Department of Agriculture, Forestry and Fisheries

FINAL REPORT

Manual Digitizing of Gully Erosion in South Africa Using High Resolution SPOT 5 Satellite Imagery at 1: 10 000 Scale

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Other correct citation specifically for Eastern Cape and Kwazulu Natal data is as follows:

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EXECUTIVE SUMMARY

Soil erosion is an important form of land degradation and is among South Africa's most critical environmental issues. Gully erosion (in addition to sheet and rill erosion) has been identified as being a major source of sediment entering waterways in many catchments in South Africa (SA). However, previous erosion studies conducted at a regional scale emphasized the interrill and rill aspects of erosion, whereas none mapped gully erosion. Therefore, very little is known regarding the spatial distribution or density of gullies at regional scales, especially at provincial and/or national scales. In order to obtain an understanding of the spatial extent of gully erosion problem, this project was initiated and the purpose was to map gully erosion in SA using high resolution SPOT 5 satellite imagery, at a scale of 1:10 000. Classification algorithms appropriate for gully erosion mapping were investigated hoping that it will achieve higher accuracy and at the same time speed up the process. However, due to the spectral complexity of gullies, challenges of distinguishing gullies and the surrounding areas and low accuracy of classification techniques, it was decided to map gullies through manual digitizing. Gullies were visually identified using SPOT 5 (2006 – 2008 images) as a backdrop in ArcMap and boundaries of gullies were delineated by hand.

The results show that all Provinces are affected by gully erosion. The Northern Cape (160 885 ha) and Eastern Cape (151 759 ha) Provinces are the most severely affected, followed by Kwazulu Natal (87 522 ha), Free State (64 674 ha), Limpopo (58 669 ha), Western Cape (25 403 ha), Mpumalanga (17 420 ha), North West (10 782 ha) and Gauteng (110 ha) Provinces. Although the methodology followed was straight forward, some challenges were encountered, such as distinguishing gullies with natural river channels, distinguishing gullies with flooded areas, distinguishing gullies and landslides, distinguishing gullies with bare soil, distinguishing gullies with other erosion forms and mapping gullies with high vegetation cover. Since there are no previous gully erosion maps available at a regional scale for South Africa, verification was based on field observations of gullies adjacent or near roads during 2008 to 2010. Field observation indicates that 89% of gullies visited in the field were correctly interpreted or captured by the interpreters, proving to be superior to previous modelling approaches.

The limitations of this study include subjectivity during interpretation by the gully erosion interpreters, it was not possible to visually delineate different categories of eroded lands (e.g. active or non-active gullies), and only a qualitative appreciation of the factors influencing gully behaviour was obtained with the processes behind gully erosion remaining poorly understood. For example, it is postulated that many erosion features in the Northern Cape Province are of considerable age and may not be contributing to current sediment yields. In contrast, observations in the field and several other sources of literature indicate that several gullied areas in the Eastern Cape are active and contribute to current sediment yields.

Recommendations include estimation of the degree of erosion in conjunction with collateral classification techniques and the quantification of the influence of factors in gully development. Quantifying the influence of factors in gully development will facilitate the selection of suitable alternatives for preventing or reducing soil loss, especially at municipal and provincial levels.

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PART 1: INTRODUCTION

1.1.Background Information

Soil erosion is an important form of land degradation and is among South Africa's (SA) most critical environmental issues (Le Roux *et al*., 2010). Soil erosion refers to the detachment, transportation and deposition of soil particles from one place to another through water, wind and gravitational forces. Soil erosion may occur naturally, referred to as geologic erosion, or may occur as a result of human activities, referred to as accelerated erosion. Geologic erosion refers to the natural balance of the rate of soil loss and soil formation (Omuto *et al*., 2009). Accelerated soil erosion is a normal process of erosion, increased in magnitude and frequency by human actions through creating erosive situations such as clearing of vegetation for cultivation, overgrazing and roads construction (Lindemann & Pretorius., 2005). Soil erosion results in loss of fertile top soil and decreased soil productivity coupled with serious off-site impacts related to increased mobilization of sediment and delivery to rivers. As a result, eroded soil material leads to sedimentation/siltation of reservoirs, as well as an increase in water pollution due to suspended sediment concentrations in streams.

One of the strategic goals of the Department of Agriculture, Forestry and Fisheries (DAFF) is the sustainable management of natural resources (DAFF, 2010). Soil is an important natural resource especially in agriculture and has a wide variety of other functions, however degradation problems such as soil erosion undermine soil sustainability to provide a variety of functions. In light of this, DAFF, through its Directorate Land Use and Soil Management (LUSM) has initiated soil protection programme in order to develop effective and efficient policies and strategies to address soil from degradation. One of the short term interventions proposed was the identification of priority areas and mapping of land use and soil erosion status (Lindemann & Pretorius, 2005). It has been mentioned that before remediation and prevention of soil erosion is undertaken, spatial extent of the problem has to be established (Le Roux *et al*., 2006, Marker & Sidorchuk, 2003). In SA, there is a lack of detailed information regarding the spatial extent, type and severity of soil erosion. The most recent study applied a simplification of the Universal Soil Loss Equation (USLE) to the whole country, emphasizing the sheet and rill aspects of the erosion cycle (Le Roux *et al*, 2008b). Gully erosion is not accounted for by the USLE model mainly because the process of gully development is too complex and involves a combination of processes outside the scope of the model (Le Roux *et al*., 2006).

1.2. Aim and Objectives of this Study

The main aim of this study was to map and determine gully erosion status per Province using SPOT 5 satellite imagery at a scale of 1:10 000. This aim was achieved through meeting the following objectives:

- Evaluation of automatic gully erosion extraction techniques;
- Mapping of all visible gully erosion per Province through manual digitizing;
- Verifying gully erosion maps at selected study sites through field observation;
- Compute gully erosion statistics in all Provinces.

Sheet and rill erosion were not mapped in this study because they could not be interpreted from SPOT 5 imagery with the required accuracy. It was deemed impossible to discern and delineate the boundaries of sheet and rill erosion because of usual gradual changes from eroded to bare and to vegetated areas.

Mapping of gully erosion will allow DAFF and other land managers to allocate and implement erosion control measures in priority areas, thereby developing local capacity and employment. The outcome of this study will also be useful for comparison purposes with other data from projects within and outside DAFF such as national land degradation assessment.

1.3. Gully Erosion Process

Gully erosion is a process whereby surface (or subsurface) water concentrates in a narrow flow paths and removes the soil, resulting in incised channels that are too large to be destroyed by normal tillage operations (Kirkby and Bracken, 2009). Gullies normally occur along drainage lines, caused by water action and are the most apparent soil erosion feature in a landscape. Gullies extend and deepen in an up-valley direction by waterfall erosion and progressive collapse of their upslope parts. Gully sides may collapse by water seepage or undermining by water flow within the gully. They tend to form where land slopes are long and land use has resulted in loss of vegetation and exposure of the soil surface over a large area so that the land now produces more runoff. They are particularly prevalent in deep loamy to clayey materials, in unstable clays (e.g. sodic soils), on pediments immediately downslope of bare rock surfaces and on very steep slopes subject to seepage of water and to landslides (Stocking & Murnaghan, 2000). According to Geyik (1986) gullies may be classified as continuous or discontinuous. Continuous gullies have many branches, main channel and many mature or immature branches. A gully network or gully system is made up of many continuous gullies and a multiple gully system may be composed of several gully networks. Discontinuous gullies are also known as independent gullies and may develop on a hillslope after a landslide. During its initiation, a discontinuous gully does not have a distinct connection with the main gully or stream channel. There may be water flow in discontinuous gullies spreading over a nearly flat area and after some time it reaches the main gully channel or stream. Discontinuous gullies may be scattered between branches of a continuous gully or they may occupy an area where no continuous gullies are present.

Gully erosion has been identified as a major source of sediment entering waterways in many catchments in SA, especially the Eastern Cape and KwaZulu-Natal Provinces (e.g. Flügel *et al*., 2003; Le Roux *et al*., 2008a). Gullies can also damage structures such as houses, roads, bridges and fences.

1.4. Mapping Gully Erosion

Conventionally, gullies were mapped using mainly aerial photographs (e.g. Betts & DeRose, 1999). According to Bergsma *et al* (1996) it is easier to map gullies with the use of aerial photographs than ground surveys. Recognition of gully erosion is not difficult on large and medium scales of airphotos. The following properties are generally used to recognize gully erosion on aerial photographs at scales 1:10 000 to 1: 40 000: greytone, pattern, position, stereodepth and vegetation. The main disadvantage of using aerial photography is that they do not provide complete coverage of a larger area compared to satellite derived imagery. The problem with satellite-derived imagery (until recently), was that the course resolution of imagery (e.g. Landsat TM is 30m) made it difficult or impossible to detect individual gullies. For example, Le Roux *et al*. (2008a) could not delineate single and/or small gullies using Landsat TM data due to its limited resolution. Landsat sensors could only detect pixels that are affected by erosion and could not distinguish between erosion and bare soil. However, the development of new sensors such as SPOT 5 provides fine scale imagery that greatly improved gully mapping efforts both visually and automatically.

The most important characteristics of remote sensing instruments for gully erosion mapping are spatial, spectral and temporal resolution (Taruvinga, 2008). Spatial resolution is a limit on how an object on the earth surface can be represented by a single pixel in an image (Lillesand *et al*., 2008). Images with higher spatial resolution allow classification technique to detect a smaller feature. For example, Pirie (2009) indicated that gully erosion smaller than 10m cannot be detected using SPOT 5 imagery because each pixel is 10m x 10m, therefore smaller gullies become embedded within the pixel. Spectral resolution refers to the response of different features to distinct wavelength ranges (Aggarwal, 2004b). Spectral characteristics of gullies vary, because some gullies may contain vegetation and some may be un-vegetated (Taruvinga, 2008). Furthermore, the spectral signature of bare soil or un-vegetated gully is dependent on the moisture content, organic matter content, texture, structure and iron oxide content. Spectral characteristics of vegetation vary with wavelength. Plant pigment leaves strongly absorb red and blue wavelengths but reflect green wavelength (Aggarwal, 2004a). Temporal resolution is the capability of a satellite to scan exact area at different times (Aggarwal, 2004b) and it offers possibility of monitoring gully erosion over time (Taruvinga, 2008).

Most environmental applications of remote sensing rely on visual image interpretation (Chipman, 2006). Basic characteristics used to visually interpret satellite images include object shape, size, pattern, tone or hue, texture, shadows, site, association and resolution. Characteristics that are useful in interpreting gully erosion visually from a satellite image include tone, pattern and association. Tone refers to the brightness of object on an image. Pattern is the spatial arrangement of objects. Association is the occurrence of certain features in relation to others (Lillesand *et al*., 2008). Gullies that are characterised by bare soil appear bright in visible red and infrared portion of electromagnetic spectrum. Gullies follow drainage patterns such as dendritic, parallel, radial, centrifugal, centripetal, distributaries, angular, trellis and annular (Taruvinga, 2008). As indicated earlier, gullies occur along drainage lines and are caused by water action (Stocking & Murnaghan, 2000).

PART 2: METHODOLOGY

2.1. Alternative Gully Erosion Mapping Methodologies

This study searched literature for successful methodologies to map water erosion features, especially gullies, by means of satellite remote sensing at a regional scale, referred to in here as automatic gully erosion extraction. Additionally, other methodologies for mapping gully erosion were investigated.

The study of Taruvinga (2008) evaluated semi-automatic methods of mapping gullies in a tertiary catchment in KwaZulu-Natal. More specifically, the study evaluated the level of accuracy that Landsat TM can map gullies using semi-automatic methods, as well as whether higher spatial resolution SPOT 5 imagery could be used to delineate gullies using classification algorithms. Surprisingly, the study illustrates that medium resolution (30 m) Landsat TM data imagery outperformed the higher resolution (10 m) SPOT 5 imagery for mapping gullies using several classifiers (i.e. maximum likelihood, minimum distance and support vector machine). One would have anticipated that the SPOT 5 image would produce a more accurate classification due to its finer spatial resolution. However, Taruvinga (2008) states that the spectral resolution (7 bands) of Landsat TM was more important for identifying the gullies due to the large spectral variability within the gullies. Taruvinga (2008) explained that the heterogeneity of gullies made it difficult for the classifiers to identify gullies if less spectral information is provided as in the case of SPOT 5 which only provides 4 spectral bands. Best results achieved were with Landsat TM combined with the Support Vector Machine (SVM) with a Kappa-statistics-derived accuracy of 0.6. The SVM represents a group of theoretically superior machine-learning algorithms that aim to determine the location of decision boundaries that produce the ideal separation of classes (Huang *et al*., 2002). SVM classification can be further defined as a nonparametric classifier that attempts to separate the different classes by directly searching for adequate boundaries between them. According to Vapnik (1998; cited in Taruvinga, 2008), SVM does not rely explicitly on the dimensionality of the training data but uses pattern recognition, regression, and density estimation in high-dimensional spaces to separate the classes.

Since the SVM classification algorithm produced the highest accuracy for mapping gullies in the above-mentioned study, the current study also performed and evaluated additional, but similar, techniques of classification to map gullies. In collaboration with Geoterraimage (Pty) Ltd., segmentation vector data models were derived from SPOT 5 multispectral imagery (3 bands at 10 m resolution) using object-based modelling, i.e. eCognition software. In short, eCognition software attempts to identify surfaces and objects within images, and compute contextual information with which these objects can be attributed to classes (Eloff, 2006). The methodology is also referred to as Object Oriented Image Analysis and is described in more detail in Lück (2002). In the current study, segmentation vectors were derived for a small area (subset) located in a tertiary catchment (T35) in the Eastern Cape Province. More specifically, Geoterraimage (Pty) Ltd. applied two spatial levels of segmentation (with an index of 20 and 50) to SPOT 5 multispectral data to visually assess model performance at gully detection. The segmentation vectors were assumed to represent homogenous landscape units, including individual gullies or different fractions of a relatively large gully (see Figure 2.1). In order to reduce processing time and refine/focus thematic class boundaries to relevant eroded areas, the above-mentioned procedures were applied to only bare soil areas. Bare soil masks were created by the co-author by means of the transformed soil adjusted vegetation index (TSAVI) applied on a Landsat TM image covering catchment T35. However, even after reducing the extent to bare soil areas, only small subsets could be individually segmented at the required spatial level. Therefore, it was decided not to continue with segmentation as it would require large amounts of pre-processing when applied at provincial scale.

