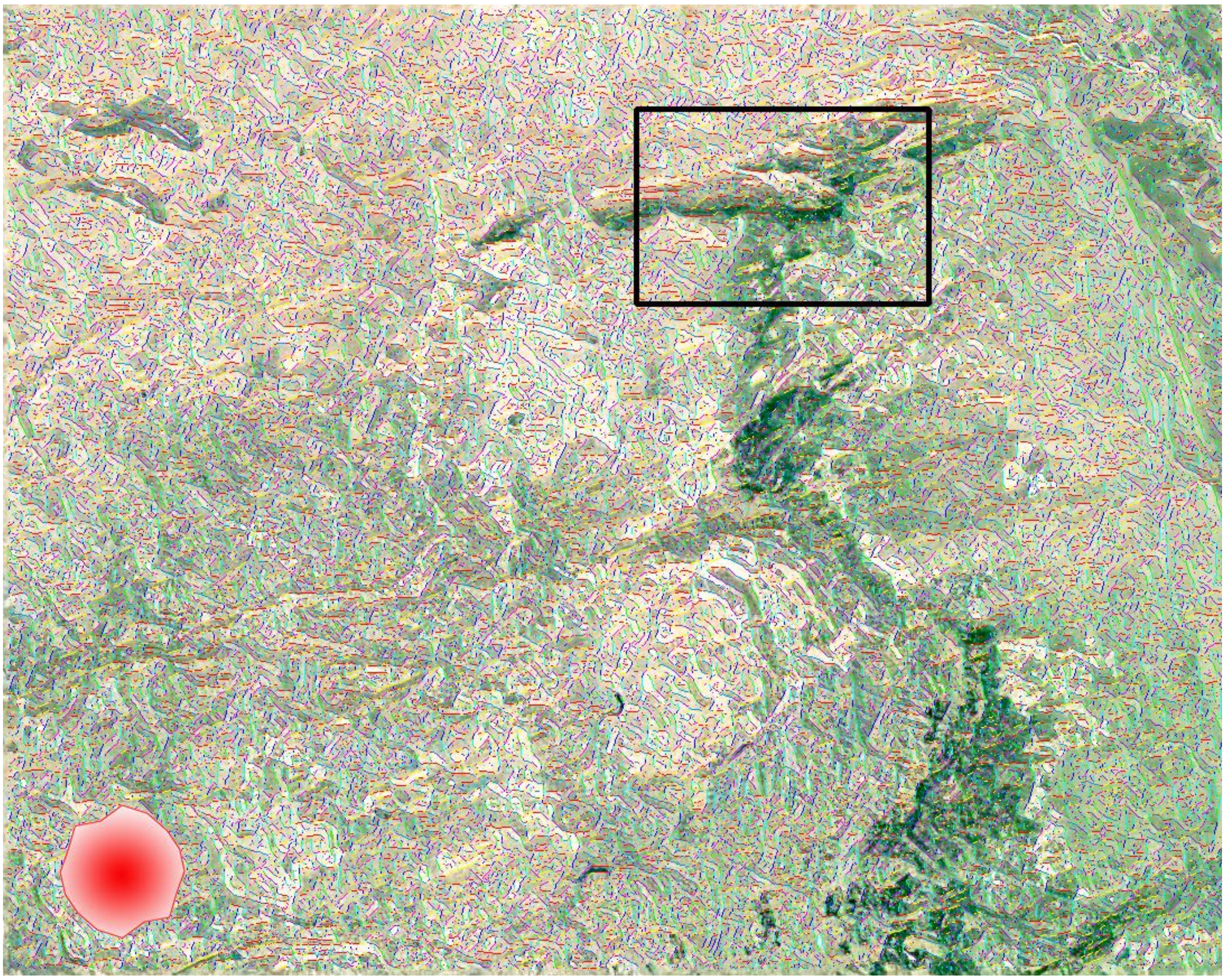
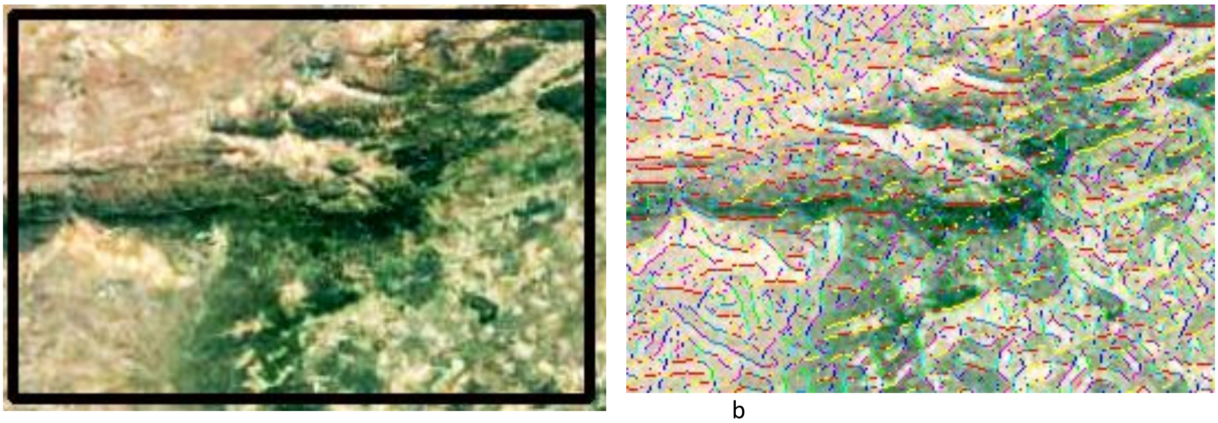


Fig. 7.9 The strokes distinguished by the LESSA software and their rose diagram.

[76] Details related the software package see at www.lineament.ru

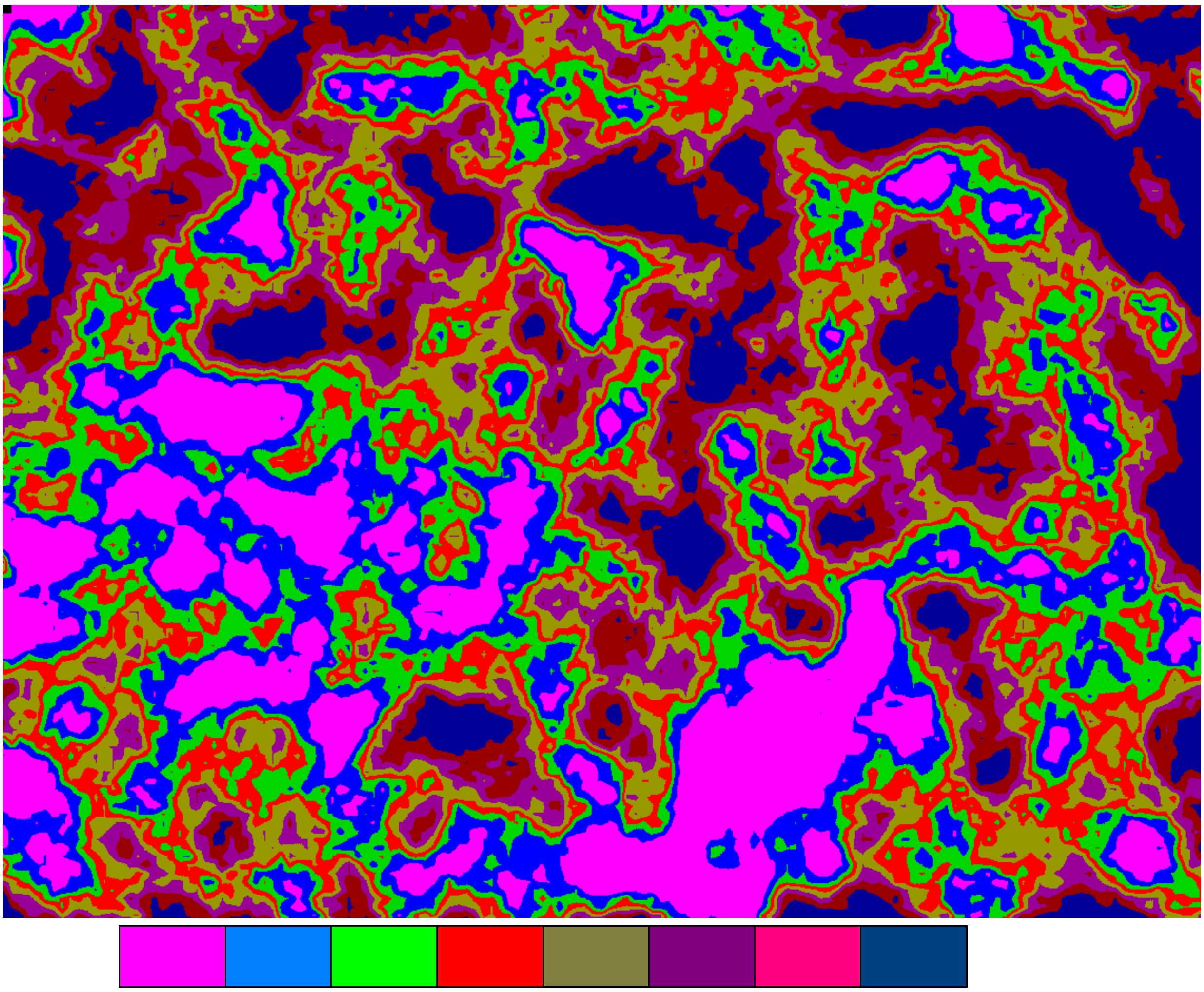


b

a

Fig. 7.10 Increased fragment of the image and the strokes distinguished in it by LESSA.

The software calculates the statistical characteristics of the distinguished strokes. The most customary characteristic is the intensity of strokes per unit area. Usually the more strokes, the more fractured the rocks are (**Figure 7.11**).



Max Min

Fig. 7.11 Map of the stroke density (highest density of strokes = purple, lowest density = blue); the more strokes the more fractured rocks. If there is a high density of strokes in the same (or roughly the same) direction LESSA interprets it as a lineament.

Usually the increased densities of strokes correspond to the areas of neotectonic rises. As a rule, the zones of rectangular borders of maximums and minimums relate to the areas of maximal gradients of related rises and plunges.

Orientation of the strokes is shown, as it was mentioned, in form of rose diagrams. In **Figure 7.12** it is seen that similar roses form groups of closely located similar rose diagrams. It is possible to suppose that clusters of similar rose diagrams are located within the same block, and different rose diagrams correspond to different ones. Such characteristics may also be used for revealing of blocks.