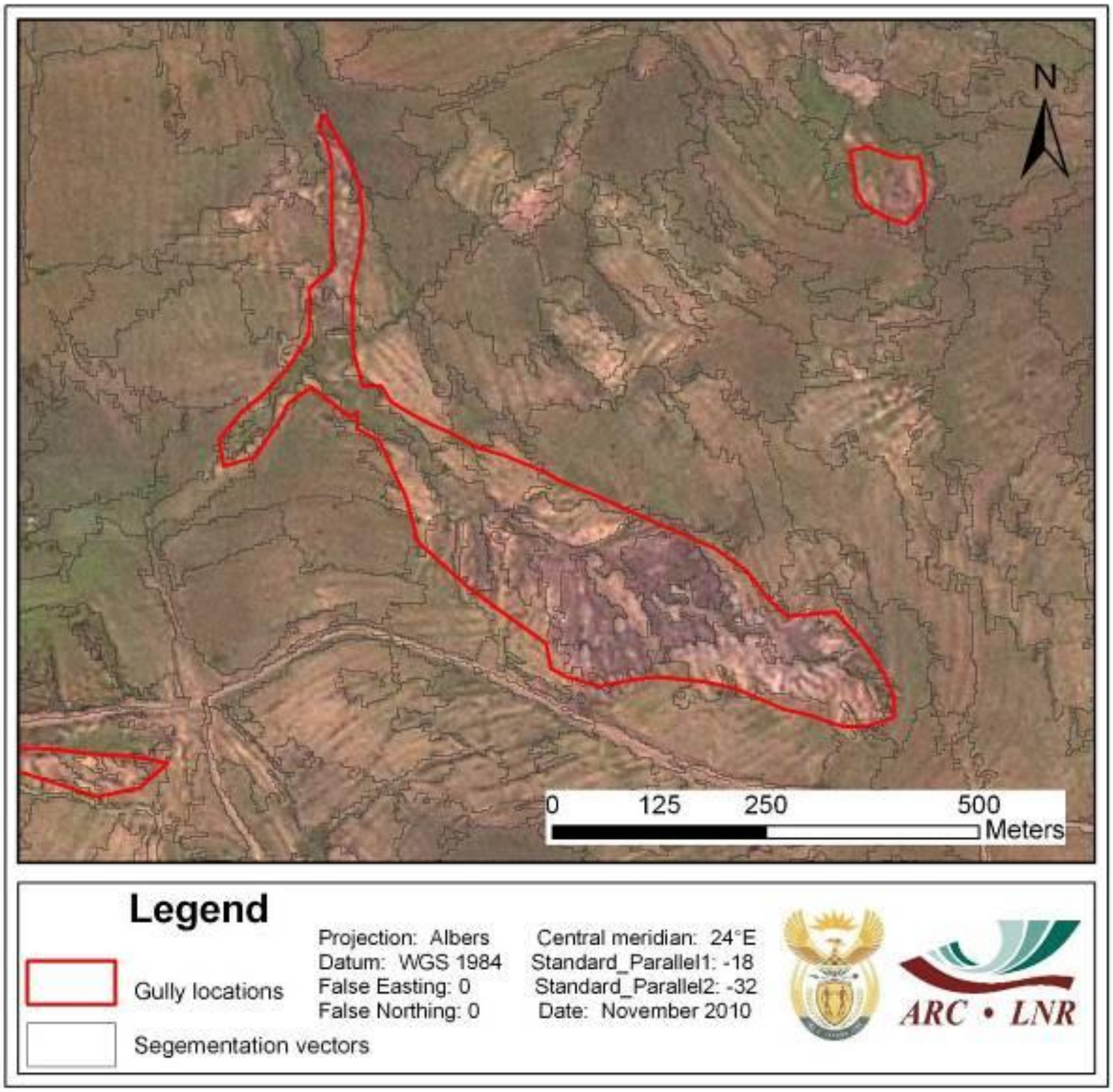

Figure 2.1: Segmentation vectors (with an index of 50) derived for a small area located in a tertiary catchment (T35) in the Eastern Cape Province (after Le Roux *et al*., 2010).

Technique investigated by the main author is imagine objective tool of ERDAS Imagine 2010 software. Imagine objective is an automated feature extraction model that incorporates many image processing techniques such as image segmentation, threshold or clump etc. (Phan *et al*., 2009). The tool was evaluated in a selected area of Capricorn District Municipality, Limpopo Province. The area was chosen because it is severely affected by gully erosion ranging from small (discontinuous) to large (continuous) gullies (as shown in figure 2.2) within a well differentiated and diverse land use patterns. The functionalities of imagine objective implemented include single feature probability, threshold and clump, probability filter, size filter, island filter and ribbon: width minimum/maximum. The results were compared with manual digitized gullies (figure 2.2) and produced a kappa statistics accuracy of 0.52, which is considered moderate correlation. Imagine objective maps contained both continuous and discontinuous gullies as shown in figure 2.3. Detailed information regarding mapping of gullies using imagine objective tool is available in Mararakanye (2011). Although this tool offered a prospect of mapping gully through classification technique, it was not tested in other areas because of the unavailability of license for the tool. Imagine objective required a specific tool licensing which DAFF currently do not have. For purposes of the mentioned study, imagine objective was evaluated using the trial version of ERDAS Imagine 2010.

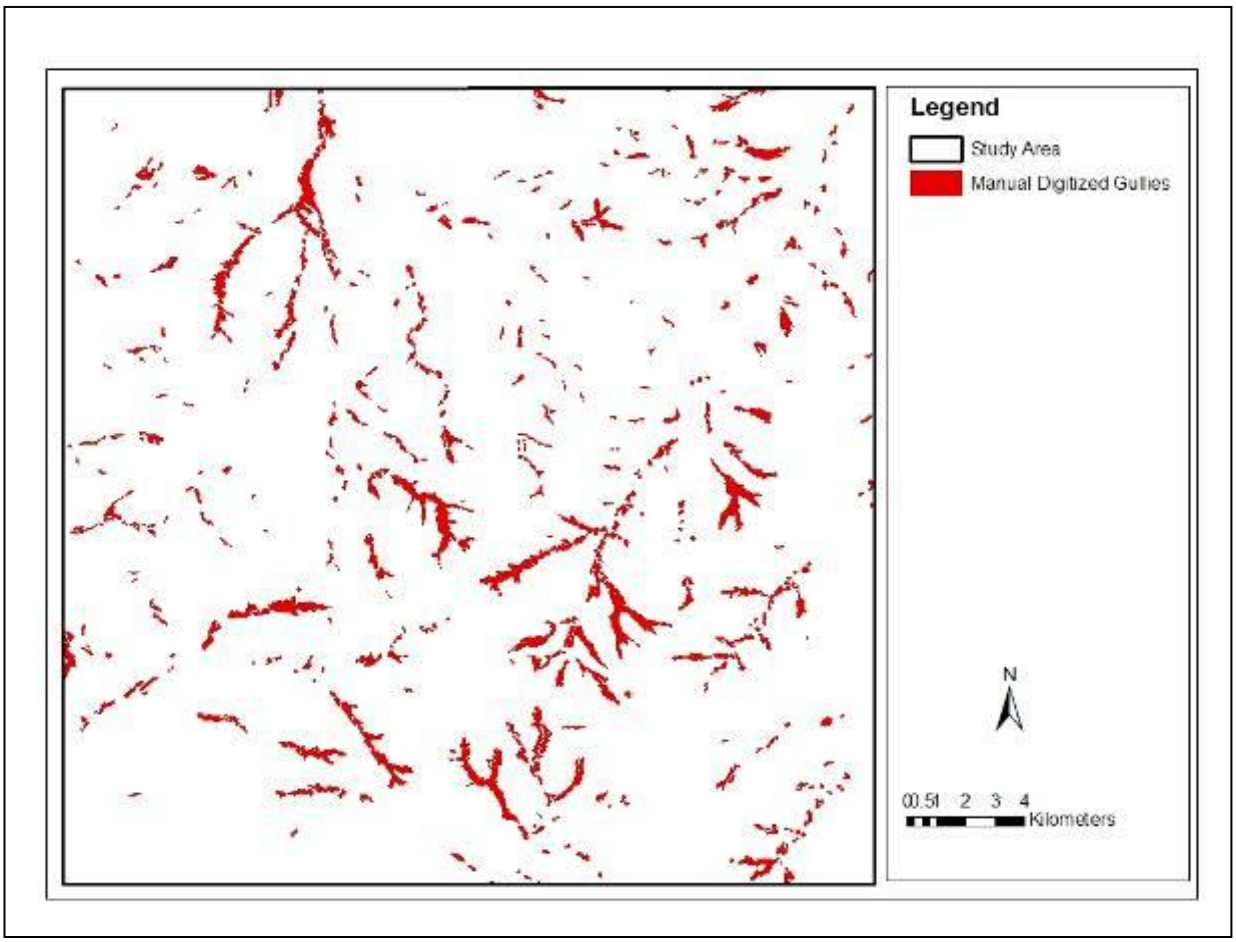

Figure 2.2: Manual digitized gully erosion map in the selected area of Capricorn District Municipality, Limpopo Province.

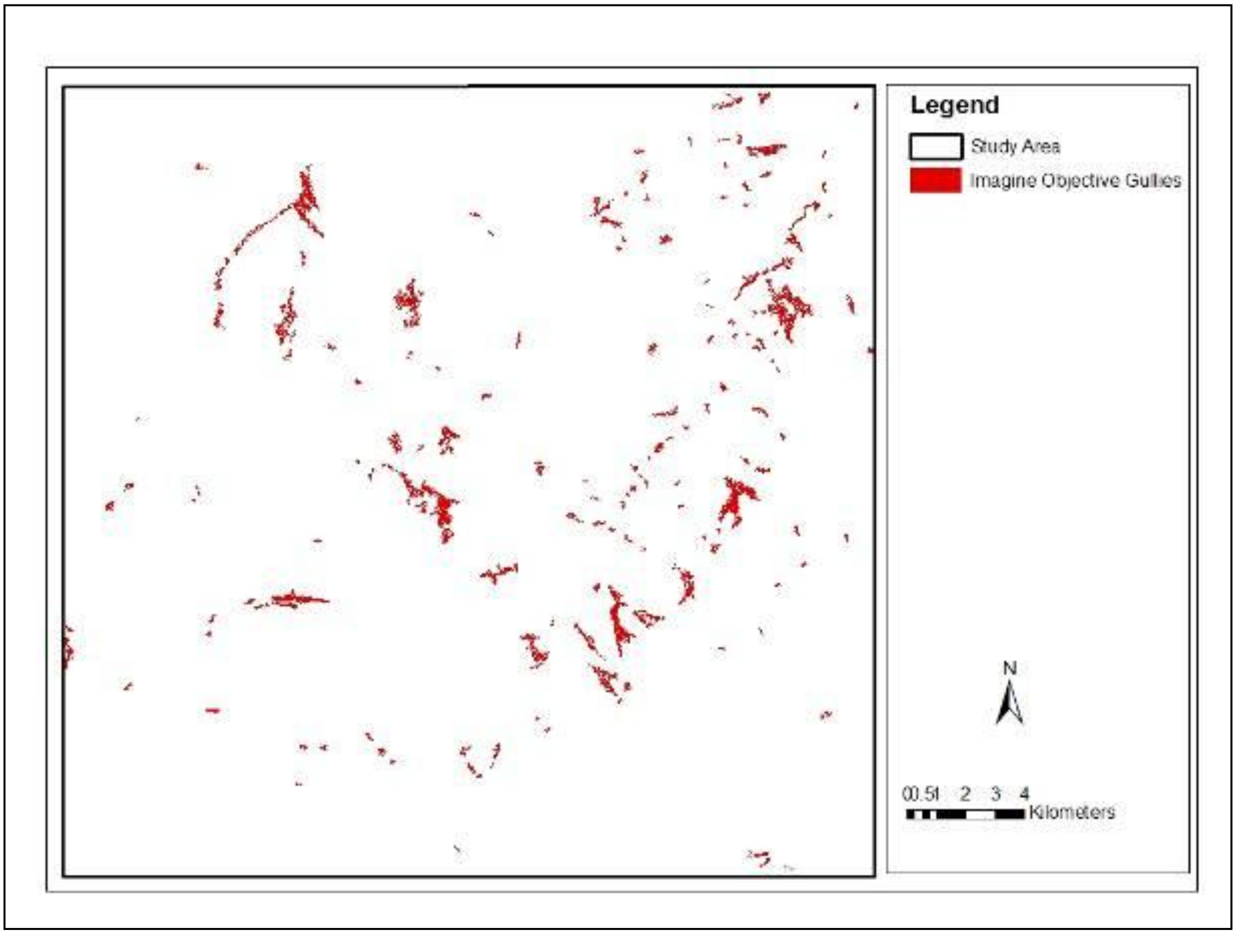

Figure 2.3: Imagine objective gully erosion map in the selected area of Capricorn District Municipality, Limpopo Province.

Seed tool in ERDAS Imagine 2010 software was also evaluated by the main author for the purpose of gully erosion mapping (Mararakanye, 2011). In seed tool, gullies are mapped by selecting a pixel inside a gully, from which the whole gully is then automatically grown based on the spectral properties of the surrounding pixels. The spectral distance (digital number) from the mean of the seed properties is referred to as the Spectral Euclidean Distance (SED). The digital number selected by the user depends on the variations between the gully and gully-free areas. Figure 2.4 shows the results of seed tool gully mapping in the selected area of Capricorn District Municipality, Limpopo Province. The kappa accuracy achieved is 0.86, showing strong correlation with manual digitized data. This tool, however, has to be applied manually to each and every individual gully, and is therefore not an automated technique. Although this method is more accurate, it proved to be time consuming and sometimes gully do not grow entirely and required more than one application.

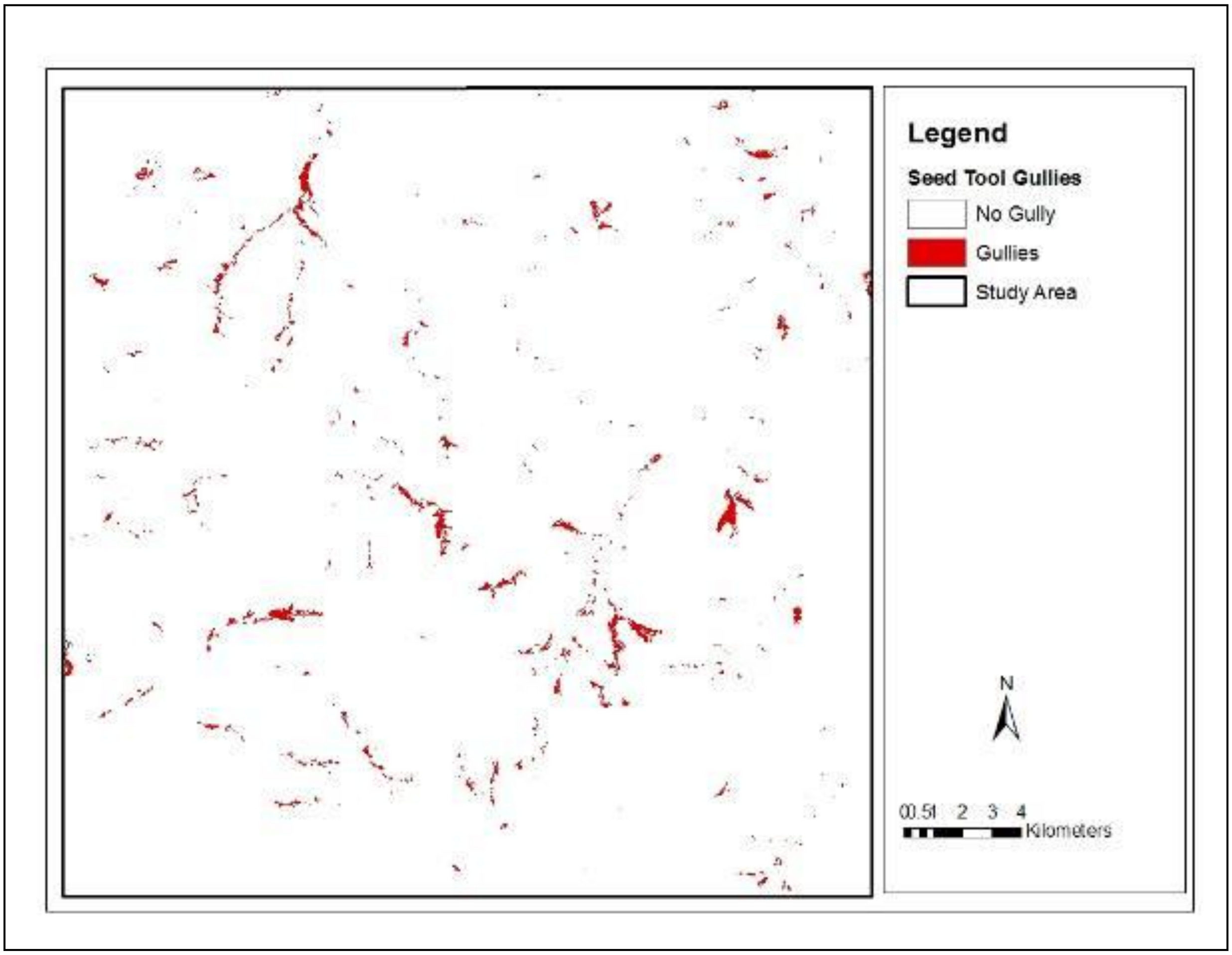

Figure 2.4: Seed tool gully erosion map in the selected area of Capricorn District Municipality, Limpopo Province

Automatic extraction speeds up the processing of data for large areas and excludes subjectivity of manual interpretation due to its quantitative procedure (Fulajtar, 2001). As a final point, mapping gullies using classification algorithms highlighted the spectral complexity of gullies and the challenges faced when trying to distinguish them from the surrounding areas. As a result, much higher accuracies are achievable by conventional mapping techniques compared to automated techniques (Le Roux *et al*., 2008a; Taruvinga, 2008; Pirie, 2009; Mararakanye, 2011).

2.2. Manual Digitizing of Gully Erosion Methodology

Gully erosion mapping in this study was based on visual interpretation and vectorization of SPOT 5 imagery (panchromatic sharpened images at 2.5 m resolution and multispectral bands merged with panchromatic bands at 5m resolution) from various acquisition dates in 2006 to 2008 for the entire country. SPOT 5 satellite imagery was utilized because it has already been acquired by governmental agencies for the whole of SA and provides high resolution air photo-like quality for gully mapping (Le Roux *et al*., 2008a; Taruvinga, 2008). Furthermore, compression of imagery (i.e. to enhanced compressed wavelets) made it possible to rapidly and simultaneously view several images as one layer in a seamless coverage (i.e. using Image Catalogue developed as an extension in Esri® ArcMap software). In order to ensure that the full extent of both Provinces is roamed at a scale of 1:10 000, an annotation layer in the form of a series of vertical and horizontal lines was created using Hawth's Analysis Tools (developed as an ArcGIS 9.3 extension). Gullies were mapped by delineating the outer boundary of a gully banks from SPOT 5 satellite images in ArcMap and were identified by their tone, shape, drainage pattern and association.

Although the viewing procedure was quite simple, gully interpretation or detection often required verification in the field and high-level scrutiny from experts. For example, it was sometimes difficult to distinguish between:

- Gullies and natural river beds/channels (see figure 2.5);
- Gullies and flooded areas/floodplains (see figure 2.6);
- Gullies and landslides (see figure 2.7);
- Gullies with vegetation cover (see figure 2.8);
- Gullies imbedded in bare soil areas (see figure 2.9);
- Gullies and other erosion forms (e.g. severe sheet and rill erosion) (see figure 2.10).

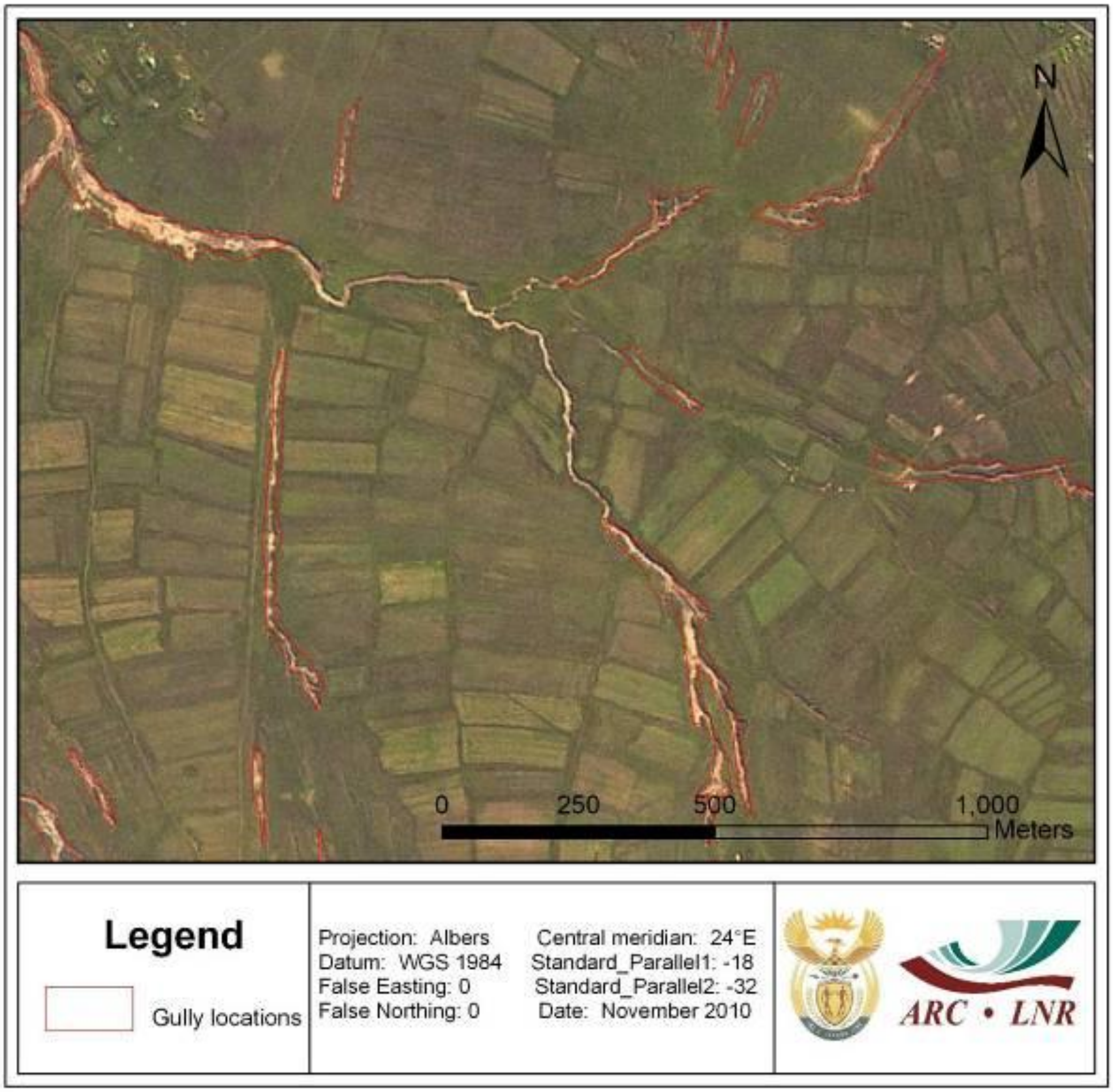

Figure 2.5: Gullied and gully-free river channels as visualized from SPOT 5 imagery near Nqutu in KwaZulu-Natal (after Le Roux *et al*., 2010).

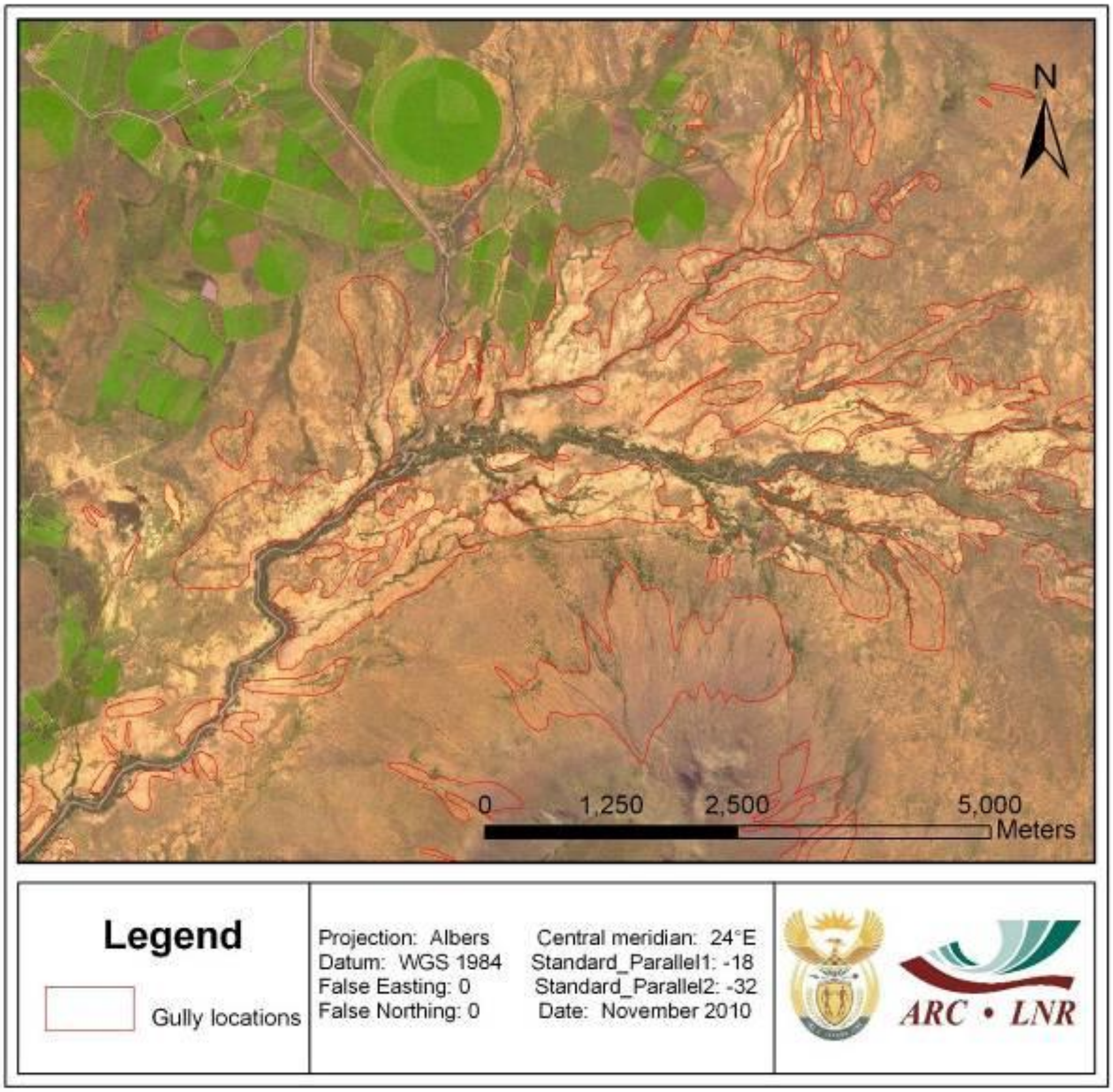

Figure 2.6: Gullied floodplain as visualized from SPOT 5 imagery near Steynsburg in the Eastern Cape (after Le Roux *et al*., 2010).

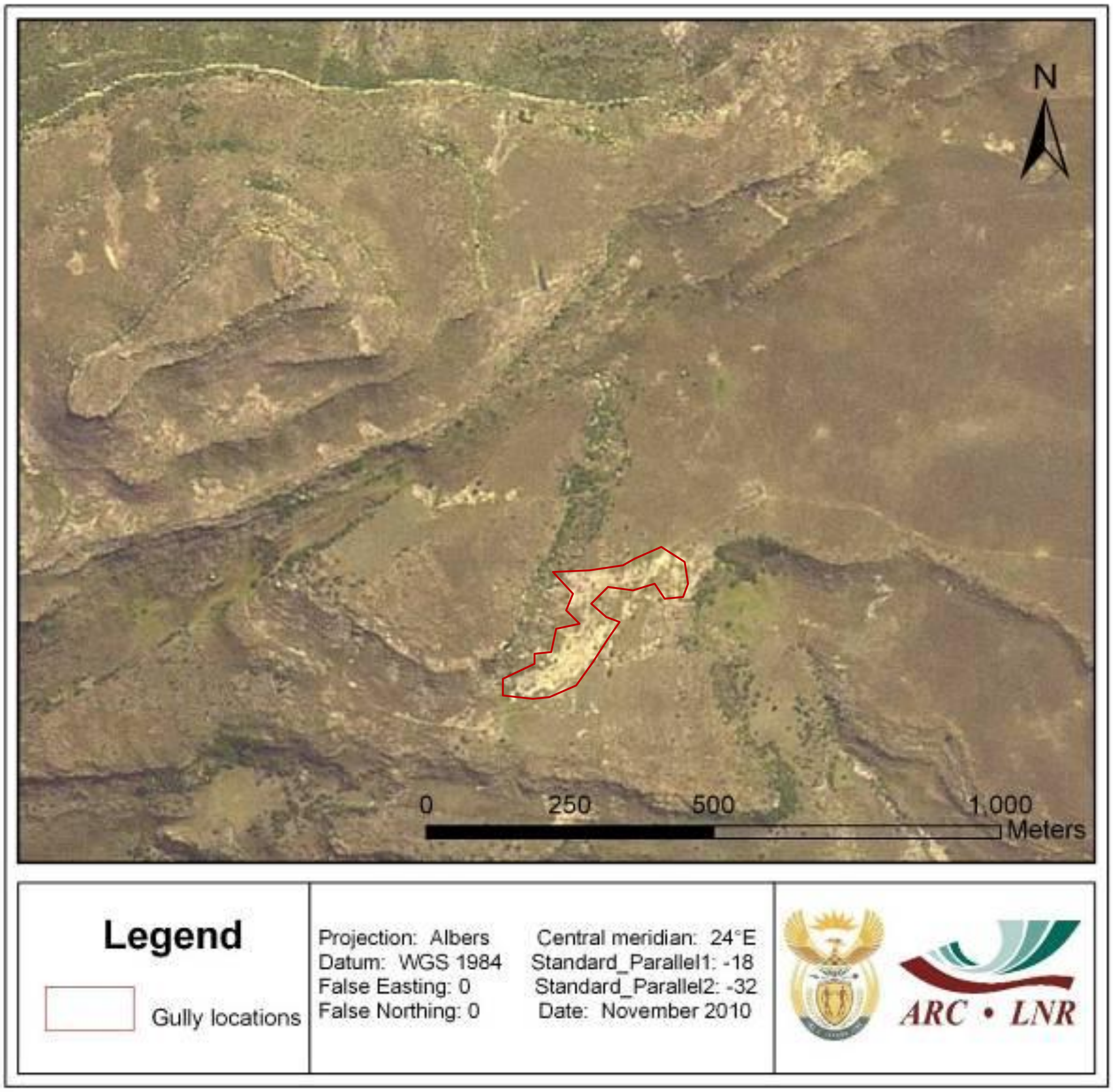

Figure 2.7: Landslides (with gully appearance) as visualized from SPOT 5 imagery near Aliwal North in the Eastern Cape (after Le Roux *et al*., 2010).