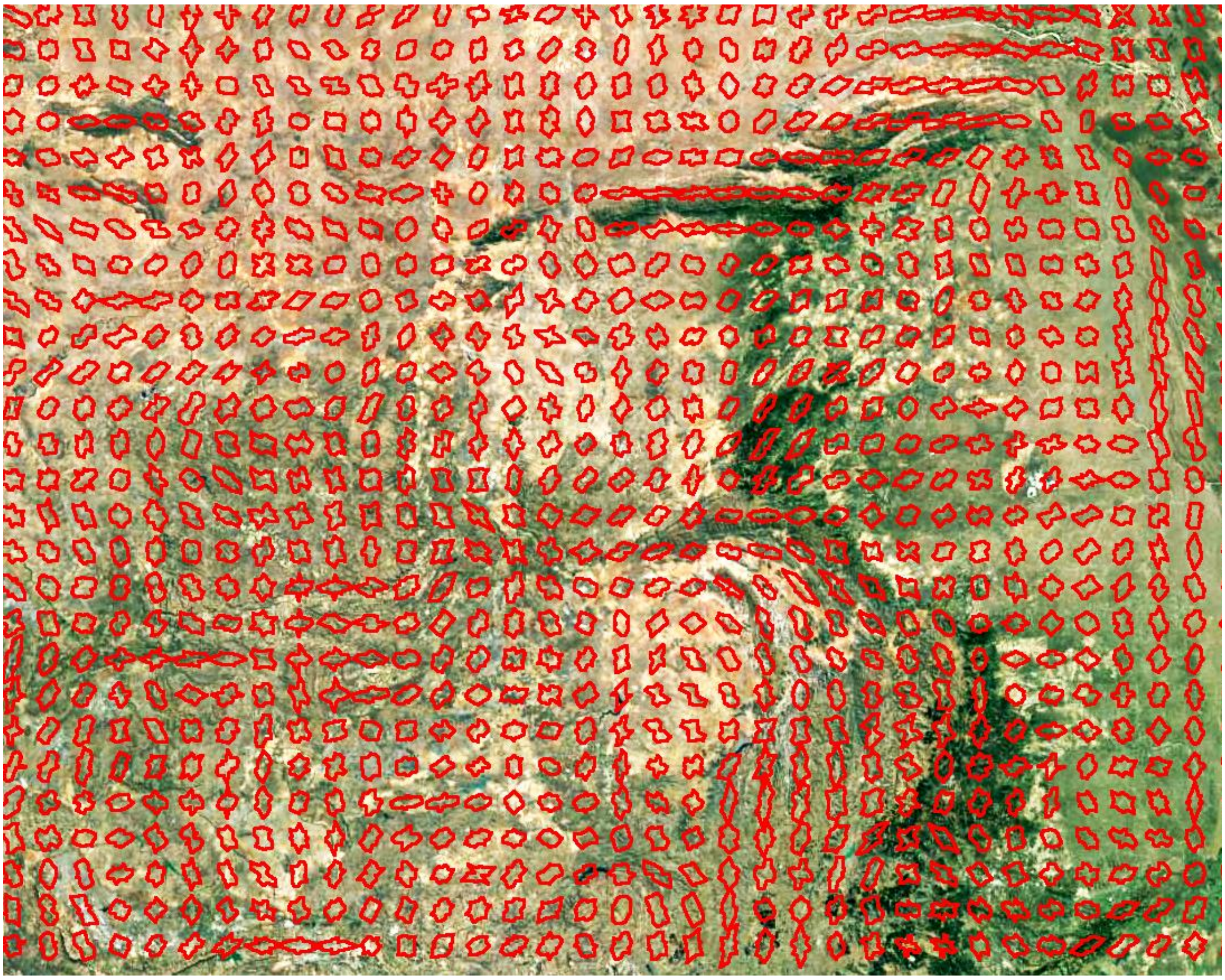


Fig. 7.12 Diagrammatic map of rose diagrams

It is seen that some roses are isometric, some are elongated, and the longer axis may differ both in orientation and length. Such characteristics is know in statistics as the random resulting length, but in the LESSA software it is named 'elongation vector' (**Figure 7.13**). In that diagrammatic map the blocks are seen more clearly.

Fig. 7.13 Diagrammatic map of the elongation vector

Apart from that, the long axes of the rose diagrams, i.e. the directions of the maximal number of strokes having a given direction may or may not be followed from one rose to another (**Figure 7.14**).

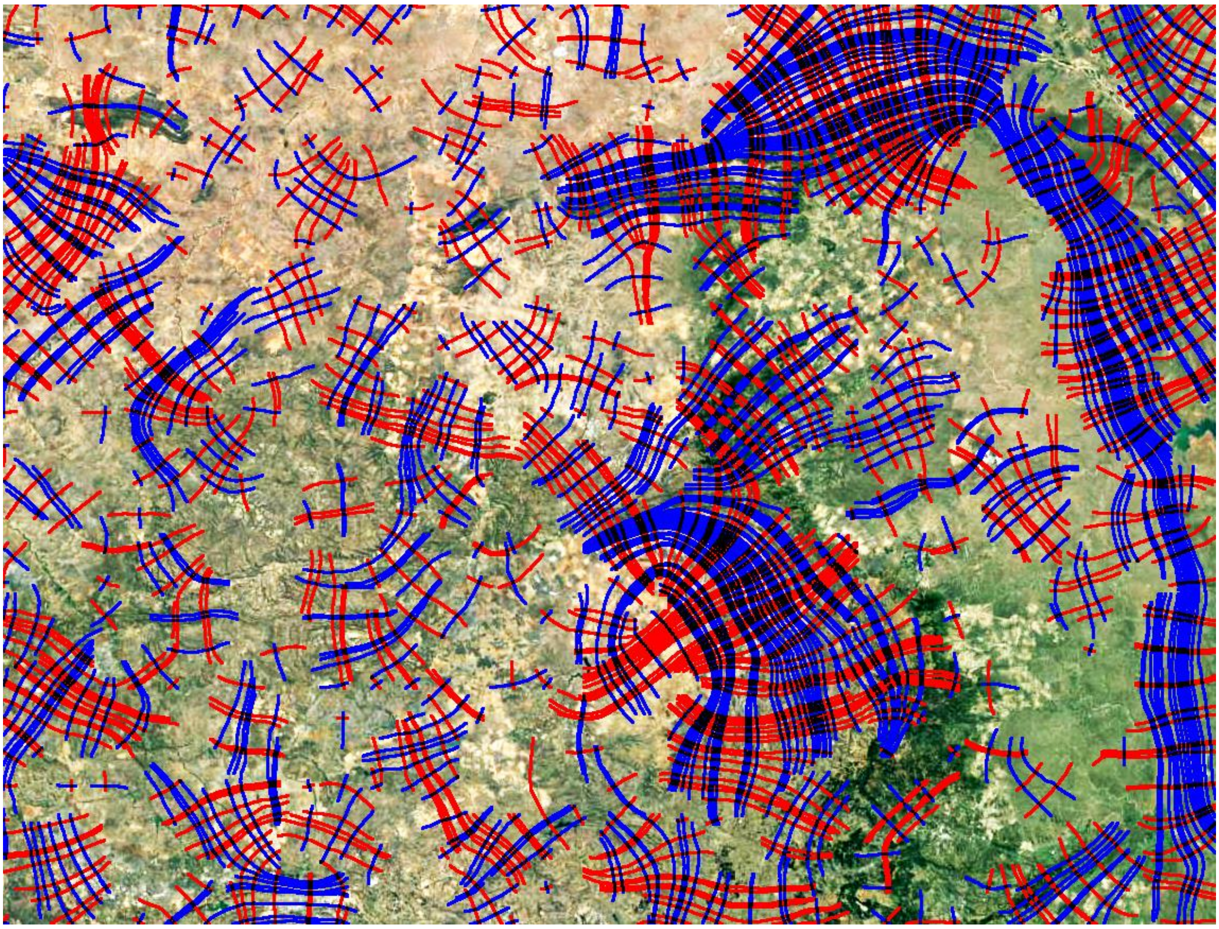


Fig. 7.14 Map of the elongation lines

Proceeding from the ratio of the axes of the of the main normal stresses and the directions of ruptures and throws, it can be assumed that the elongation lines of the rose diagrams (blue in **Figure 7.14**) correspond to the projection of compression axes, and the red lines signify stretch directions. It is clearly seen that these directions change their orientation either smoothly or abruptly. The latter usually means the appearance of new blocks or an impossibility to detect the direction of the stress.

In **Figure 7.15**, a map displaying the long lineaments is shown that is drawn by red strokes having directions located within the same 'corridor'.

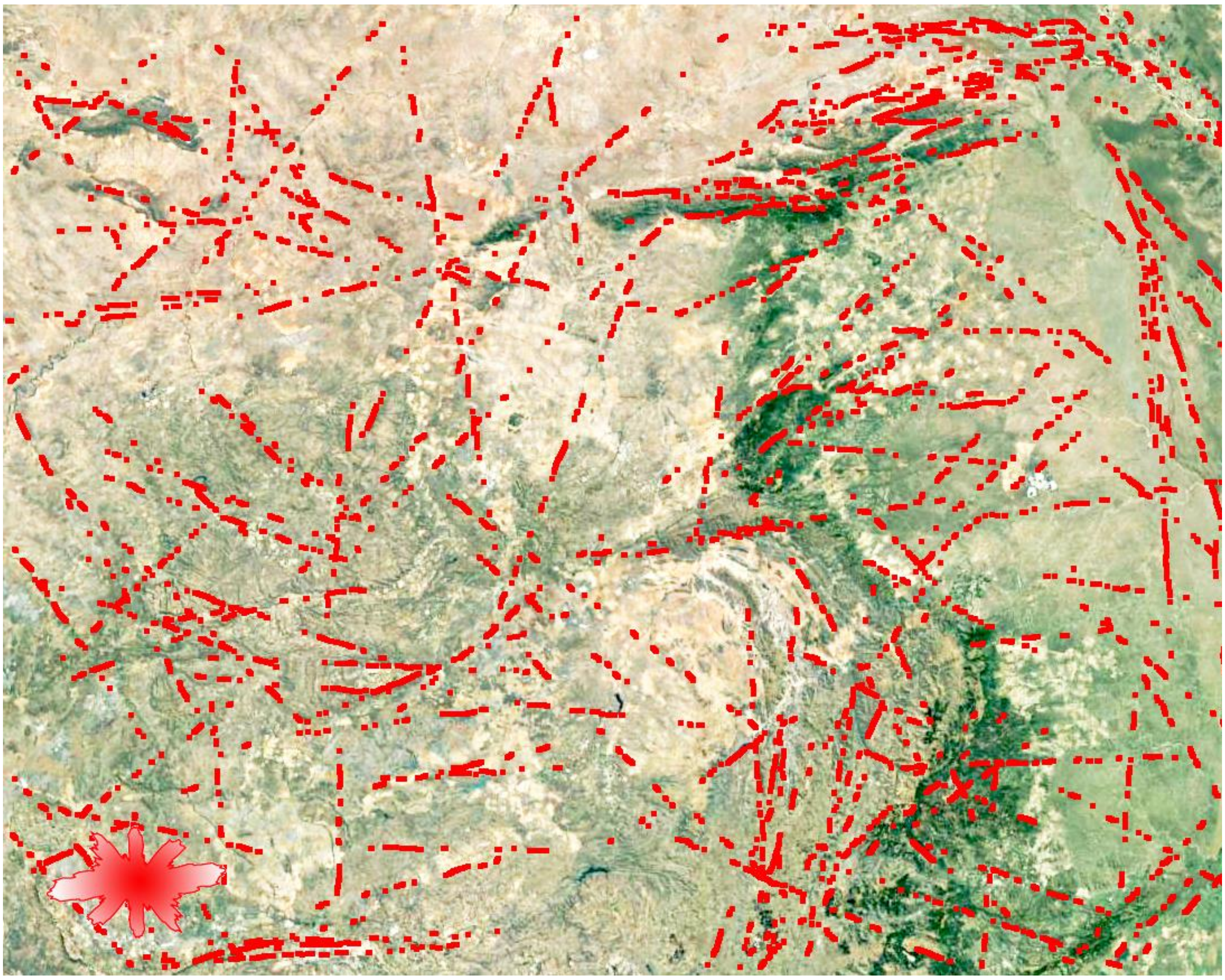


Fig. 7.15 Map of lineaments and their rose diagram.

The LESSA software is capable of distinguishing long lineaments with different degrees of reliability that are proven by red strokes. In the present case, the lineaments are proven by 50% of strokes. The determined network is clearly seen; in some parts (east) the lineaments of the meridianal orientation dominate; in the north-east part they are mainly in a latitudinal orientation, and in the central part they are in diagonal and longitudinal directions. The dominating orientation of the lineaments is shown in the rose diagrams, in which the rays of latitudinal (dominating), meridianal, and diagonal directions are clearly seen. This reflects the development of a regmatic network of planetary directions. This is the reason why one more map of the lineaments of planetary directions was drawn (**Figure 7.16**).