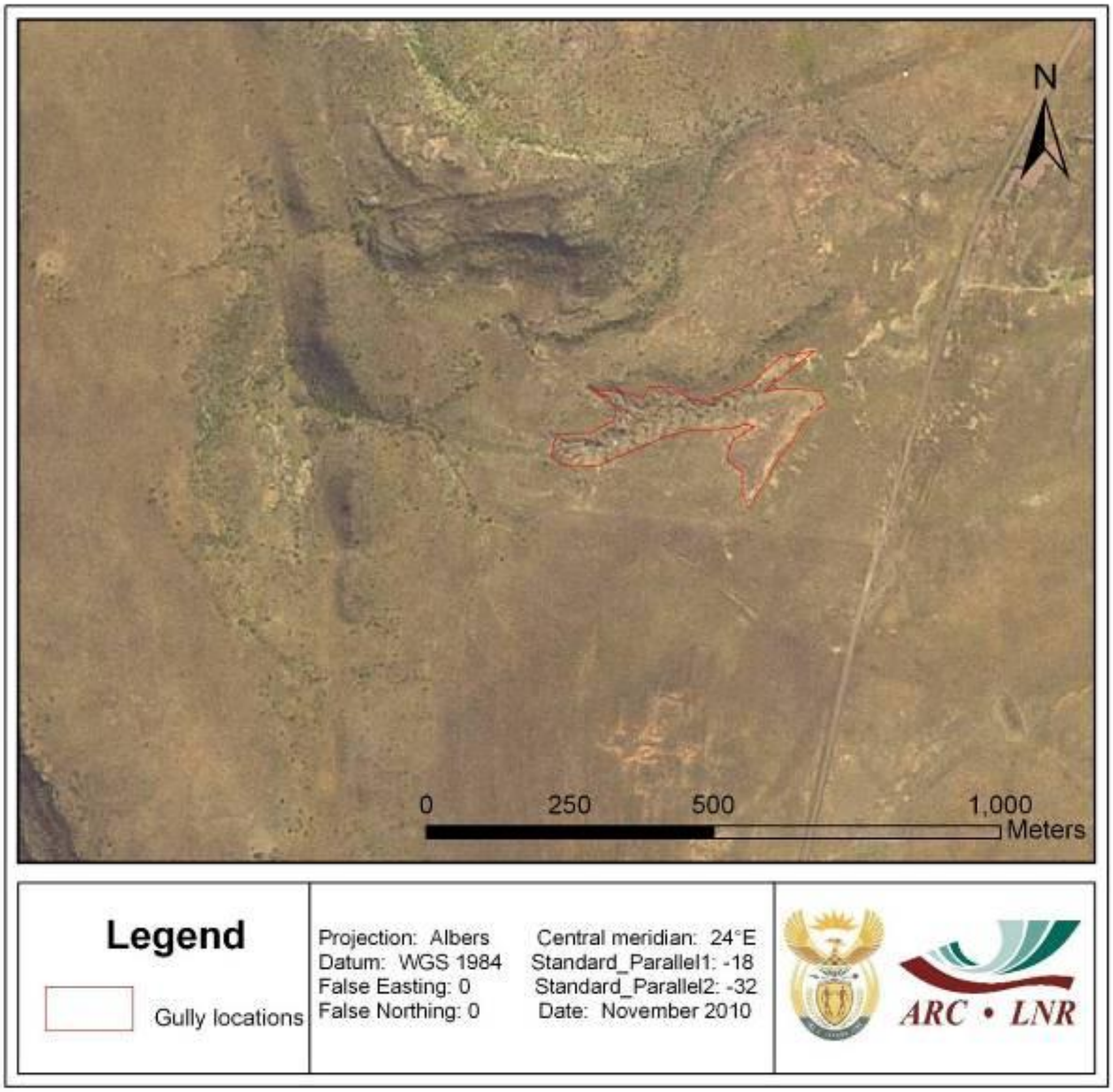

Figure 2.8: Gullies with good vegetation cover as visualized from SPOT 5 imagery near Aliwal North in the Eastern Cape (after Le Roux *et al*., 2010).

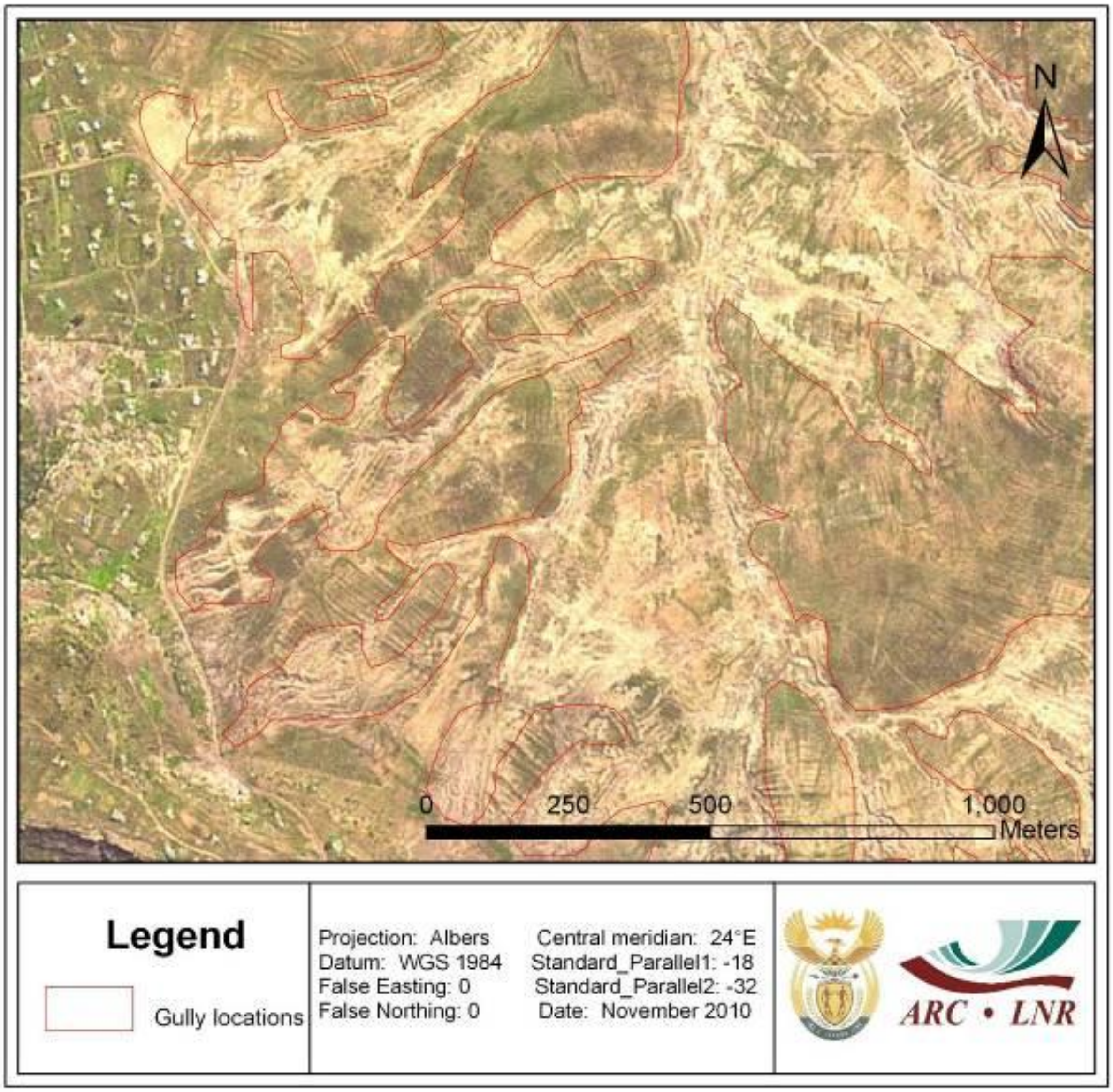

Figure 2.9: Gullies imbedded in bare soil areas as visualized from SPOT 5 imagery near Sterkspruit in the Eastern Cape (after Le Roux *et al*., 2010).

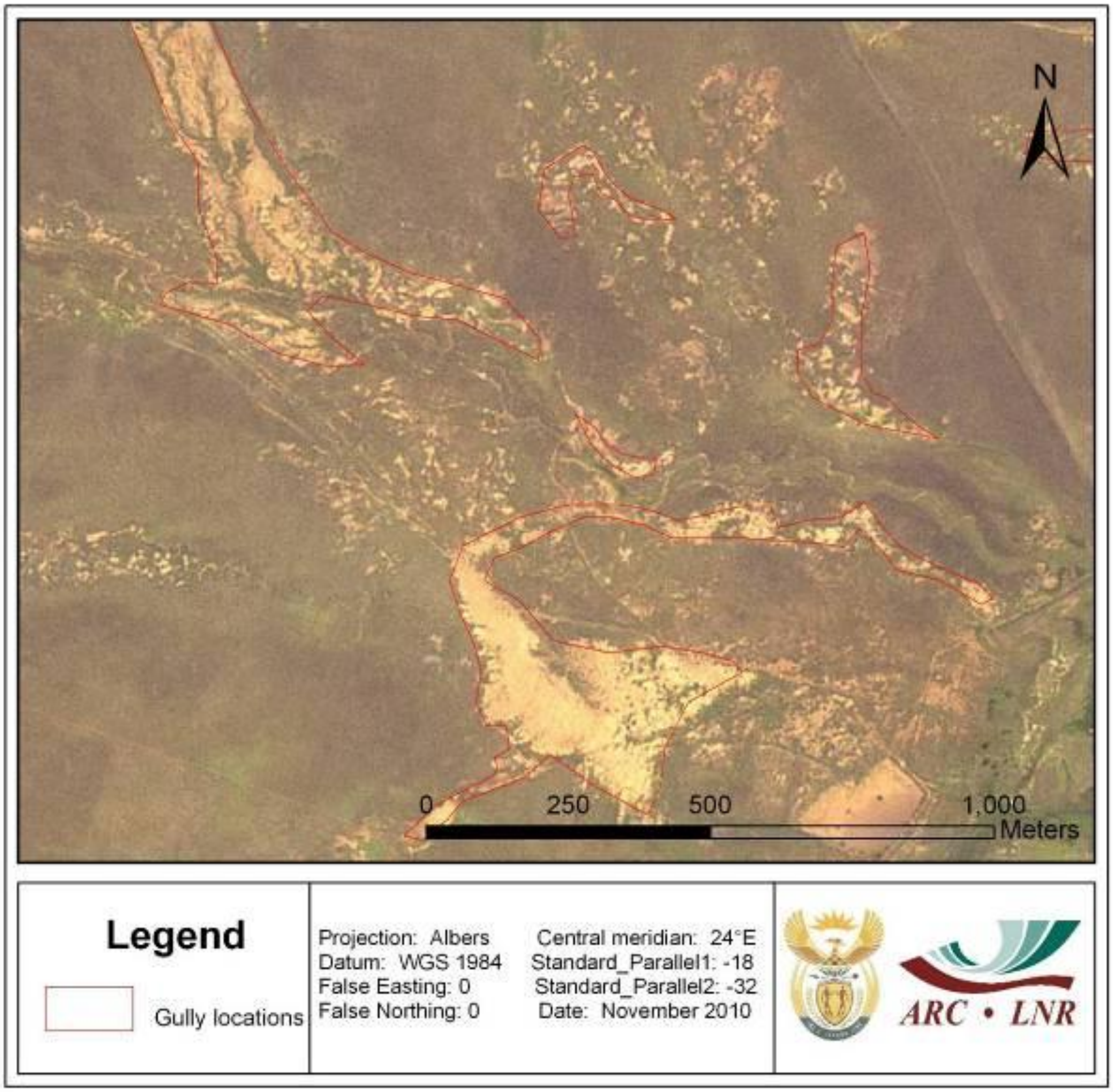

Figure 2.10: Severe sheet and rill erosion (with gully appearance) as visualized from SPOT 5 imagery near Burgersdorp in the Eastern Cape (after Le Roux *et al*., 2010).

Not all gullies were difficult to interpret and map as illustrated above, some typical gullies have noticeable channels with a typical 'branchy' appearance including shadows that are commonly caused by steep gully sidewalls as shown in figure 2.11.

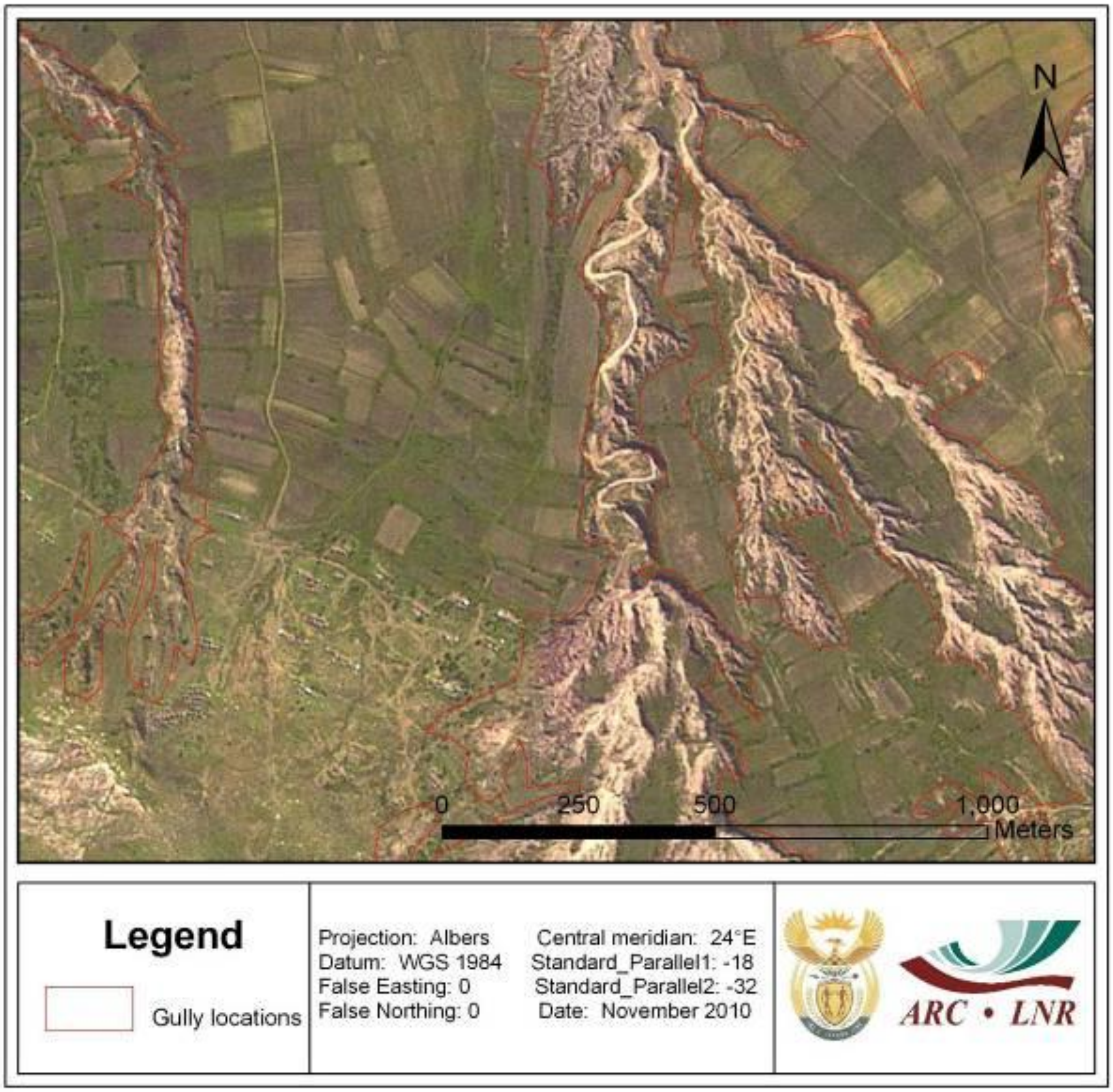

Figure 2.11: Typical gully with 'branchy' appearance and channel sidewall shadows near Nqutu in KwaZulu-Natal (after Le Roux *et al*., 2010).

It is worth mentioning here that some of the affected areas (gully polygons) include more than one gully, especially where several small gullies are situated in close proximity to each other (see figure 2.12).

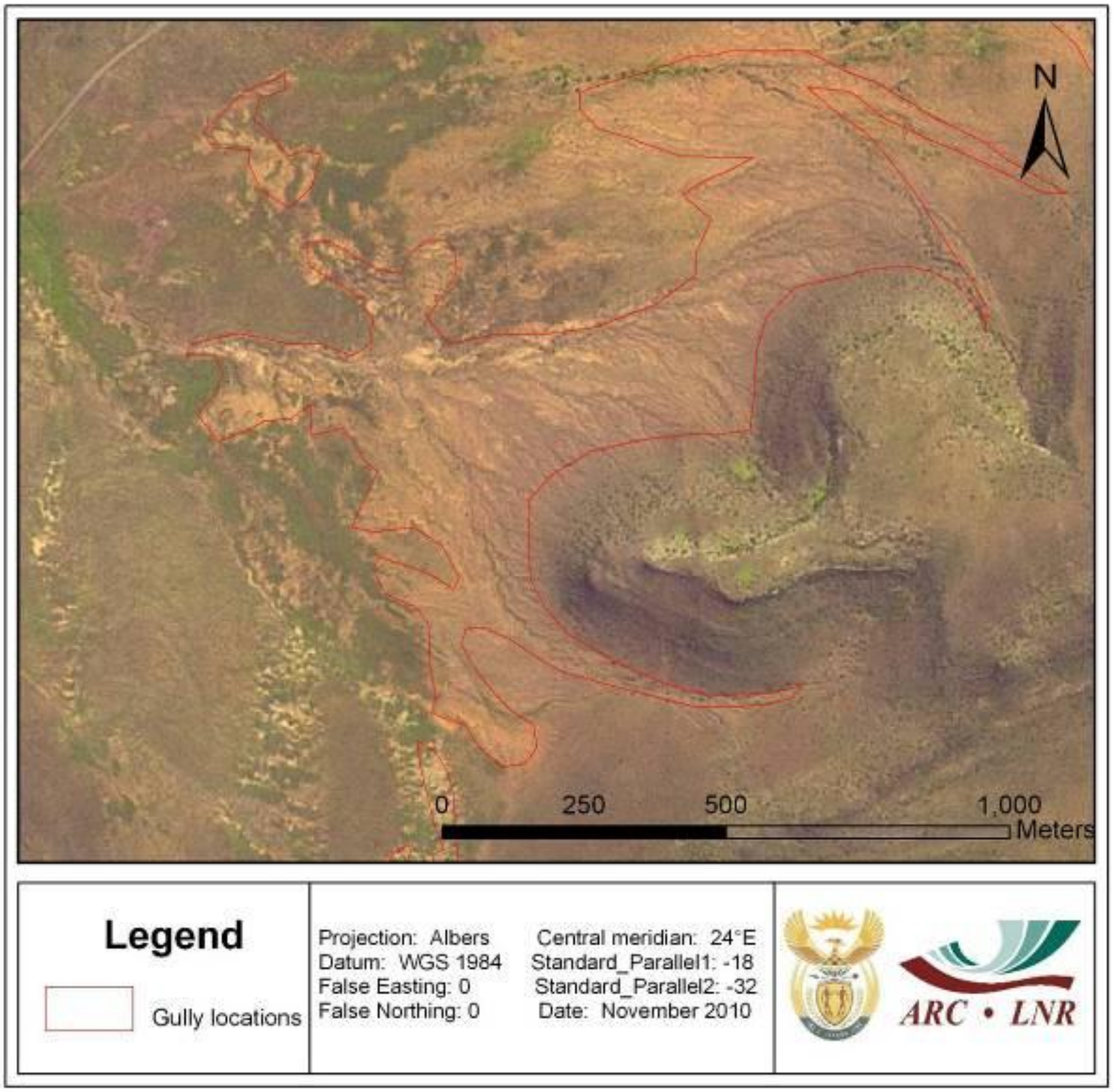

Figure 2.13: One gully polygon representing several small gullies situated in close proximity to each other near Steynsburg in the Eastern Cape (after Le Roux *et al*., 2010).

2.3. Verification Methodology

Results need to be validated with independent data (Svorin, 2003). Other than visual comparison of maps, there are very few pattern comparison techniques at a regional scale (Jetten *et al*., 2003). Since there are no published gully erosion maps available for South Africa (SA), verification was based on field observations and discussion with other experts. The main purpose of verification in this study was to correct unnecessary omission and commission of gullies. It is noteworthy that field observations were aimed at areas or gullies that were difficult to map, e.g. gullies amid bare soil or accompanied by other erosion forms. Firstly gullies that could not be identified by the interpreters with certainty were marked by a point shapefile for further investigation either on the field or through discussion with other experts. Additionally, gullies were selected across the entire country based on their accessibility by road. The majority (about 89%) of gullies selected across the entire country were correctly interpreted and captured as shown in table 2.1.

Table 2.1: Summary of verification statistics

Provinces	**No. of Points**	**Correctly Captured Gullies**	**Accuracy in %**
Limpopo	133	125	94%
Mpumalanga	41	36	87.8%
North West	26	21	80.8%
Gauteng	21	15	71.4%
Free State	193	176	91.2%
Northern Cape	209	172	82.3%
Western Cape	68	63	92.6%
Eastern Cape	191	175	91.6%
Kwazulu Natal	137	132	96.4%
Total Accuracy	**1019**	**915**	**89.7%**

PART 3: RESULTS AND DISCUSSION

This section displays and discusses a set of maps and statistics presenting the extent of gully erosion in each of the Provinces.

3.1. Gully erosion in the Limpopo Province

Table 3.1 summarizes the results of gully erosion mapping in Limpopo Province per local municipality. Figure 3.1 illustrates the location of identified gullies in Limpopo Province. Severe gullies are located in the north eastern and central to south eastern parts of the Province. These areas include Aganang (7 082 ha, 3.62%), Fetakgomo (4 774 ha, 4.12%), Greater Letaba (2 438 ha, 1.23%), Greater Tubatse (13 014 ha, 2.70%), and Polokwane municipalites (12 175 ha, 3.09. These municipalities are severely affected, and each has more than 1% of the total area under gullies. Additionally, municipalities such as Greater Giyani (1 508 ha, 0.48%), Greater Groblersdal (2 365 ha, 0.61%), Kruger National Park (2 819 ha, 0.27%), Makhuduthamaga (1 596 ha, 0.73%), Mogalakwena (4 399 ha, 0.68%) and Thulamela (1 883 ha, 0.62%) are also largely affected and each has more than 1 000ha of land under gullies. In short, about 58 669 hectares (0.45%) of Limpopo Province is affected by gully erosion.

Table 3.1: Gully erosion information for each local municipality in Limpopo Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (ha)	Gullied Area (%)
Aganang	NP352	195399	159	70816352	7082	3.62
Ba-Phalaborwa	NP334	314316	0	0	0	0.00
Bela-Bela	NP366	353414	30	9524760	952	0.27
Blouberg	NP351	473476	23	3455330	346	0.07
Fetakgomo	NP03a3	115920	173	47738146	4774	4.12
Greater Giyani	NP331	311951	340	15075077	1508	0.48
Greater Groblersdal	NP03a5	389301	149	23647099	2365	0.61
Greater Letaba	NP332	197578	518	24376466	2438	1.23
Greater Marble Hall	NP03a4	200055	34	3658693	366	0.18

Greater Tubatse	NP03a6	481794	224	130143067	13014	2.70
Greater Tzaneen	NP333	339088	121	4829019	483	0.14
Kruger National Park	NPDMA33	1057378	504	28192942	2819	0.27
Lepele-Nkumpi	NP355	362360	22	2256866	226	0.06
Lephalale	NP362	2044849	14	1153296	115	0.01
Makhado	NP344	889773	79	2909473	291	0.03
Makhuduthamaga	NP03a2	219596	88	15962512	1596	0.73
Maruleng	NP335	339741	14	814591	81	0.02
Modimolle	NP365	651146	28	4723579	472	0.07
Mogalakwena	NP367	644045	160	43988561	4399	0.68
Molemole	NP353	349575	33	4156817	416	0.12
Mookgopong	NP364	446971	19	1087308	109	0.02
Musina	NP341	789566	16	2360366	236	0.03
Mutale	NP342	244710	0	0	0	0.00
Polokwane	NP354	393667	606	121752726	12175	3.09
Thabazimbi	NP361	1030835	22	5238094	524	0.05
Thulamela	NP343	302579	430	18827114	1883	0.62
Limpopo Province		**13139085**	**3806**	**586688255**	**58669**	**0.45**

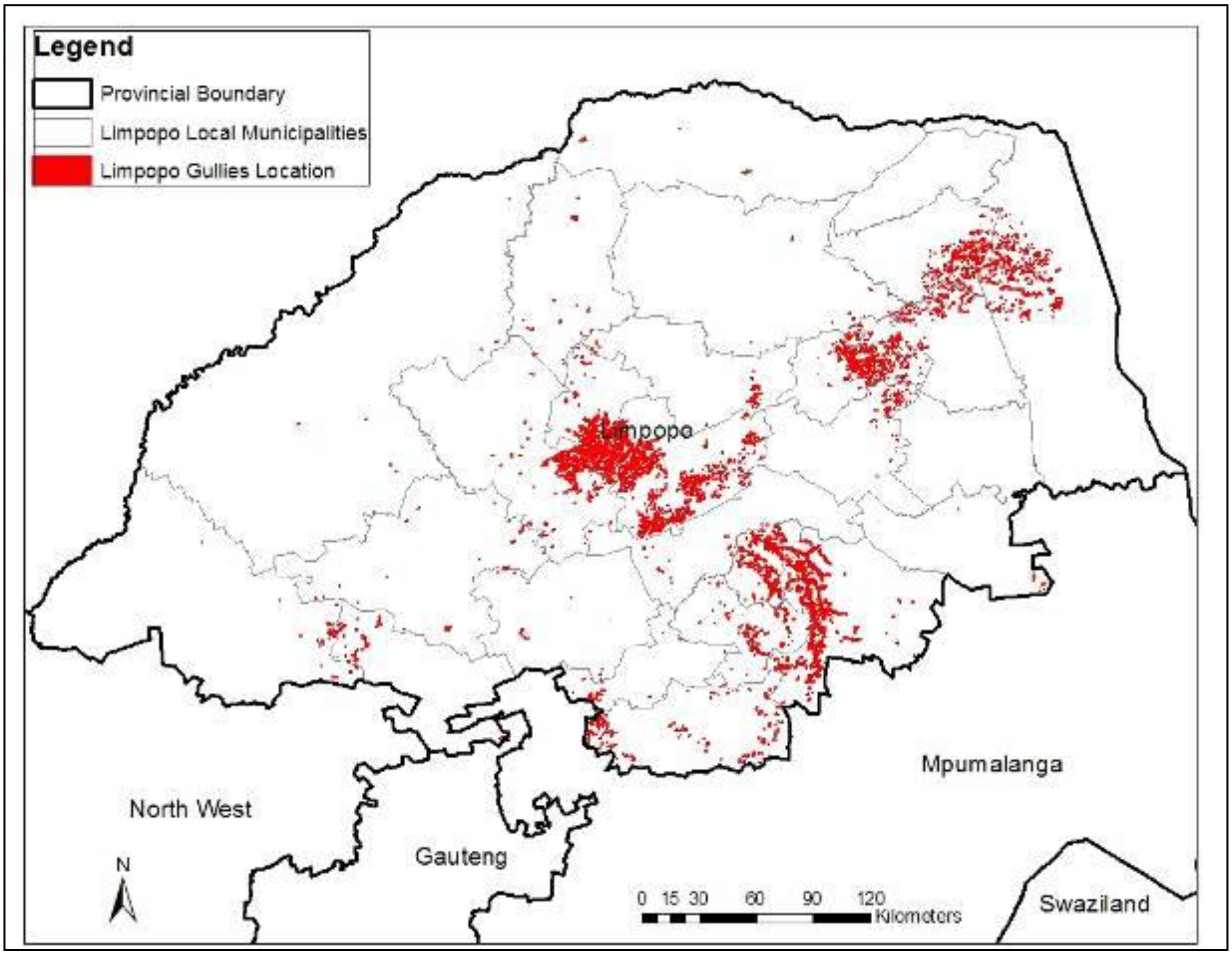

Figure 3.1: Gullies location map of Limpopo Province.

3.2. Gully erosion in Mpumalanga Province

Table 3.2 summarizes the results of gully erosion mapping in Mpumalanga Province per local Municipality. Figure 3.2 illustrates the location of the identified gullies in Mpumalanga Province. Gullies are largely located in the north eastern, central and southern parts of the Province. Municipalities such as Albert Luthuli (4 751 ha, 0.81%) Bushbuckridge (1 355 ha, 0.50%), Lekwa (1 862 ha, 0.39%), Thaba Chweu (1 701 ha, 0.28%), Pixley ka Seme (1 970 ha, 0.36%) and Kruger National Park (2 212 ha, 0.19%) are the most severely affected. Each of these municipalities has more than 1 000 hectares of land affected by gullies. Overall, 17420 hectares (0.22%) of the total area is affected by gullies in Mpumalanga Province.