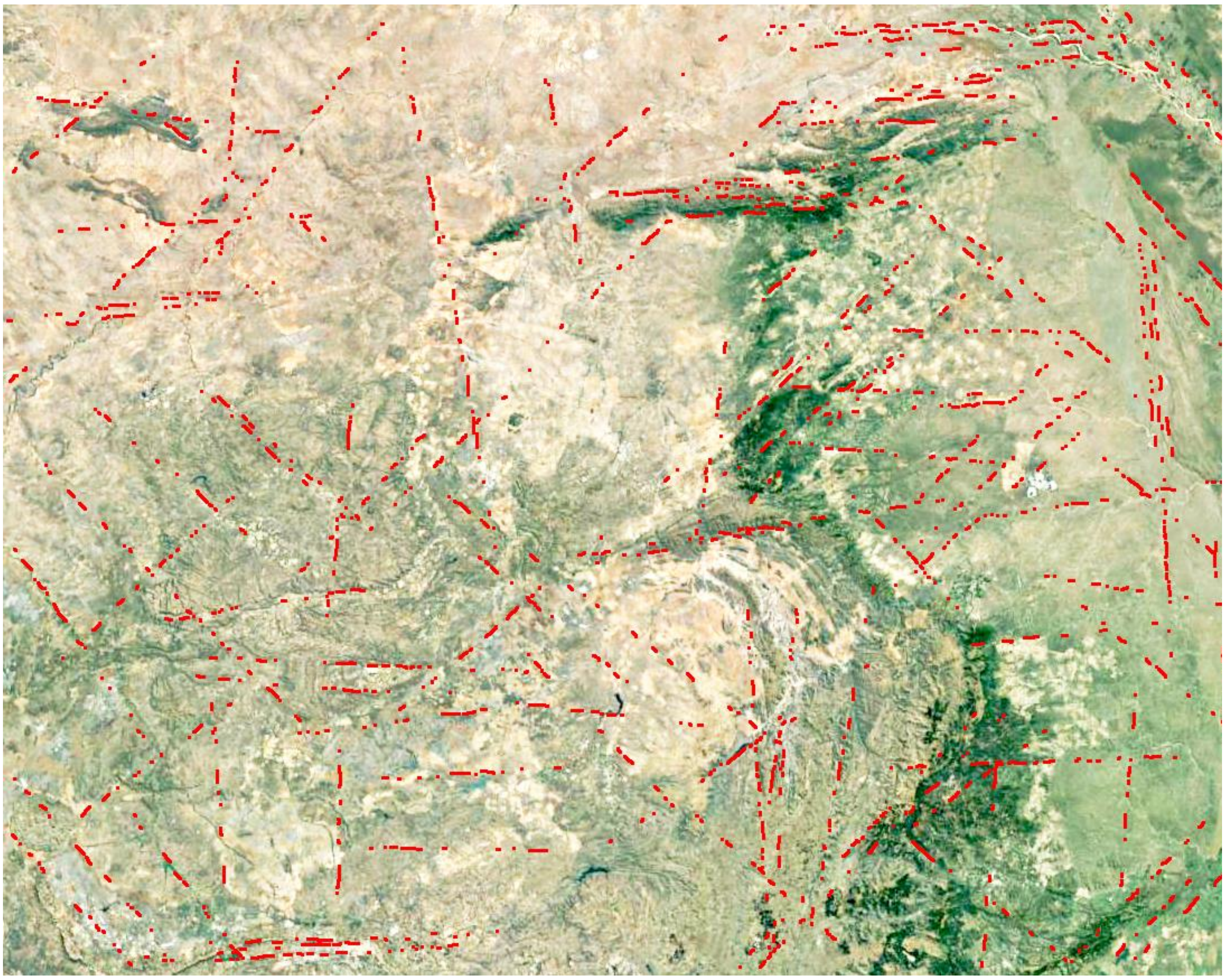


Fig. 7.16 Map of lineaments in different planetary directions

The presence of regular equidistant (in their location and regular orientation) lineaments of planetary directions gives the possibility to take into account revealed regularities. It is supposed that these lineaments reflect the zones of increased fracturing and fragmentation. These are 'living' (active) zones along which constantly occur small-size shifts caused by tidal forces and other constantly acting reasons that occur across the planet.

Based on visual analysis and an overview of the presented schemes of lineaments and the statistical characteristics of strokes, blocks are revealed (**Figure 7.17**), the borders between which may be considered as the zones of maximal disintegration. The next step is to examine each such block on a more detailed scale.

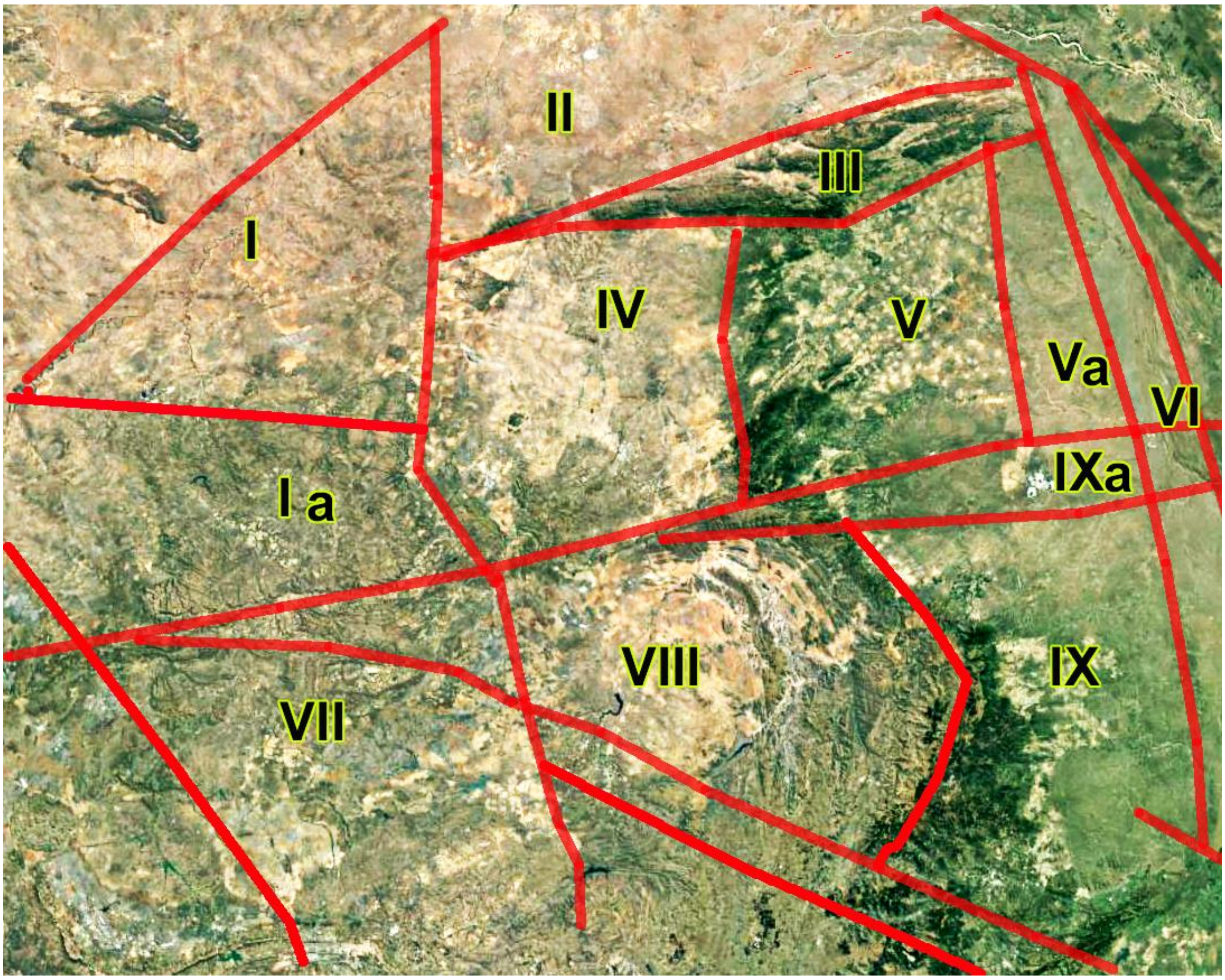


Fig. 7.17 The main blocks of the Limpopo Province

All together 9 blocks have been revealed for Limpopo. Some of them have additional indexes like I and Ia. It was done in the cases when the blocks were looking similar from a tectonic stand point but different from the point of landscape or other characteristics.

A regional level of overview (Block III Case Study)

Let's consider as an example the territory of Block III. It is mainly composed of an effusive-clastic section from the Proterozoic age. These are mainly basalts and tuffs alternating with sandstones and conglomerates. In the south, mainly Archaean migmatites are located, and in the north occur terrigene heterochronous formations of Paleozoic and Mesozoic era. The territory is broken up by numerous faults, often gaping ones, that are differently oriented (**Figure 7.18**).

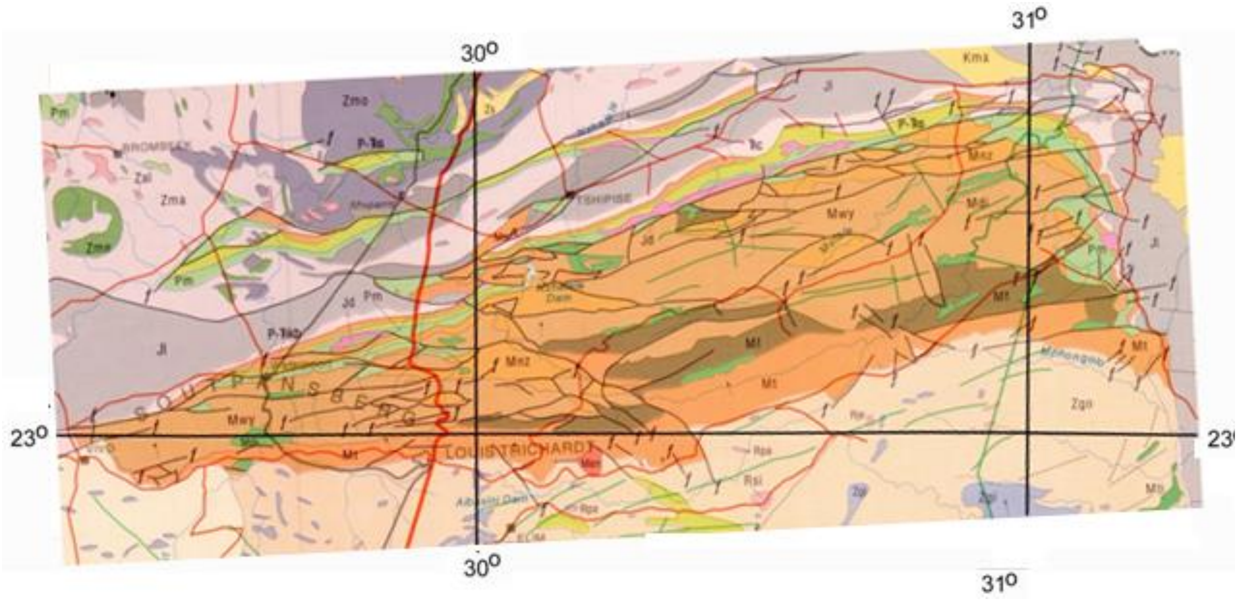


Fig. 7.18 Fragment, Geological map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland, 1997, 1:1,000,000, SA Council for Geoscience

This block and the faults are clearly seen in the space image by differences in forms and micro-forms of the relief (**Figure 7.19**).

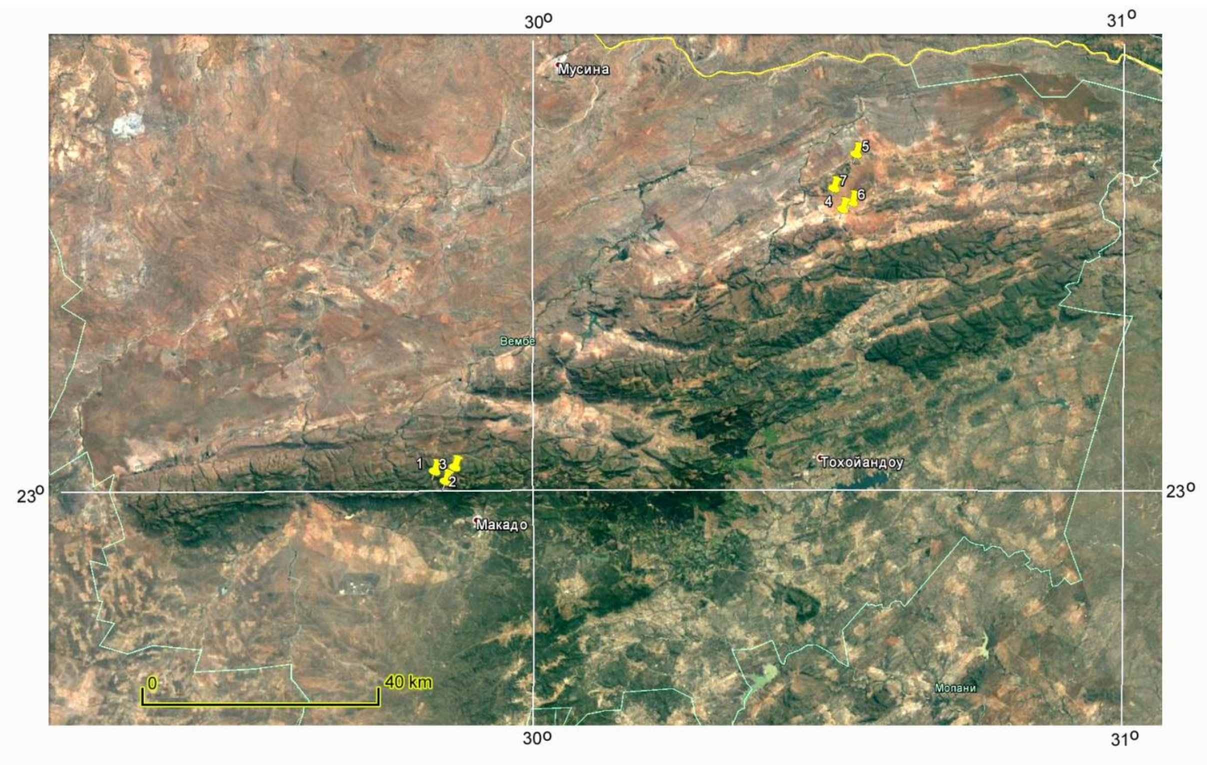


*Fig. 7.19 Fragment of the space image, Landsat. The marks show the areas that were examined in more detail below in **Figures 7.26-7.33**.*

The lineaments that mainly reflect the faults and the fissures, often the gaping ones, were interpreted in the images reduced to the scale 1:500,000 (**Figure 7.20**).