Table 3.2: Gully erosion information for each local municipality in Mpumalanga Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (ha)	Gullied Area (%)
Albert Luthuli	MP301	584437	339	47514770	4751	0.81
Bushbuckridge	MP325	271532	173	13551542	1355	0.50
Delmas	MP311	164644	2	140896	14	0.01
Dipaleseng	MP306	275205	23	1208944	121	0.04
Dr JS Moroka	MP316	148389	28	5305709	531	0.36
Emalahleni	MP312	281193	12	564215	56	0.02
Govan Mbeki	MP307	310643	16	326680	33	0.01
Highlands	MP314	497143	86	4720202	472	0.09
Kruger National Park	MPDMA32	1173544	689	22124663	2212	0.19
Lekwa	MP305	482616	234	18615376	1862	0.39
Mbombela	MP322	358219	28	1146962	115	0.03
Mkhondo	MP303	514524	103	7064066	706	0.14
Msukaligwa	MP302	632882	168	5172584	517	0.08
Nkomazi	MP324	340612	21	1008136	101	0.03
Pixley Ka Seme	MP304	550782	413	19702771	1970	0.36
Steve Tshwete	MP313	417524	14	331627	33	0.01
Thaba Chweu	MP321	599835	146	17007494	1701	0.28
Thembisile	MP315	250028	5	196452	20	0.01
Umjindi	MP323	183418	88	8500994	850	0.46
Mpumalanga Province		**8037169**	**2588**	**174204083**	**17420**	**0.22**

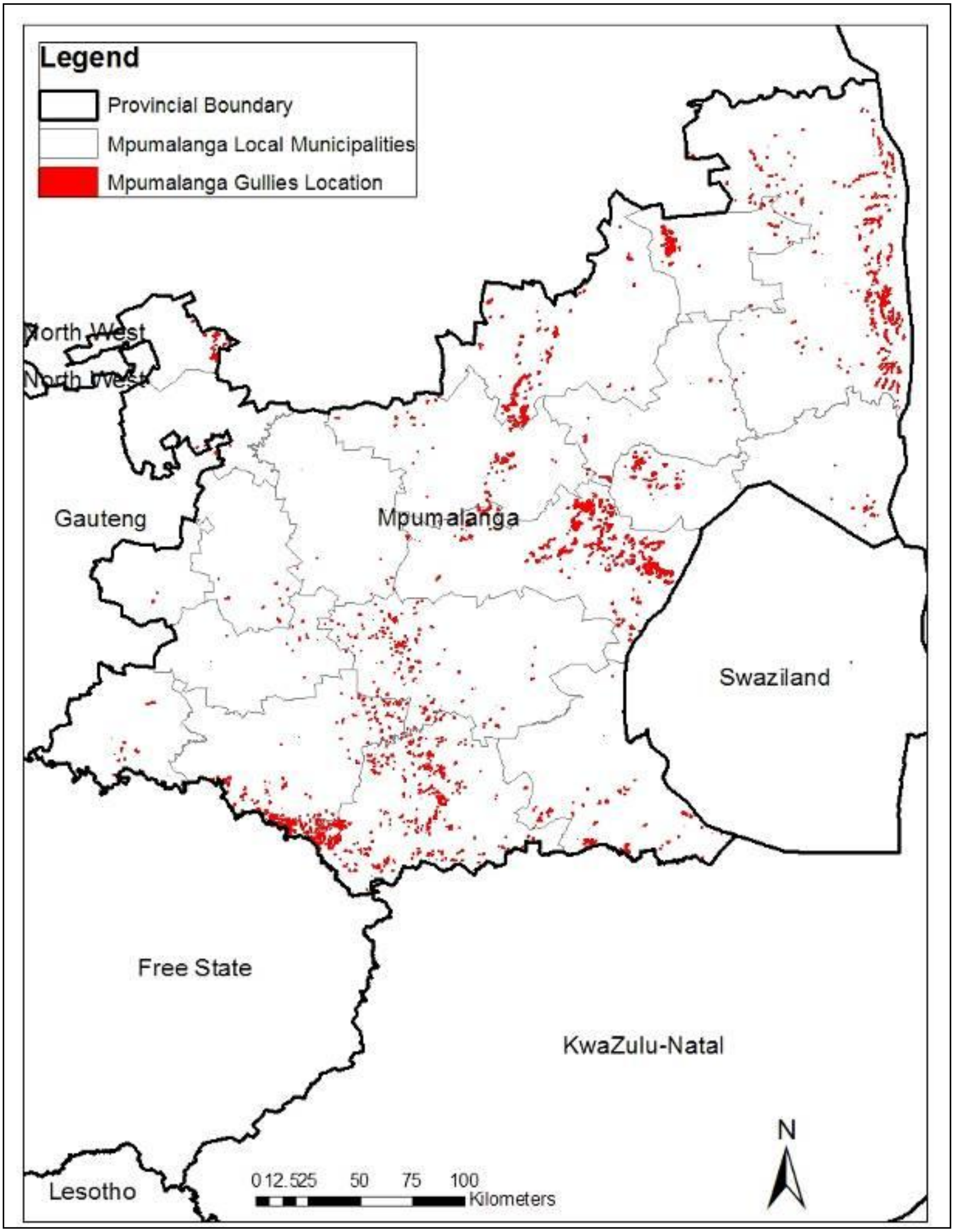

Figure 3.2: Gullies location map of Mpumalanga Province.

3.3. Gully erosion in Gauteng Province

Table 3.3 summarizes the results of gully erosion mapping in Gauteng Province per local Municipality. Figure 3.3 illustrates the location of the identified gullies in Gauteng Province. Gauteng is not severely affected by gully erosion with only 110 hectares (0.006%) of the total area being affected.

Table 3.3: Gully erosion information for each local municipality in Gauteng Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m2)	Gullied Area (ha)	Gullied Area (%)
City of Johannesburg Metropolitan	JHB	172679	0	0	0	0.000
Ekurhuleni Metropolitan	EKU	202071	2	23526	2	0.001
Emfuleni	GT421	101494	2	61142	6	0.006
Kungwini	GT02b2	231075	26	261629	26	0.011
Lesedi	GT423	156146	21	114637	11	0.007
Midvaal	GT422	181335	45	452600	45	0.025
Mogale City	GT481	115312	2	14699	1	0.001
Nokeng tsa Taemane	GT02b1	206265	10	67126	7	0.003
Randfontein	GT482	50072	0	0	0	0.000
Tshwane Metropolitan	TSH	228007	11	106817	11	0.005
West Rand	GTDMA48	25481	0	0	0	0.000
Westonaria	GT483	66953	0	0	0	0.000
Gauteng Province		**1736891**	**119**	**1102176**	**110**	**0.006**

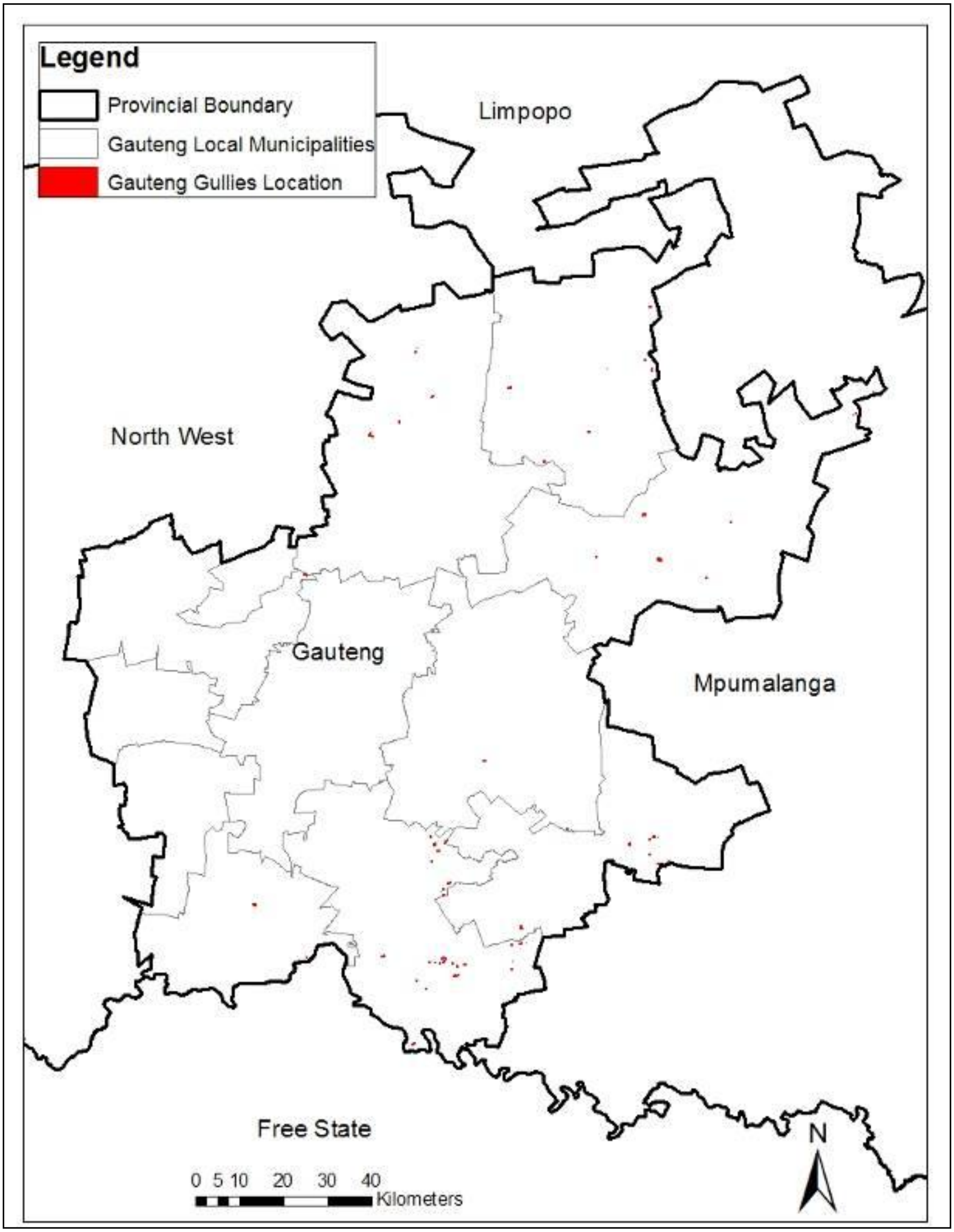

Figure 3.3: Gullies location map of Gauteng Province

3.4. Gully erosion in the North West Province

Table 3.4 summarizes the results of gully erosion mapping in North West Province per local Municipality. Figure 3.4 illustrates the location of the identified gullies in North West Province. Severe gullies can be identified in the north eastern parts of the Province. These areas include Kgetlengrivier (1 001 ha, 0.24%), Ramotshere Moiloa (4 068 ha, 0.54%) and Rusternburg municipalities (1 446 ha, 0.40%). Overall, 10 782 hectares (0.09%) of the total area in North West Province is affected by gully erosion.

Table 3.4: Gully erosion information for each local municipality in North West Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (Ha)	Gullied Area (%)
City of Matlosana	NW403	374083	1	16820	2	0.0004
Ditsobotla	NW384	677753	0	0	0	0.0000
Greater Taung	NW394	592242	166	7168603	717	0.1210
Kagisano	NW391	1189719	34	563323	56	0.0047
Kgetlengrivier	NW374	416299	50	10006746	1001	0.2404
Lekwa-Teemane	NW396	387206	0	0	0	0.0000
Madibeng	NW372	402220	58	8037702	804	0.1998
Mafikeng	NW383	387382	21	422700	42	0.0109
Mamusa	NW393	379805	52	1738094	174	0.0458
Maquassi Hills	NW404	488084	0	0	0	0.0000
Merafong	NW405	171198	9	1354123	135	0.0791
Molopo	NW395	1304604	12	272584	27	0.0021
Moretele	NW371	144384	7	541497	54	0.0375
Moses Kotane	NW375	598394	25	8039544	804	0.1344
Naledi	NW392	761685	41	872491	87	0.0115
Potchefstroom	NW402	280902	10	513468	51	0.0183

Ramotshere Moiloa	NW385	752382	67	40682535	4068	0.5407
Ratlou	NW381	478314	142	9071775	907	0.1897
Rustenburg	NW373	358739	56	14458552	1446	0.4030
Tswaing	NW382	626042	64	3998787	400	0.0639
Ventersdorp	NW401	394973	2	62937	6	0.0016
North West Province		**11166413**	**817**	**107822281**	**10782**	**0.0966**

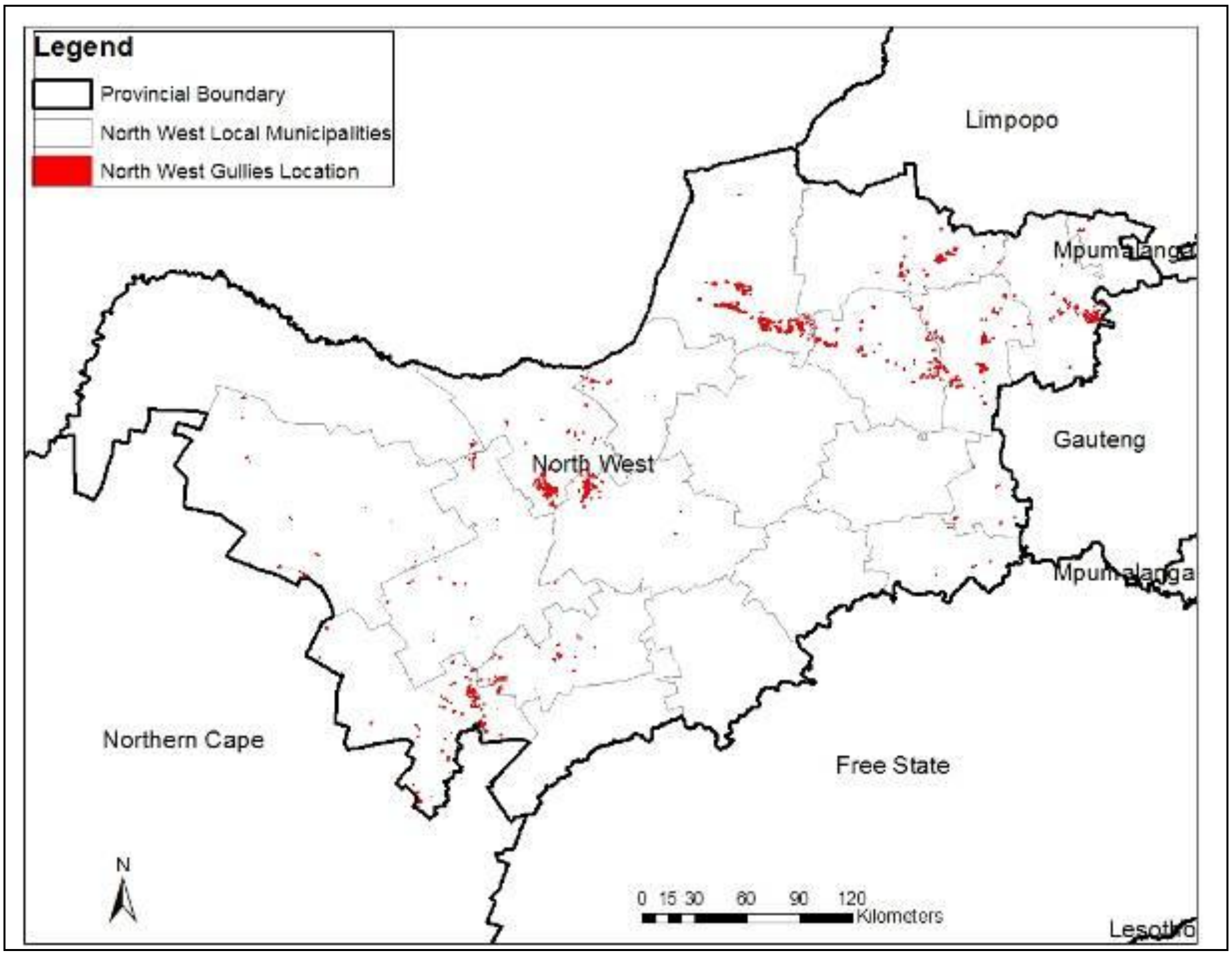

Figure 3.4: Gullies location map of North West Province

3.5. Gully erosion in the Free State Province

Table 3.5 summarizes the results of gully erosion mapping in Free State Province per local Municipality. Figure 3.5 illustrates the location of the identified gullies in Free State Province. Gullies in Free State are largely located along the border of Kwazulu Natal and Eastern Cape Province as well as along the border of Lesotho. The local municipalities that are severely affected include Mantsopa (5 229 ha, 1.15%), Mohokare (9 532 ha, 1.02%), and Setsoto (8 812 ha, 1.40%). Each of these municipalities has more than 1% of the total area affected. Additionally, Naledi (3 591 ha, 0.99%), Phumelela (2 424 ha, 0.30%), Ngwathe (1 682 ha, 0.23%), Moqhaka (2 217 ha, 0.27%), Mangaung (4 513 ha, 0.68%), Maluti a Phofung (2 493 ha, 0.53%), Letsemeng (5 785 ha, 0.54%), Kopanong (10 146 ha, 0.63%) and Dihlabeng (4 570 ha, 0.91%) municipalities each has more than 2 000 ha of land affected by gully erosion. Overall, a total of 64 674 hectares (0.47%) of land is affected by gully erosion in Free State Province.

Table 3.5: Gully erosion information for each local municipality in Free State Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (ha)	Gullied Area (%)
Dihlabeng	FS192	500363	945	45701039	4570	0.91
Golden Gate Highlands NP	FSDMA19	6449	2	30225	3	0.05
Kopanong	FS162	1614497	1224	101456915	10146	0.63
Letsemeng	FS161	1080465	442	57847624	5785	0.54
Mafube	FS205	484886	486	7028732	703	0.14
Maluti a Phofung	FS194	466637	869	24929120	2493	0.53
Mangaung	FS172	664107	741	45133072	4513	0.68
Mantsopa	FS173	453662	1011	52292694	5229	1.15
Masilonyana	FS181	717314	401	8739452	874	0.12
Matjhabeng	FS184	543333	203	5455195	546	0.10
Metsimaholo	FS204	180599	147	1460993	146	0.08

Mohokare	FS163	930432	1987	95323076	9532	1.02
Moqhaka	FS201	834223	762	22167981	2217	0.27
Nala	FS185	434566	7	123830	12	0.00
Naledi	FS171	362495	886	35907728	3591	0.99
Ngwathe	FS203	742547	808	16818683	1682	0.23
Nketoana	FS193	591634	494	7346071	735	0.12
Phumelela	FS195	796369	1324	24241774	2424	0.30
Setsoto	FS191	630035	1483	88123598	8812	1.40
Tokologo	FS182	983140	112	6474062	647	0.07
Tswelopele	FS183	687264	6	134316	13	0.00
Free State Province		**13705018**	**14340**	**646736180**	**64674**	**0.47**

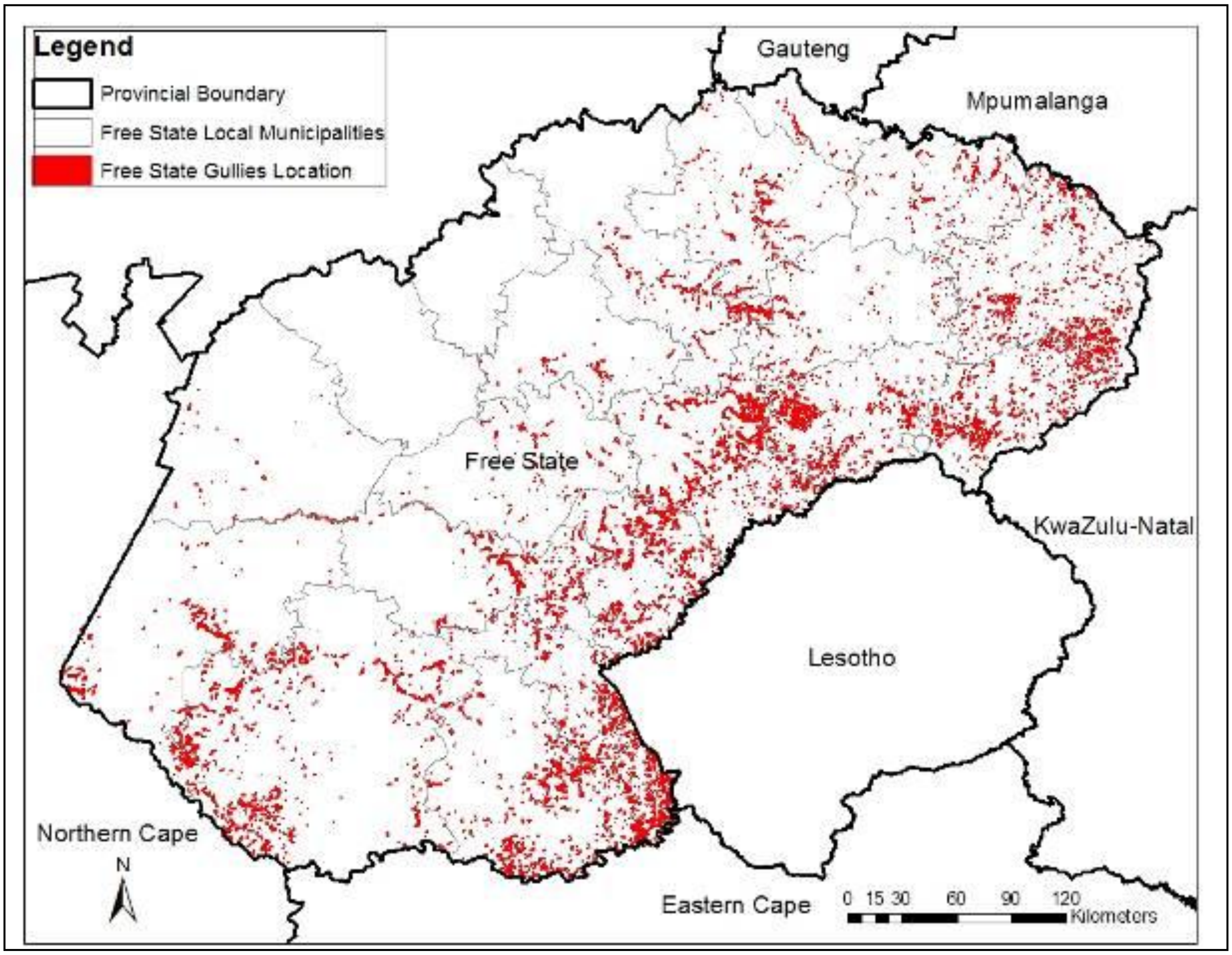

Figure 3.5: Gullies location map of Free State Province

3.6. Gully erosion in the Northern Cape Province

Table 3.6 summarizes the results of gully erosion mapping in Northern Cape Province per local Municipality. Figure 3.6 illustrates the location of gullies in Northern Cape Province. Gullies largely dominate the landscape in the south eastern parts of the Province. These areas include Emthanjeni (35 780 ha, 2.96%), Renosterberg (24 831 ha, 4.24%), Ubuntu (53 107 ha, 2.45%) and Umsobomvu (17 097 ha, 2.36%) local municipalities with more than two percent of the total area affected by gully erosion. Additionally, Thembelihle (3 630 ha, 0.49%), Siyancuma (3 356 ha, 0.31%), Richtersveld (1 031 ha, 0.10%), Kareeberg (13 164 ha, 0.70%), Hantam (2 926 ha, 0.09%) and Bo Karoo (2 219 ha, 0.13%) municipalities are largely affected with more than 1 000ha of land affected. Overall, 160 885 hectares (0.4%) of the total land is affected by gully erosion.

Table 3.6: Gully erosion information for each local municipality in Northern Cape Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (ha)	Gullied Area (%)
Kheis	NC084	677881	18	331412	33	0.005
Benede	NCDMA08	6838304	90	1780251	178	0.003
Bo Karoo	NCDMA07	1656048	440	22185752	2219	0.134
Dikgatlong	NC092	975708	151	9726435	973	0.100
Emthanjeni	NC073	1207553	3392	357796589	35780	2.963
Gamagara	NC453	275157	0	0	0	0.000
Ga-Segonyana	NC452	471948	0	0	0	0.000
Hantam	NC065	2961833	822	29264947	2926	0.099
Kai !Garib	NC082	783615	10	141887	14	0.002
Kalahari CBDC	NCDMA45	1120858	0	0	0	0.000
Kamiesberg	NC064	1239627	26	934778	93	0.008
Kareeberg	NC074	1873693	1698	131639724	13164	0.703
Karoo Hoogland	NC066	3121130	246	6294385	629	0.020
Kgatelopele	NC086	260784	0	0	0	0.000
Kh?i-Ma	NC067	877220	11	1213695	121	0.014
Khara Hais	NC083	362194	1	5703	1	0.000
Magareng	NC093	162331	55	1075300	108	0.066
Mier	NC081	1227830	57	814192	81	0.007
Moshaweng	NC451	993661	9	381361	38	0.004
Nama Khoi	NC062	1582125	101	2475463	248	0.016
Namaqualand	NCDMA06	2616137	171	5112050	511	0.020
Phokwane	NC094	87729	6	191280	19	0.022
Renosterberg	NC075	585275	1828	248313304	24831	4.243

Richtersveld	NC061	1009559	450	10311652	1031	0.102
Siyancuma	NC078	1057420	380	33563866	3356	0.317
Siyathemba	NC077	866416	20	274988	27	0.003
Sol Plaatje	NC091	197958	78	5728830	573	0.289
Thembelihle	NC076	737743	503	36297068	3630	0.492
Tsantsabane	NC085	619547	26	949087	95	0.015
Ubuntu	NC071	2164582	5522	531071891	53107	2.453
Umsobomvu	NC072	723519	2258	170972862	17097	2.363
Northern Cape Province		**39335383**	**18369**	**1608848750**	**160885**	0.409

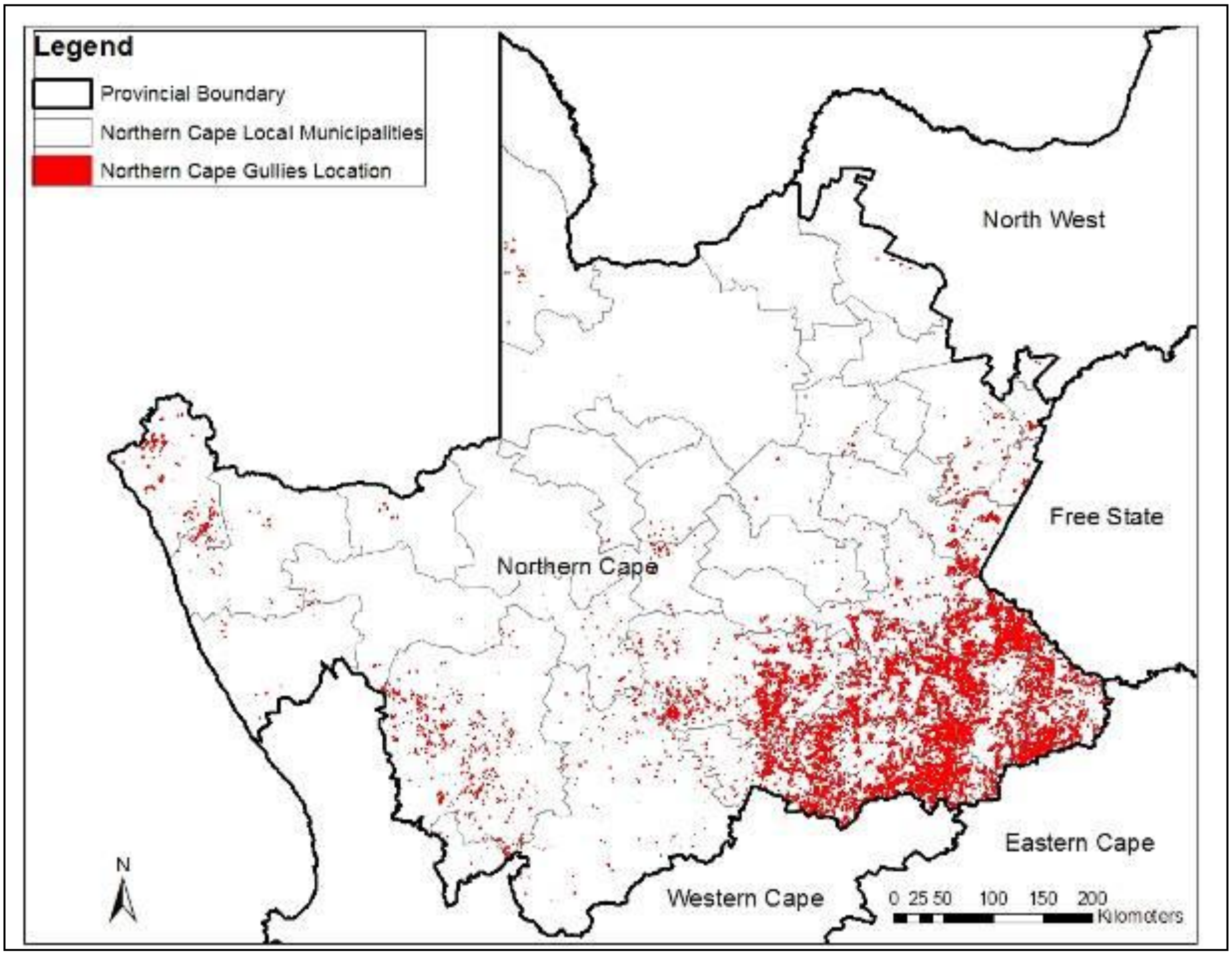

Figure 3.6: Gullies location map of Northern Cape Province

3.7. Gully erosion in the Western Cape Province

Table 3.7 summarizes the results of gully erosion mapping in Western Cape Province per local Municipality. Figure 3.7 illustrates the location of the identified gullies in Western Cape Province. Gullies are largely located in the north eastern and north western part of the Province including Central Karoo DC (6 009 ha, 1.01%) and Matzikama (8 011 ha, 1.36%) municipalities. Each of these municipalities have more than one percent of the total area affected by gully erosion. Other severely affected areas include West Coast DC (3 400 ha, 0.38%), South Cape DC (1 408 ha, 0.31%), Kannaland (1 744 ha, 0.34%) and Hessequa (1 076 ha, 0.17%). Overall, 25 403 hectares (0.18%) of the total land is affected by gully erosion in Western Cape Province.

Table 3.7: Gully erosion information for each local municipality in Western Cape Province.