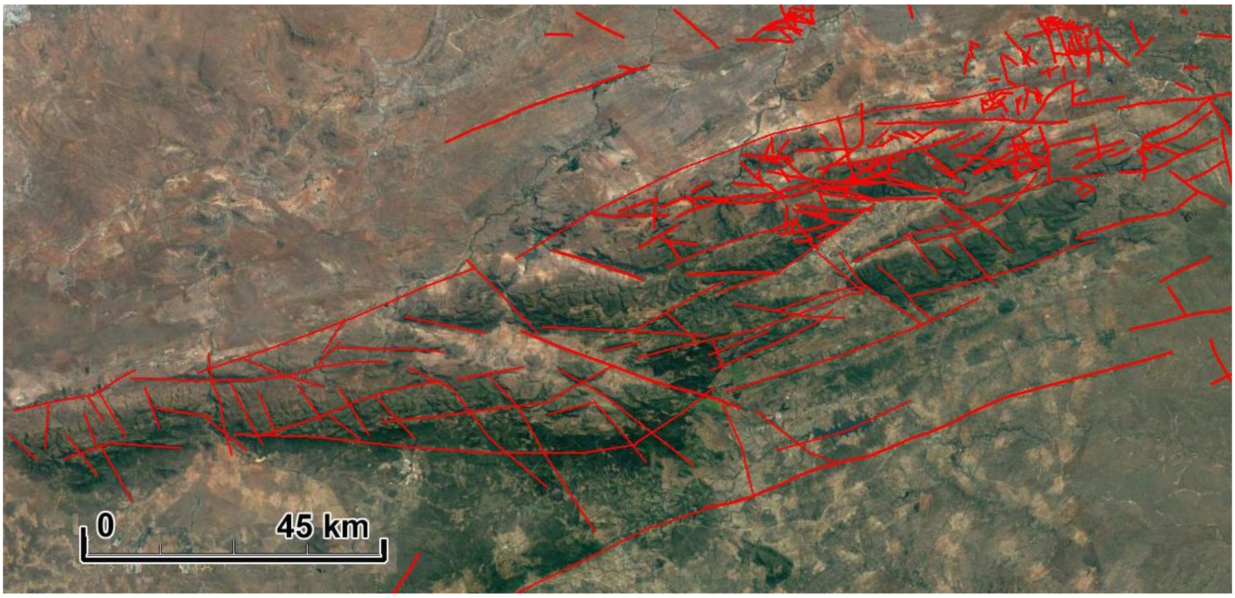


Fig. 7.20 Scheme of interpretation of disjunctive dislocations

It is clearly seen in the scheme of interpretation that the territory is sectioned by a dense network of deep disjunctives; along many of such dislocations waterways have developed. These disjunctives form, from the point of their directions, sub-latitudinal and the north-west systems. The same is confirmed by the results of processing with LESSA on the 'overview level'. The borders of the revealed block are clearly of a fault nature.

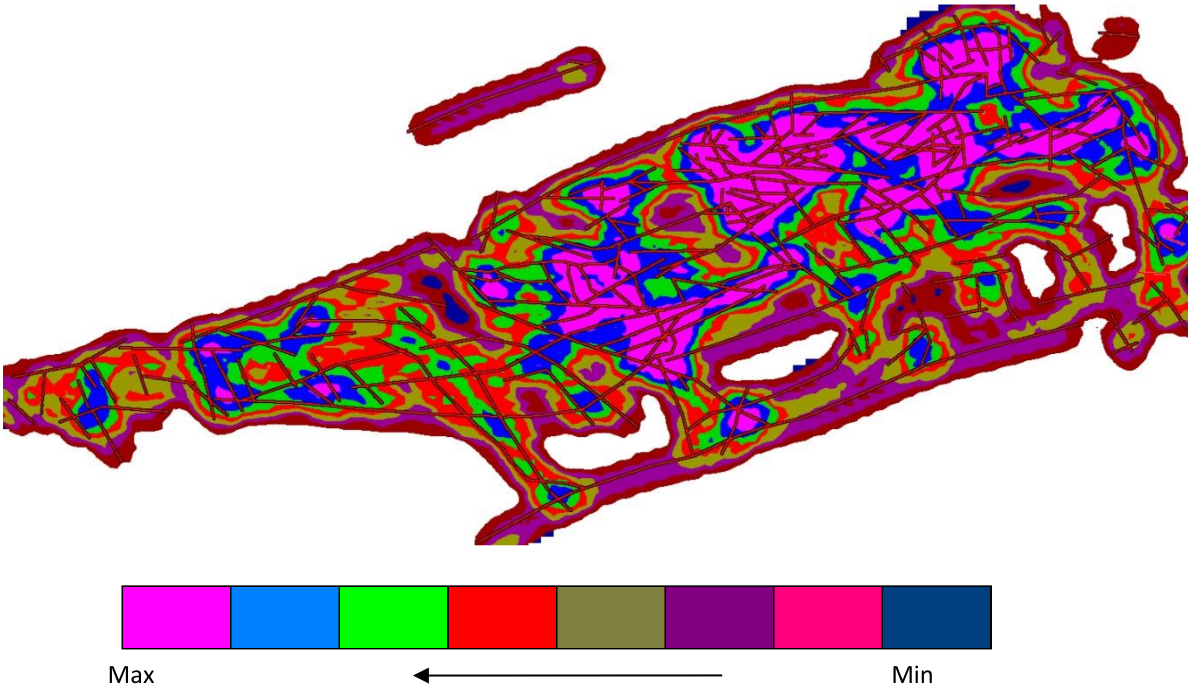
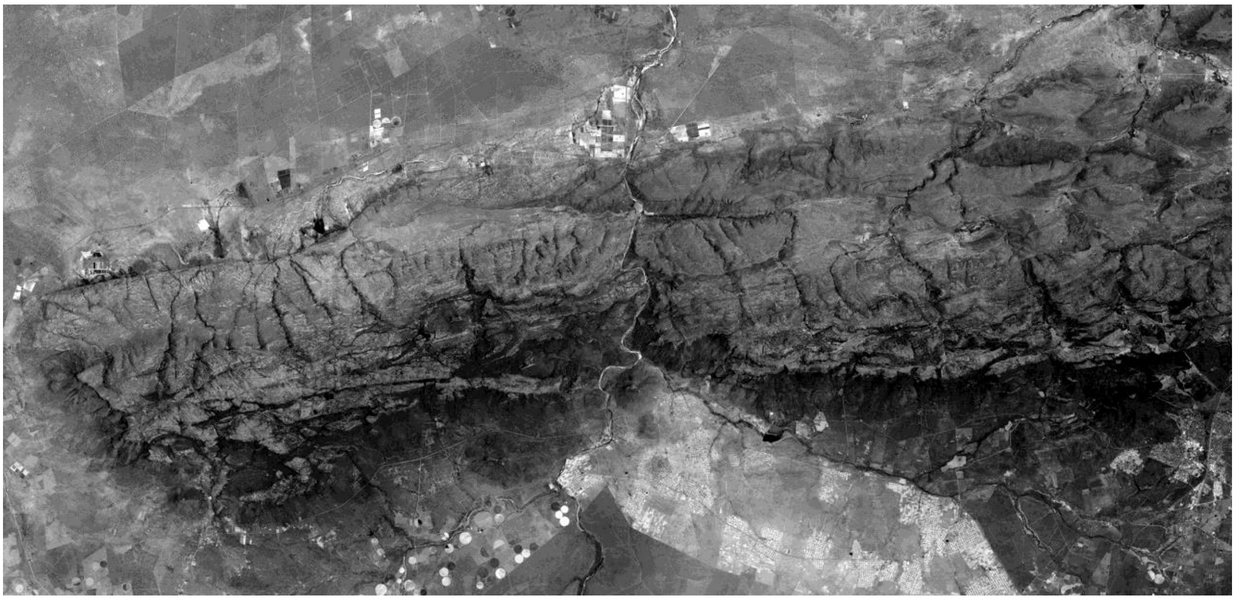


Fig. 7.21 The cross points of the faults (nodes), the highest densities of cross points are pink and the lowest are blue.

Such disjunctives are seen even better in monochrome infrared (IR) images. As an example, the fragment of the image is shown in the 7th channel (thermal) by Landsat 7 (**Figure 7.22**).



F*ig. 7.22 Fragment of the western part of the Block III, channel 7 (thermal diapason), Landsat-7 spacecraft*

The outlines of the faults and the character of the gapping make us believe that at this level of overview the sub-meridional disjunctives traverse to Proterozoic rocks related to breakdowns while the sub-latitudinal ones probably have a upcast or a upcast and shift character.

According to the data published[77, 78] for the neighbouring Karoo Basin, it was proved that increased water yields are confined to the crossings of faults. We suppose that it is needed to distinguish the terms 'node' and 'cross point'. The name 'nodes' denote the areas of accumulation of crossing points. It is convenient to reveal such nodes by LESSA, which gives the possibility to work with half-tone images and with schemes of interpreted faults. In **Figure 7.21**, an example of processing of an interpretation scheme from **Figure 7.22** is shown with areas (not points) that are nodes of faults.

The yields of water in wells of the area are very different. The diagram of their frequencies drawn by the GRIP Limpopo data is shown in the **Figure 7.23**. It is seen in the diagram that the overwhelming majority of wells either has no yield at all or has insignificant yield. with this understanding, the analysis of 7 characteristic wells were selected; their location is shown in the **Figure 7.19**. Three of these wells are located close to the southern border of Proterozoic rocks in the western part of the area, and four other wells are located close to the northern border in the central part of the area.

[77] K.T. Witthüser, M. Holland, *et al*., Hydrogeology of basement aquifers in the Limpopo Province; WRC Report No. 1693.1/10
[78] L. Chevallier, M. Goedhart, A.C. Woodfort - The influences of dolerite sills and ring complexes on the occurrence of groundwater in Karoo fractured aquifers: a morptho-tectonic approach.

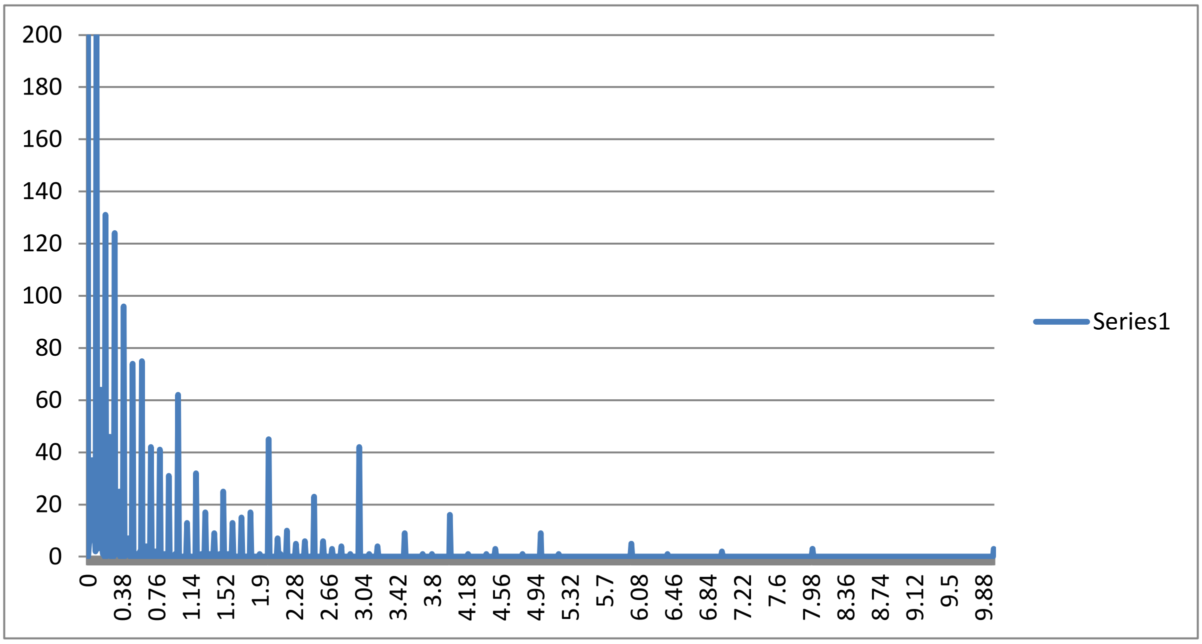


Fig. 7.23 Diagram of frequencies of yields in the wells, by GRIP Limpopo data[79], axis X is yield, axis Y is number of wells

Detailed level of overview

At a ‘detailed level’ of overview, we consider the case of two fragments with wells numbered 1, 2, and 3 in the south-western part of the area, and with wells 4, 5, 6, and 7 in its north-east.

The south-western fragment is located in the southern zone close to the contact of Archaean (in the south) and Proterozoic (in the north) rocks. Although the geological map shows the stratigraphic relation of the formations, judging by the image, the contact appears to be either tectonic, or complicated by small tectonic disturbances of a sub-latitudinal strike and by a series of transverse and diagonal ruptures caused by rivers. The north-eastern fragment is located close to the contact of Proterozoic basalts with Mesozoic, mainly terrigene, rocks (**Figure 7.24**).

[79] Limpopo frequency of well yields, GRIP data, WRC and DWS - http://griplimpopo.co.za

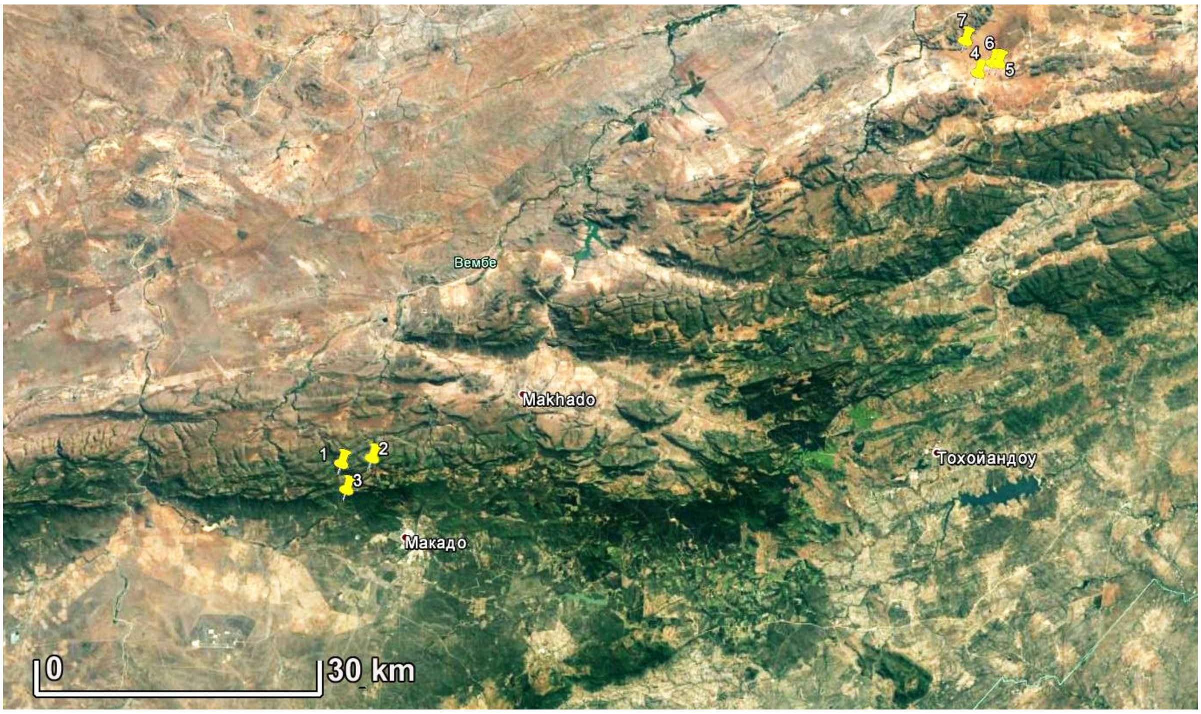


Fig. 7.24 Location of detailed fragments, Proterozoic basalts, with wells marked in yellow and numbered 1-7.(Landsat)

Let's consider the location of three wells in the south-western fragment. Well No. 1 was drilled on 2009-03-21 to a depth of 126 m, it has high yield with continued output to this day. It is located at a disjunctive oriented in a transverse direction in relation to the general strike of the rocks, located by the river valley. According to the morphological features, this disjunctive corresponds to a discontinuity associated with breaking stresses (**Figure 7.25**).

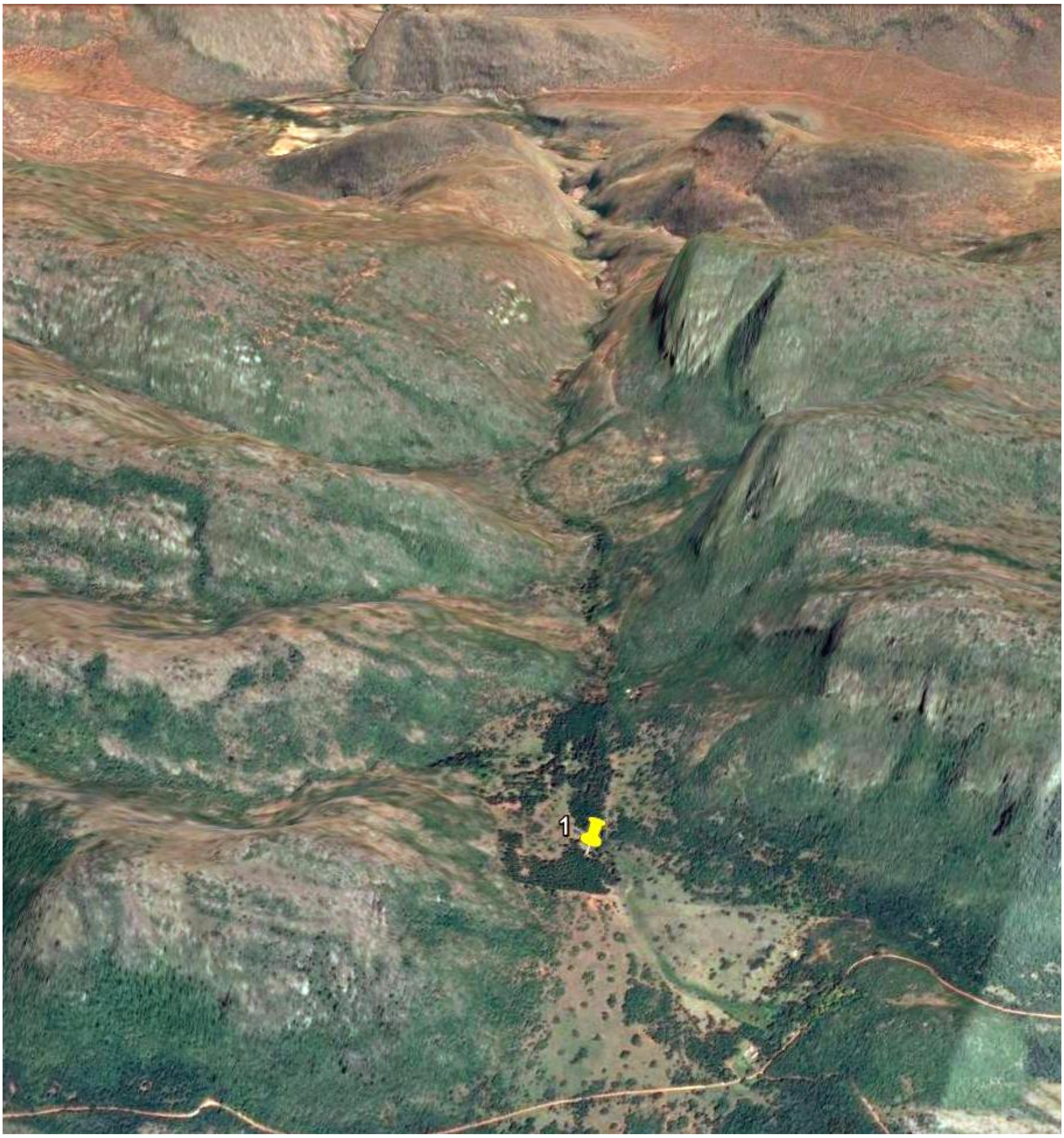
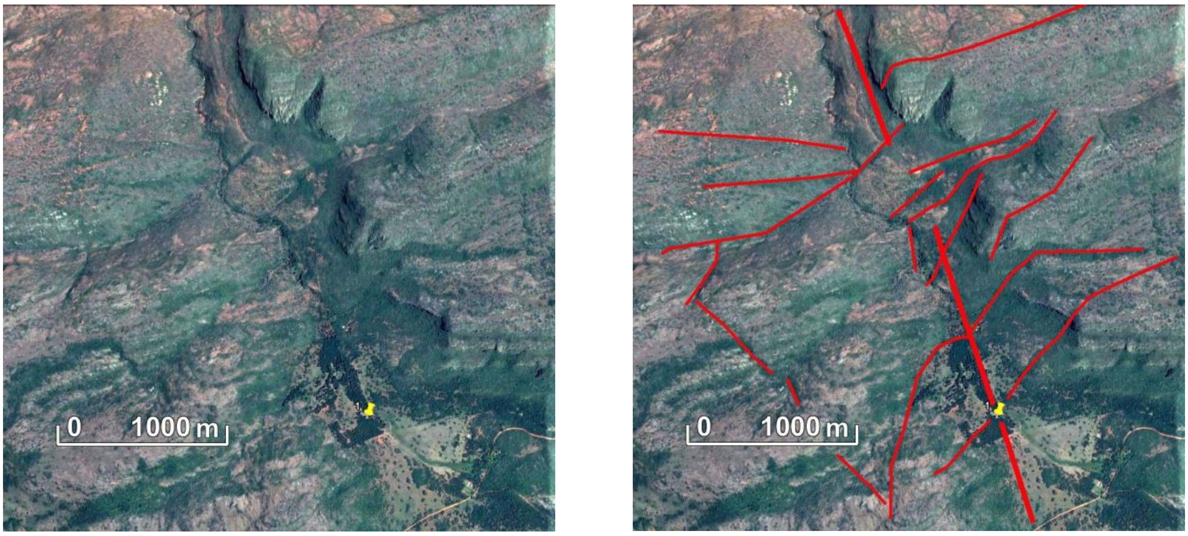


Fig. 7.25 Perspective image of the transverse valley following the disjunctive (Landsat)

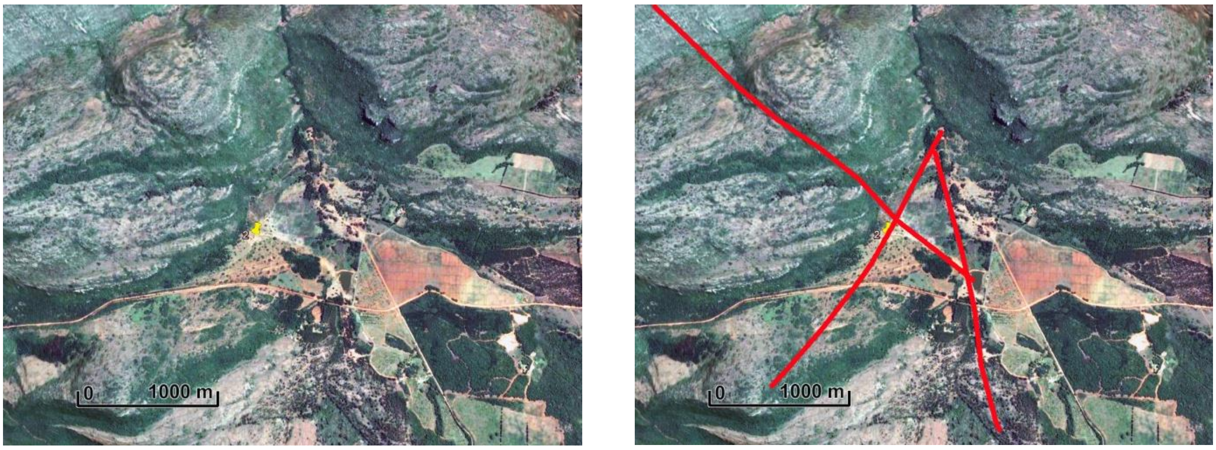
The flanks of the valley are sectioned by numerous fissures oriented both along the strikes of the layers and in the diagonal direction. Well No. 1 was drilled at the intersection of the main fault, along which the valley is washed-out, and a small diagonal fault (**Figure 7.26**).



a b

Fig. 7.26 Transverse valley and small faults (marked in red) sectioning it with well No. 1 marked in yellow (Landsat)

Well No.2 was drilled on 2009-03-26 to a depth of 102 m giving a high yield, and is still operating. It is located in the near-estuary part of the valley at the intersection of disjunctives oriented diagonally in relation to the total strike of the layers (**Figure 7.27**).

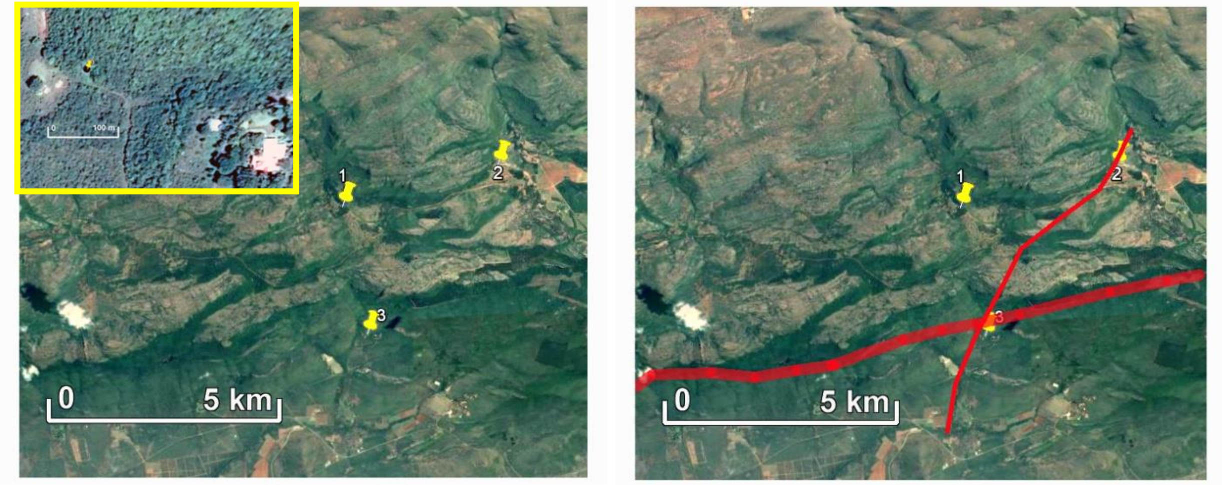


a b

Fig. 7.27 Well No.2 and its location amongst the faults of the area (Landsat)

Well No.3 has a low yield, ca. 0.2 l/s only, but was built with a plunged electrical pump; drilled on 2003-05-28. It is located at a large sub-latitudinal fault of the southern contact of Proterozoic basalts and Archaean granites and is intersected by a diagonal fault that is characteristic for this territory (**Figure 7.28**).

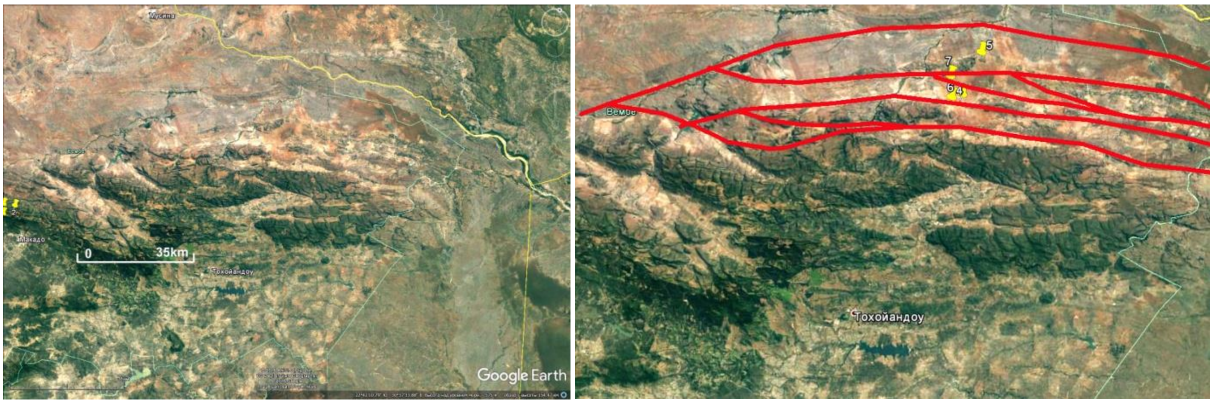
In the inset map of **Figure 7.28**, a dark spot of irregular shape is visible, this is a well equipped with a pump.



a b

Fig. 7.28 Well No.3 and its location among the faults of the area (Landsat)

The other group of reviewed wells is located in the north-east of the area. They all are concentrated along a large sub-latitudinal lineament located in Mesozic and Paleozoic formations. In the geological map these contacts are shown as stratigraphic ones, but as judged by the images they are of a tectonic character. It looks chiefly like a large zone of fragmentation (**Figure 7.29**). The figure does not show the faults that cut the Proterozoic basalts as they were discussed above.



a b

Fig. 7.29 Wells at the north-eastern contact (Landsat)

Well No.4 is equipped with a diesel powered pump at a depth 36 m, drilled on 1998-06-23. It is located in the village of Muswodi Dipeni within a manor. It is located on a small and unclearly expressed lineament displayed at the boundary of a deluvium fan (Fig. 30).

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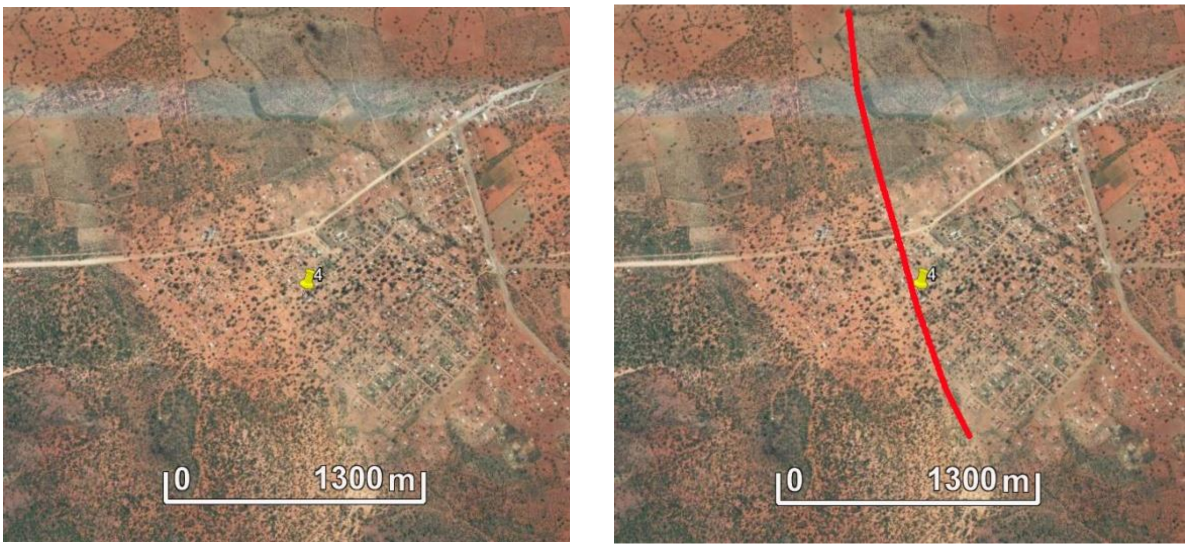


a b

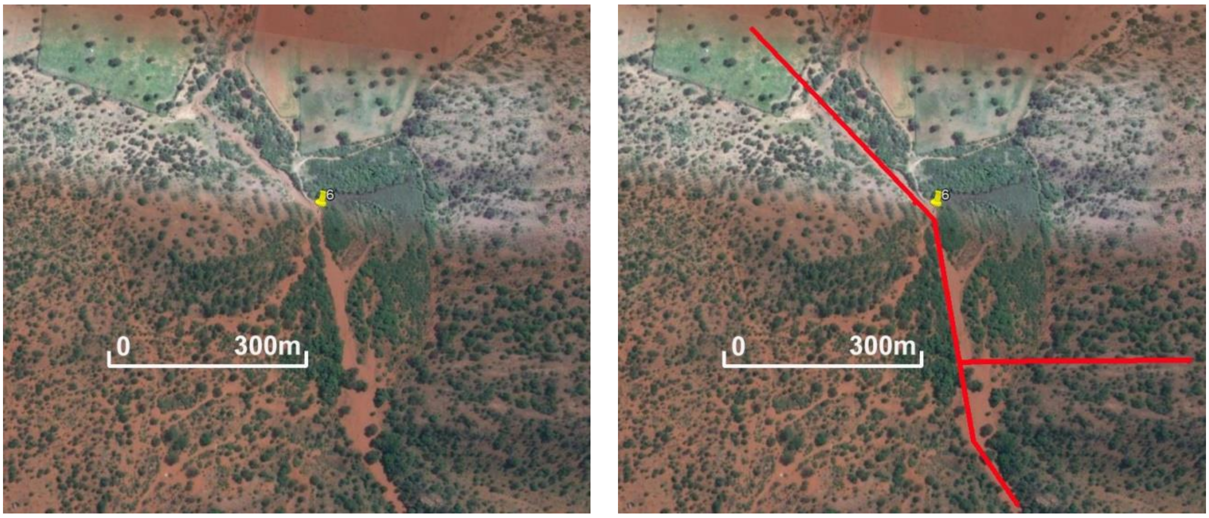
Fig. 7.30 Well No.4 and its location at a lineament (marked in red). (Landsat)

The high-yield at wells 5, 6, and 7 has not run out. Well No.5 located somewhat to the north, near outcrops of basalts is also placed at the node of lineaments (**Figure 7.31**).

a b

Fig. 7.31 Well No.5 and its location at a lineament (Landsat)

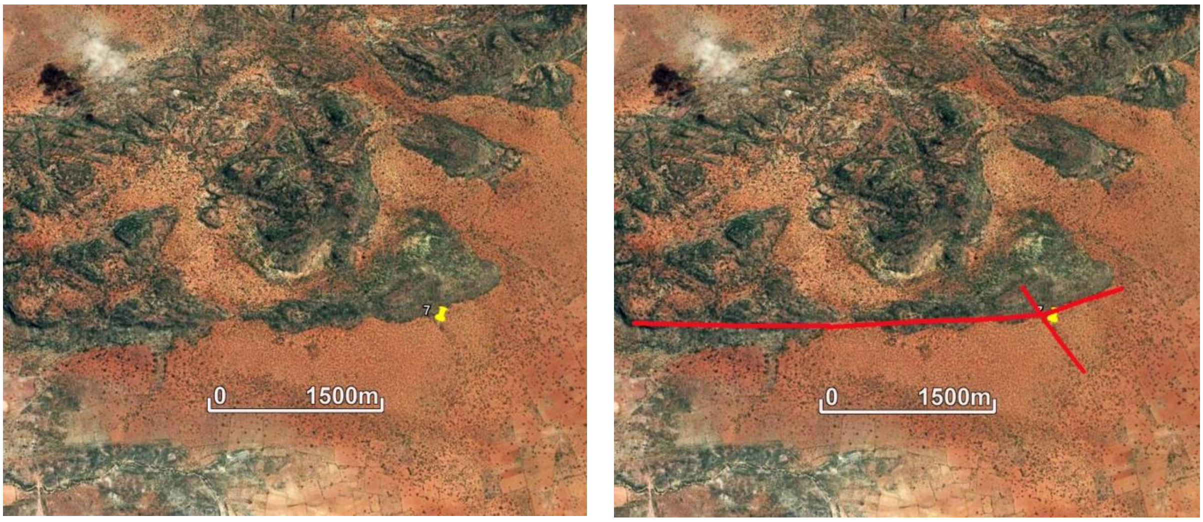
Well No. 6 is located in the river valley among alluvial deposits. The interpretation of the geological situation at this point is masked by images of the field borders as well as the gluing of individual images. However, the straight duct, expressed by the lineament, indicates a weakened zone in this area (**Figure 7.32**).



a b

Fig. 7.32 A straight duct displaying a weakened zone (lineament) controlling a high-yield well. (Landsat)

Well No.7 also has a high yield; it is located at the contact of Proterozoic basalts and Mesozoic sediments, at the cross section with a transverse fissure (**Figure 7.33**).



a b

Fig. 7.33 A straight duct shows a weakened zone (lineament) at the contact of Mesozoic sediments (south) and Proterozoic basalts (north). (Landsat)

7.3 Conclusions of the Limpopo Province Survey

The interpretation was carried out for the case of the Limpopo Province with the use of generally available and free Landsat data.

The interpretation gave the possibility to reveal a regular grid of lineaments that sections the area into several blocks. It was proved that the blocks are different from a tectonic point.

It is especially important that numerous lineaments revealed by space images, including very large ones, were not previously displayed in official geological maps and in specialised maps of the area.

All wells with relatively high yields are confined to lineaments or to lineament nodes that are seen in space images. However, when reviewing yields of the wells, it is needed to take into account hydrogeological parameters like directions of groundwater flow, thickness of the aeration zone, porosity coefficient of enclosing rocks, etc.

Geomorphological and neotectonic analysis of the lineaments revealed in space images allows us to distinguish 'alive' active and non-active faults, and this way to exclude non-active faults from further consideration since they have no water-bearing prospects.

The survey carried out by the technique described above provides the possibility to create a geological base to forecast deposits of underground water. Such surveys are quick and cheap compared to more common on-ground methods, and they may be used both in other regions of South Africa and in other countries around the world.

The geological base obtained by such a survey shall be verified, specified and detailed within the identified prospective areas by ground surveys like electrical prospecting, microseismic and atmo-emanational surveying.

Overall this survey of the Limpopo Province has achieved all the goals CSTP intended. With only one month (approximately) of analysis CSTP has managed to demonstrate the first steps of its methods and validate their potential in SA. These steps include:

- Collecting and corroborating some existing data – made possible through the extensive data that is freely available on the Limpopo Province through GRIP (because of time and budget constraints CSTP was unable to liaise closely with CGS to obtain more detailed and less publically available geological and geophysical (seismic, gravimetric etc.) data that it would also normally review for a project)
- Applying human geological/ hydrogeological expertise and LESSA software analysis to satellite images to quickly and efficiently divide a large area of land into manageable 'blocks'.
- Confirming that existing high-yield groundwater wells are generally confined to the cross points of large faults
- Assessing features of interest within the blocks (Block III in particular) to refine and focus the survey down still further to areas with a high potential to yield groundwater
- Identifying features of interest (lineaments, faults, etc.) that are associated with already known and utilised high-yield groundwater assets.

The outcome of this analysis is that the geological features identified by CSTP as indicative of groundwater potential were confirmed by existing well and GRIP data on the region. This collation with existing data validates CSTPs ability to locate groundwater in SA. Furthermore, some of the geological features (lineaments, etc.) identified by CSTP as indicants of potential groundwater sources had not been noticed or linked to water (in the existing data CSTP assessed). This firstly suggests that with further work in these areas, CSTP could locate novel groundwater sources in the Limpopo Province, and secondly that CSTP has a good chance of locating novel groundwater sources in the Northern Cape, where the sources of groundwater are mainly confined to fractured aquifers like in the Limpopo Province and where less water prospecting has been attempted and there is a higher likelihood of geological indicants like these having gone unnoticed or undiscovered.

8. Proposed Northern Cape Project

The geology of the Northern Cape Province consists of three different geological areas. In its south-east, the western part of the Karoo Basin[80, 81] is located; in the centre, Bushmanland roughly coincides with the basin of the Orange River[82] and north / north-east are occupied by the southern part of the Kalahari basin[83]. Respectively, the hydrogeological conditions differ too.

In the western part of the Karoo Basin are located the Dwaka glacial deposits from the Late Carboniferous to Early Permian ages with underlying deposits mainly presented by diamictite (tillite), glacial deposits of the Ecca group and formations of the Beaufort group presented by sandstones and mudstones. The Dwaka and Ecca deposits are usually characterised by very low hydraulic permeability, and the primary pores are practically absent. At the same time, such deposits may include sandstone bodies of limited distribution accumulated in glacial valleys. Generally, Dwaka and Ecca fractured aquifers are most important, although it is impossible to neglect some water-bearing bodies in sandstones. The Beaufort Group is presented by argilletes, clayey schales and fine-grained sandstones with very low primary permeability. The geometry of aquifers confined to these sediments is complicated, the water-bearing horizons are multi-layered; they are characterised by changing porosities and variable thicknesses and complicated by the lateral migration of meandering flows of subsurface waters. The contact planes between sedimentary layers determine breaks in the hydraulic properties of composite aquifers. Numerous sandstone bodies are presented. Such complicated structures of the aquifers of the Beaufort Group is complicated yet further by the fact that many coarse-grained and therefore more permeable sedimentary bodies have forms of lenses and by the extensive presence of various dykes, Drakensberg lavas, Karoo dolerites, Kimberlites and associated intrusive complexes.

Bushmanland features meta-sedimentary, meta-volcanic and intrusive formations by Namaqua, volcanogene-sedimentary deposits and granites of the Swazian-Randian age. Non-metamorphosed non-orogenic formations of the Koras group occur practically at the daylight surface and are only overlapped by thin (less than 100 m) irregular layers of Cainozoic, mainly alluvial deposits. In this scenario, fractured aquifers will play a determining role, but the alluvial aggradations mainly concentrated in the basin of Orange River and its tributaries are of significant interest.

The Kalahari Basin is quite a typical sedimentary one. Rocks dating from the Archaean to present are exposed on the edges of the basin as well as covered by Kalahari Group sedimentary rocks. Many of the rocks shown on the sub-Kalahari geological map record a history of rifting and subsequent collision, with the north-east and south-west trending structures appearing to have been reactivated at various times in the geological past. The lithologies have been intruded by dolerite dykes and sills and the massive Botswana Dyke Swarm. The surface of the Basin is overlapped by thick aeolian

[80] A.C. Woodfort and L. Chevallier (2002) Hydrogeology of the Main Karoo Basin; Current Knowledge and Future Research Needs. – WRC Report No. TT 179/02
[81] G. Van Todder (2012) Karoo Groundwater Atlas, SRK Consulting (Pty) Ltd., SRK Project Number 439159.
[82] J. R. Vegter, Hydrogeology of Groundwater, Region 26: Bushmanland, WRC, WRC Report No TT 285/06,
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deposits that are largely hidden by the underlying relief. Due to this fact, water prospecting in the area will be particularly difficult.

The preliminary survey carried out in the Limpopo Province (**Section 7**) has shown that CSTP's techniques can bring positive results, because disconnections of various sizes or other landscape reflections can be seen in space images either by direct or indirect indicants. It is also important that the technique used by CSTP uses the principle of sequential circumstantiation of the naturally ranked objects, controls reproducibility and reliability of the obtained results and confirms its results by independent methods.

8.1. Project Outline

As discussed in **Section 4.1.1**, CSTP's proposed IPP project in the Northern Cape could be split into two potential deliverables. The first deliverable would represent the results of CSTP's remote sensing analysis (satellite prospecting methods), then handed over to DWS to utilise as they feel necessary. The second deliverable would follow-on from the first to supply water to communities in need. This second deliverable would require heavy SA partner involvement to confirm the presence of groundwater and to build the necessary equipment (irrigation, well, decontamination, etc.) to facilitate its supply. Therefore the projections on the times and costs for the second deliverable will require further discussion with SA collaborators after this study and in the lead up to the IPP grant application.

For now CSTP will estimate the prospecting work and costs required for the first deliverable, the main objective being to apply CSTP prospecting methods to efficiently survey areas in the Northern Cape Province that are most likely to yield groundwater and to assess potential contaminants that may need to be considered before its use.

Stage	Task description	The expected results	Labour (Days)
1. Preparation	Accumulation and analysis of the initially available geological, geophysical, hydrogeological data and space images for the territory of the project (Northern Cape as a whole)	Adjusted and specified Technical assignment	40
2. Overview level	Specialised geological interpretation of the area at the general 'overview level'. Collation and correlation of the interpretation results with other existing geological and geophysical data at the 'overview level'.	Creation of an initial model of the territory by understanding the main regularities and revealing the fault & block structure. Preparation of the specialised space data originated geological map, scale 1:2,500,000.	60
3. Working level	Specialised geological interpretation of the area at a general 'working level'. Correlation of the interpretation results with other existing geological and geophysical data at a 'working level'.	Specialised space data originated geological maps, scale 1:500,000, for the areas specified in the adjusted Technical assignment (from stage 1).	100

4. Detailed level	Specialised geological interpretation of the area at a general 'detailed level'. Correlation, interpretation, and generalisation of all the data existing for the area. Detailed analysis of the existing hydrogeological data. If possible, a complete understanding of the water resources for the areas specified in the adjusted Technical assignment (from stage 1). Revealing of permeable 'living' faults by geomorphological and neotectonic indicants.	Specialised geological maps, scale 1:50,000 for the areas specified in the adjusted Technical assignment (≈ 10 % of the Province area) related to the geological structure and underground water prospects.	140
5.Permeability validation	If needed (to be determined in stage 4) the addition of a survey assessing the viability of some faults to contain water, through the inclusion of structural-atmosphere-hydrogeochemical analysis.	Creation of a scheme of permeable faults on a scale acceptable for the detailed survey.	Labour dependent on output from stage 4.
6. Finalising	Summary of the results of the survey carried out. Preparation of recommendations and the final report.	As possible, description of newly discovered water resources for the areas specified in the adjusted Technical assignment (from stage 1). Preparation of recommendations for detailed land-based surveys in the specified areas, before borehole drilling to confirm findings. Preparation of detailed forecast maps/models for the areas specified in the adjusted Technical assignment.	60
7. Training classes	Training local teams from DWS, CGS and SANSA to most effectively utilise CSTP findings and to implement some of the same techniques in the future.	Ensured sustainability of CSTPs services after the end of the IPP project.	20

*Table 8.1 An overview of the work (divided by stage) required by CSTP for the first deliverable (noted in **Section 4.1.1**), in the far right column is an estimate of the number of chargeable labour days required by CSTP members to complete the identified stage (this does not signify a completion or schedule time for the particular stage).*

Stage 1. Preparation

Accumulation and examination of the existing geological, geophysical and hydrogeological data including, if possible, data from gravimetric and magnetic surveys; geoelectrical prospecting data, topographic maps of different scales for the survey area; interpreted seismic lines and velocity depth models for the area; sections of deep wells and geological sections for the area. In case some of this data is absent or impossible to obtain, the survey may be carried out in any case, but its accuracy will be reduced. It is assumed that the data will be provided by DWS, WRC, CGS and their local divisions in the area under study. Starting from the Preparation stage and throughout the entire survey, participation of local geologists and hydrogeologists is preferable both because of their local knowledge and for the purposes of training them in CSTP techniques.

It is assumed that freely available Landsat data will be used to demonstrate that the simplest and most easily accessible data may be very helpful for water prospecting in SA. However, for some cases or some areas, high-resolution data, archived data for specific seasons and radiolocation images may be needed. It is planned to obtain such images with the help of SANSA.
Since we have proved that the hydrogeological situation (areas underground where water may have accumulated, charged, recharged, etc.) in the area corresponds closely with certain geological structures, the priority task for the analysis of existing data (provided by DWS, SANSA and CGS) is to reveal how the desired geological structures look in the landscape, to determine the indicants of such structures and to find evidence of them in landscapes.

At this stage, on the basis of available geological data with due attention to the socioeconomic needs of the local citizens, and in close cooperation with SA partners, smaller areas within the Northern Cape province shall be revealed, where groundwater is most desired and at the same time may have a reasonable potential for discovery.

Stage 2. Overview level

At this stage the interpretation of geological and geophysical data and the geological interpretation of space images are carried out for the creation of an initial geological model of the area. This is divided into separate tectonic blocks which have differences in geological structure and modern tectonics that predetermine the development of mainly accumulative or denudation processes with all hydrogeological consequences. It is possible at this stage to try to reveal the largest lineaments and their cross points that may reflect the zones of increased rock fragmentations, traces of valleys of large rivers and some other geological peculiarities of interrelated geological bodies.

Expert geological interpretation will be carried out at this stage for images taken at different times, images in various spectral bands, and images processed by LESSA software.

At the end of this stage, a specialised map will be created based on geological and geophysical data, and the interpretation of space images. This will reveal:

a. Tectonic objects that may relate to water-bearing properties of various scales.
b. The division of the territory into natural blocks of lower ranges that have their own tectonic, neotectonic, formation, hydrogeological and other important peculiarities.

The output of this stage of the survey should be a set of maps for the entire Northern Cape Province with indicated areas of priority for more detailed analysis. Such areas should be compare both on geological and socioeconomic grounds in cooperation with local partners.

Stage 3. Working level

At this stage work would be undertaken for each revealed block separately. The interpretation of space images would be carried out to reveal the most promising plots for water. However, the interpreted indicants for such plots will admittedly be different. For examples, in areas of relative submersion (so called 'closed areas') it will be most probably needed to use Synthetic Aperture Radar (SAR) satellite images and images taken in different seasons or in different parts of the spectrum. In the areas of relatively high elevation (so called 'open areas') the interpreted indicants of promising areas dependent on the development of different formations will also differ. In such areas, the statistical analysis of lineaments, alongside expert interpretation, would be applied.

In all cases, when made possible by the presence of geological, geophysical or hydrogeological data, the relevant analysis will be carried out.

At this point of the survey, it will be possible to reveal lineaments and their crossing points, as well as the territories of maximum ground moisture.

Stage 4. Detailed level

The surveyed targets at the detailed scale examines small areas (approximately 10 x 30 km – 30 x 50 km) with the highest potential for groundwater, which were revealed at the previous stage. For such small areas specialised geological interpretation shall be carried out, which, depending on the geological situation, may be concentrated on the fault & bock structure, on landscape characteristics, peculiarities of the vegetation cover, contours of hollows of temporary waterways and other peculiarities noted on space images that may indicate the possible presence of groundwater.

Stage 5. Permeability Validation

Detailed analysis of geomorphological and neotectonic peculiarities of areas in the majority cases also allows to determine some signs of small-size movements that may occur along revealed lineaments. Such movements and shifts cause an increase of fracturing and fissuring at the faults zone and, accordingly, an improvement in the water-bearing properties of the rocks. The neotectonically active disjunctives are revealed on the basis of their known and regular relations with some specific types of modern structures and relief forms. However, the local conditions do not always give the possibility to reveal 'alive' zones. The lineaments that are not 'alive' may be sealed in the course of geological history, and therefore miss their capability to contain any water; in such cases they should be excluded from further water prospecting.

For the cases where geomorphological and neotectonic analysis cannot prove movements along lineaments and therefore their probable permeability (hence their viability to yield water), the CSTP team proposes the use of structural-atmosphere-hydrogeochemical analysis: the emanation survey (radon, thoron) may be carried out for mapping zones of neotectonically active dislocations; results of the carbon dioxide survey indicates permeabilities of rocks within the survey area; revealed anomalies of helium close to the daylight surface display the ways of upward (along the permeable faults) transfer of fluids; the hydrogen survey indicates deep faults since hydrogen anomalies are characteristic for downthrow-type faults and absent in overthrust (compression) zones. Such types of gas analysis surveys represent a cheap and effective technique for mapping prospective plots for the presence of underground water.

Stage 6. Finalising

Like before, but on a larger scale, processing and calculating statistical characteristics will be carried out with help of LESSA software. The results of the expert interpretation of images and statistical calculations will be analysed together with all existing geological, hydrogeological, and geophysical data, and the forecasts related to potential of each area to yield useable water (for drinking, irrigation, sanitation, etc.) will be presented.

It is needed to mention that it is practically impossible to determine right now, without detailed examination of the local conditions within the Northern Cape Province, the exact areas, where the detailed prospecting shall be concentrated. As it was mentioned, the final decision shall be based both on hydrogeological and socioeconomic reasons and it should be taken in close cooperation with local partners. However, some preliminary ideas related to the subject have been suggested in this report. They may be based on the data related the status of groundwater resources in the area (**Figure 6.11**). It is possible to see that the general conditions of aquifers in the area and the degree of their local depletion differ significantly.

8.2. Notable Costs

The notable costs for the first deliverable are mostly incurred by CSTP, as its team would be doing the majority of the assigned work. Some of these costs can be roughly calculated from the labour figures estimated in **Table 8.1**. CSTP staff would have to field 4-5 permanent staff at a day rate of £680 for the IPP project, when applying this rate to the labour estimates for stages 1, 2, 3, 4, 6 and 7 a total price of **£285,600** is reached. This price discounts the work in stage 5 which is entirely dependent on the results of stage 4, but includes a project management rate of 10 days for each stage. From previous case studies, CSTP estimates that the first deliverable would take **12 months** to complete.

There will also be costs incurred by SA partners for the first deliverable, in terms of labour: SANSA would have to coordinate and manage interactions with other government departments, DWS would have to coordinate with local Northern Cape authorities and communities and CGS would have to coordinate with local teams of experts. SA partners would also have to provide data for CSTP to effectively apply its methods. These labour and material costs would be partly offset as in-kind contributions (required under the rules of the IPP), however the extent of this contribution and the labour estimates of SA partners can only be determined in future discussions leading up to CSTP's IPP application. Once SA partner assignments have been clarified for the first deliverable, appropriate GANTT charts and Work Packages can be drafted in preparation for the IPP application.

The estimates on time and budget for the second deliverable would require heavier interaction and planning with SA partners. It would also require a consultation with UKSA to determine its appropriateness for funding under the IPP (the IPP emphasises space based applications and the second deliverable is less 'space oriented' than the first). If it is deemed appropriate, CSTP could apply for IPP funding to cover the first and second deliverables together, or apply for separate IPP funding in a later call for the second deliverable.

9. Conclusions and Future Actions

CSTP is attempting to branch into a new line of business; it has previously been engaged in prospecting projects for minerals, oil and gas. Its experts are however also experienced in applying their methods to locate groundwater resources, and have successfully applied these methods in jobs and academic exercises before joining CSTP. After discovering the IPP grant (released by UKSA), which calls for space based applications to be used for humanitarian purposes in DAC listed countries, CSTP has seen an opportunity to apply the skills of its experts to prospect for water in regions of the world severely affected by drought, thus developing a novel branch of its business and helping communities in the process.

The only problem however, is that CSTP has no prior work to draw on in this field, which could reduce its chances of successfully applying for the IPP grant. Furthermore, as an SME working on narrow margins, it doesn't have the funds to trial its techniques ahead of its IPP application. Thanks to the Global Cooperation Feasibility Study released by Innovate UK, CSTP has been able to test the feasibility of it techniques in a foreign DAC country and make local contacts in government, space and geology that it will need to work in conjunction with to most effectively apply its methods.

To assess the feasibility of CSTP applying for IPP grant funding, to prospect for groundwater in Africa, this study attempted to answer the following objectives:

- **To define areas in Africa where CSTPs methods could most effectively be applied.**
    - This involved finding a country in Africa that is not only suffering significant negative effects from drought, but is also developed enough to source local experts able to assist CSTP, whilst still being on the DAC list. CSTP had already considered South Africa (SA) as having this ideal balance and the research in **Section 2** of this report confirms this. Despite countries in the horn of Africa being arguably some of the worst affected by drought, the section reveals that SA is also badly affected (both economically and societally) but is developed enough to commit funds towards direct aid and research, whilst still being on the DAC list.
- **To make necessary contacts in SA to aid CSTP's services and answer one of the main conditions of the IPP.**
    - As stated in **Section 3**, to prospect effectively for any resource, CSTP needs access to as much regional geological and geophysical data as possible, to complement its own satellite imagery analysis. It would also need contacts in government to provide permission to prospect and to communicate with local communities near to where it could potentially be drilling to validate its prospecting results. Cooperation with local government and industry is also a prerequisite for the IPP. CSTP therefore arranged a series of meetings in Pretoria with organisations it theorised could answer the criteria for an eventual IPP project.
    - As noted in **Section 5**, these meetings were a resounding success. Every contact proved valuable and agreed to sign either a MoU or letter of support stating their willingness to assist CSTP in an IPP project and detailing the nature of the collaboration. The three main collaborators turned out to be SANSA, DWS and CGS.
    - As the most space oriented contact and with ongoing experience in managing an IPP project, it was agreed that SANSA would be CSTPs primary contact for the IPP. As a

government department it would be able to liaise and apply management skills to coordinate the other SA collaborators. It could also possibly supply space data as an in-kind contribution to the project.
  - DWS would be able to offer advice on any legislation that may influence the IPP project and coordinate with local communities. It also has an extensive network of contacts and experts CSTP could draw on if needed.
  - CGS has access to the geological and geophysical data CSTP needs for its methods. It could also field local experts to confirm the presence of water and test for contaminants.
- **To perform some preliminary analysis on a region of SA to demonstrate the potential benefits of applying CSTPs methods in SA under the IPP.**
  - Following suggestions from both DWS and SANSA, along with in-house research conducted in **Section 6**, CSTP decided to focus this preliminary analysis on the Limpopo Province. The reasoning for this was due to the extensive geological data collected on Limpopo compared to any other Province, especially with regards to groundwater, because of national incentives like the Groundwater Resource Information Project (GRIP). There are therefore plenty of identified water resources in the region which CSTP could compare its own findings against for validation.
  - CSTP proceeded to apply the first stages of its methods on freely available Landsat data for the region. The analysis revealed geological features (lineaments, faults, etc.) that are known as indicants of groundwater resources. These results correlated with existing data on water well locations, thus demonstrating the potential for CSTP analysis to locate groundwater in the geology of SA. The results also highlighted certain geological features not linked to groundwater in any of the existing SA data assessed by CSTP, thus suggesting the value CSTP's prospecting methods could potentially add to those already being applied in SA.
- **To select an appropriate focal area within SA to implement the IPP project**
  - Having decided on SA for its prospective IPP project, CSTP consulted with its newly acquired SA contacts and performed some independent research in **Section 6,** to identify the most appropriate area in SA to focus its efforts for the IPP. The Northern Cape Province was identified as an outcome of this assessment.
  - This region of SA receives some of the lowest rainfall and highest temperatures in the country, resulting in minimal surface water resources (rivers, lakes, reservoirs, etc.). It also has the largest land area of any SA Province, coupled with the smallest population. As a consequence the Northern Cape has some of the most isolated rural communities in SA. Most of these communities also rely on agriculture as their main source of income, which is the second largest industry in the Province and the most water intensive industry in the country. This makes these people some of the most reliant on groundwater of any in SA. However, there is little geological data on the region, including data relevant to locating groundwater resources. It also receives little government support or international attention because of its low population and national GDP contributions.
  - Internal research (along with partner advice) suggests that a combination of all these factors makes rural communities in the Northern Cape stand to benefit most, in terms of a marked improvement in quality of life, from its groundwater

    - prospecting services. This justifiable potential for a measurable and positive humanitarian outcome directly answers the primary aim of the IPP grant.
- **To structure a project plan appropriate for the IPP application.**
    - This Innovate UK grant has given CSTP the time and resources needed to structure a project to answer the next IPP funding call. **Section 4** discusses the various criteria of the IPP grant and outlines the means by which CSTP can address them. Following internal research and collaborator suggestions, CSTP has decided on two potential deliverables that should satisfy the aims of the IPP.
    - The first deliverable utilises CSTPs three main partners (SANSA, DWS and CGS) to help apply CSTPs methods to the Northern Cape Province and produce a prospecting model that upgrades the geological data of the region, and which the main partners can use independently to efficiently locate novel groundwater sources. **Section 8** also goes on to break down the work required by CSTP for this deliverable and estimate the time (~12 months) and approximate costs (~£300,000 GBP).
    - The second deliverable follows on from the first, relying heavily on CSTP partner involvement to confirm CSTPs findings (by drilling exploratory boreholes), test for contaminants and design / build water supply systems (wells, irrigation and decontamination equipment, piping, etc.) to provide water to communities in need. This deliverable may however deviate too far from the interests of the IPP as it is less reliant on space based applications (with CSTP performing more of a higher level management role).
    - CSTP was also able to design a collaboration network (**Figure 4.1**) to implement the IPP project and substantiate its practicality with the main collaborators involved, refining it where necessary.

In conclusion, all the objectives set out for this study were achieved and CSTP is now in a better position to apply for IPP grant funding. Two potential deliverables were suggested as outputs for a prospective IPP project. However as for **future actions**, CSTP will have to consult with its collaborators and the IPP staff at UKSA to decide if its second suggested deliverable realistically fits the aims of the IPP. CSTP would also need liaise with its partners for the first deliverable and decide what IPP budget they will need to supply the work and resources required for the project. CSTP will finally have to construct an application for the IPP (referring to the work in this study) when the next call is released. The work in this study could also be used by CSTP to apply for other potential funding sources, such as Innovate UK's 'Emerging and Enabling' grant.

If CSTP is unsuccessful in attracting grant funding in the near future, this study will still be valuable as a comprehensive example of its services, which can be displayed to potential commercial customers.

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