Local Municipality Name	Code	Area (ha)	Number of Gullies	Gullied Area (m^2)	Gullied Area (ha)	Gullied Area (%)
Swellendam	WC034	320517	87	2511933	251	0.078
Beaufort West	WC053	1738314	32	1070589	107	0.006
Cape Agulhas	WC033	303678	47	1441868	144	0.047
Brede River DC	WCDMA02	1146825	190	7265858	727	0.063
Theewaterskloof	WC031	347268	28	535160	54	0.015
City of Cape Town	CPT	263544	4	98618	10	0.004
Central Karoo DC	WCDMA05	594364	1899	60090963	6009	1.011
Witzenberg	WC022	303787	70	2206855	221	0.073
Cederberg	WC012	779711	22	1522505	152	0.020
George	WC044	114568	0	0	0	0.000
Overstrand	WC032	181732	12	247699	25	0.014
Bitou Local	WC047	106122	0	0	0	0.000
Hessequa	WC042	613347	168	10759498	1076	0.175
Knysna	WC048	113318	0	0	0	0.000
Kannaland	WC041	508183	262	17439672	1744	0.343
Laingsburg	WC051	936556	28	1862393	186	0.020
Swartland	WC015	393154	59	1298127	130	0.033
Mossel Bay	WC043	215041	25	250622	25	0.012
Oudtshoorn	WC045	377931	197	6356849	636	0.168
Overberg DC	WCDMA03	65056	0	0	0	0.000
Drakenstein	WC023	164047	11	109733	11	0.007
Prince Albert	WC052	869577	26	1701532	170	0.020
Breede River/Winelands	WC026	355883	63	2597110	260	0.073

South Cape DC	WCDMA04	445743	187	14079775	1408	0.316
Stellenbosch	WC024	88756	0	0	0	0.000
Bergrivier	WC013	468904	91	4488954	449	0.096
Matzikama	WC011	588077	398	80107585	8011	1.362
West Coast DC	WCDMA01	885007	262	33996816	3400	0.384
Saldanha Bay	WC014	187834	9	940710	94	0.050
Breede Valley	WC025	319578	31	1047262	105	0.033
Western Cape Province		**13796423**	**4208**	**254028686**	**25403**	**0.184**

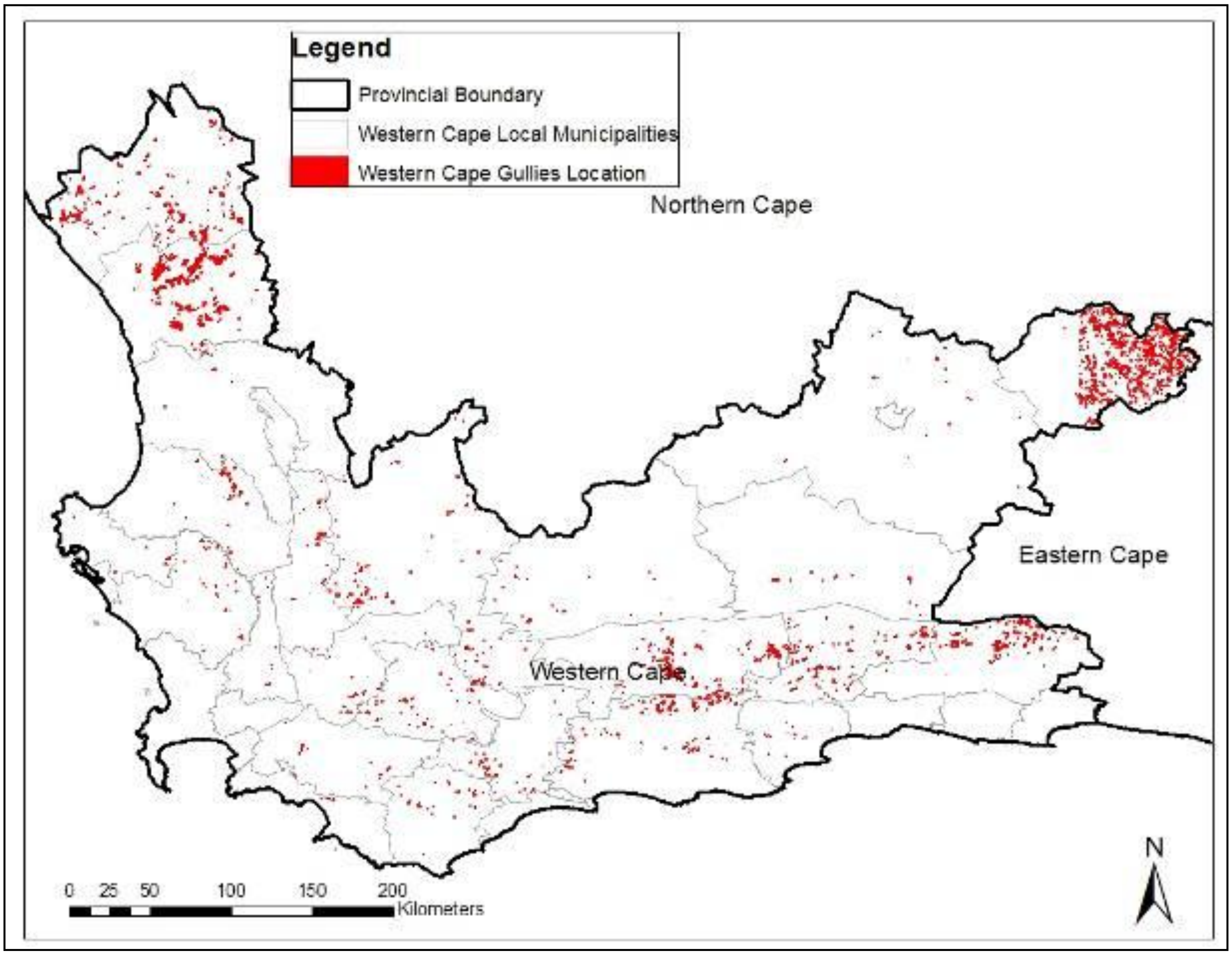

Figure 3.7: Gullies location map of Western Cape Province

3.8. Gully erosion in the Eastern Cape Province

Table 3.8 summarizes the results of gully erosion mapping in Eastern Cape Province per local Municipality. Figure 3.8 illustrates the location of gullies in Eastern Cape Province. As expected, some of the most prominent eroded areas occur in the northern regions of the Eastern Cape, especially in the former Transkei (figure 3.8). More specifically, local municipalities in the north-eastern part of the Eastern Cape that are severely affected by gully erosion as summarized in table 3.8 include Gariep (30 367 ha, 3.41%), Inxuba Yethemba (19 490 ha, 1.68%) and Tsolwana (11 515 ha, 1.91%). Local municipalities in the north-central part of the Eastern Cape that are severely affected by gully erosion include Senqu (10 068 ha, 1.37%), Maletswai (9 482 ha, 2.18%), Intsika Yethu (7 377 ha, 2.44%) and Emalahleni (6 479 ha, 1.88%). Local municipalities in the north-western part of the Eastern Cape that are severely affected by gully erosion include Matatiele (5 841 ha, 1.34%), Umzimvubu (5 234 ha, 2.09%)

and Mhlontlo (5 080 ha, 1.80. Additionally, severe gullies are prevalent in Engcobo (4 223 ha, 1.87%), King Sabata Dalindyebo (3 241 ha, 1.07%) and Ntabankulu (1 800 ha, 1.24%) municipalities. Gully erosion is also widespread in Amahlathi (1 049 ha, 0.22%), Baviaans (1 541 ha, 0.21%), Mbhashe (1 716 ha, 0.56%), Lukanji (1 819 ha, 0.48%), Ikwezi (2 060 ha, 0.46%), Mnquma (2 303 ha, 0.71%), Inkwanca (2 535 ha, 0.71%), Camdeboo (2 933 ha, 0.41%), Elundini (4 448 ha, 0.88%) and Blue Crane Route (4 996 ha, 0.51%) municipalities. Overall, 151 759 hectares of land (0.90%) is affected by gully erosion in Eastern Cape Province.

Table 3.8: Gully erosion information for each local municipality in the Eastern Cape Province (after Le Roux *et al*., 2010).

Local municipality name (and code)	Area (ha)	Gullied area (m^2)	Gullied area (ha)	Gullied area (%)
Kouga (EC108)	265924	33700	3	0.00
Ndlambe (EC105)	183866	80100	8	0.00
Port St Johns (EC154)	128799	114400	11	0.01
Kou-Kamma (EC109)	357862	142800	14	0.00
Nelson Mandela Bay (NMA)	194831	240700	24	0.01
Sunday's River Valley (EC106)	350206	731500	73	0.02
Great Kei (EC123)	173137	912100	91	0.05
Makana (EC104)	437559	1439300	144	0.03
Ngquza Hill (EC153)	246247	2032000	203	0.08
Mbizana (EC151)	241067	2159900	216	0.09
Nxuba (EC128)	273182	2771000	277	0.10
Ngqushwa (EC126)	223831	2876700	288	0.13
Buffalo City (EC125)	253288	3033900	303	0.12
Nyandeni (EC155)	247242	5189800	519	0.21

Nkonkobe (EC127)	362615	5894500	589	0.16
Sakhisizwe (EC138)	235472	8295400	830	0.35
Amahlathi (EC124)	482053	10485100	1049	0.22
Baviaans (EC107)	745730	15407200	1541	0.21
Mbhashe (EC121)	307513	17162600	1716	0.56
Ntabankulu (EC152)	145565	18004200	1800	1.24
Lukanji (EC134)	381305	18191100	1819	0.48
Ikwezi (EC103)	444884	20603600	2060	0.46
Mnquma (EC122)	326481	23033900	2303	0.71
Inkwanca (EC133)	358452	25350100	2535	0.71
Conservation areas	1336760	25677300	2568	0.19
Camdeboo (EC101)	723012	29327100	2933	0.41
King Sabata Dalindyebo (EC157)	302694	32414100	3241	1.07
Engcobo (EC137)	225841	42228400	4223	1.87
Elundini (EC141)	506456	44477500	4448	0.88
Blue Crane Route (EC102)	983919	49962900	4996	0.51
Mhlontlo (EC156)	282597	50796000	5080	1.80
Umzimvubu (EC442)	250672	52344700	5234	2.09
Matatiele (EC441)	435234	58405100	5841	1.34
Emalahleni (EC136)	344726	64791700	6479	1.88
Intsika Yethu (EC135)	302620	73772700	7377	2.44
Maletswai (EC143)	435790	94818800	9482	2.18
Senqu (EC142)	732926	100676000	10068	1.37
Tsolwana (EC132)	602443	115145000	11515	1.91
Inxuba Yethemba (EC131)	1159147	194902000	19490	1.68

Gariep (EC144)	891092	303666000	30367	3.41
EC Province	**16883040**	**1517590900**	**151759**	**0.90**

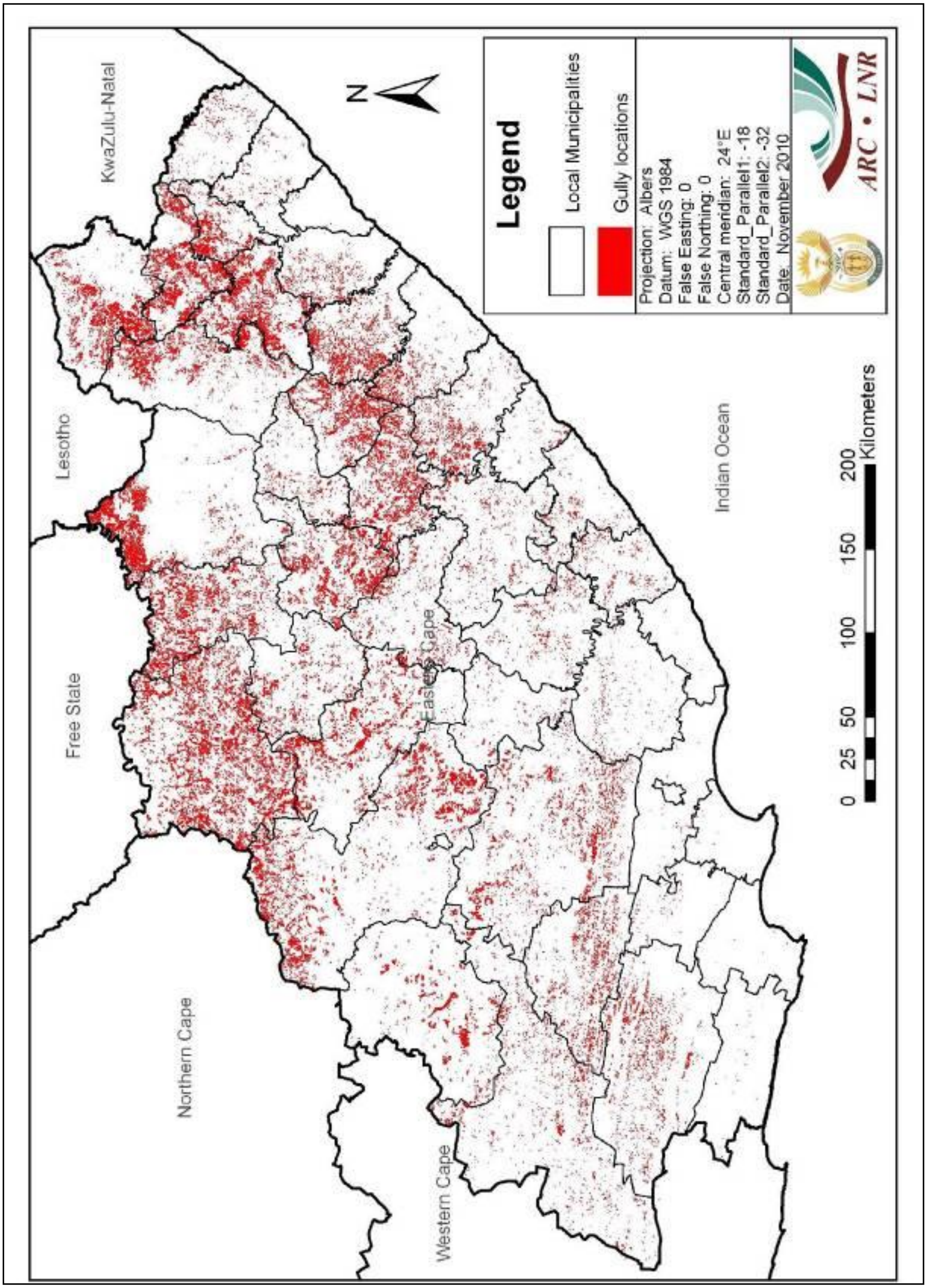

Figure 3.8: Gullies location map of the Eastern Cape Province (after Le Roux *et al*., 2010).

3.9. Gully erosion in the Kwazulu Natal Province

Table 3.9 summarizes the results of gully erosion mapping in Kwazulu Natal Province per local Municipality. Figure 3.9 illustrates the location of the identified gullies in Kwazulu Natal Province. Severe gully erosion was identified mainly in the northern part of the province and south western parts (figure 3.9). Some of the local municipalities severely affected as indicated in table 3.9 include Nqutu (15 519 ha, 7.91%), Abaqulusi (12 384 ha, 2.96 %), Endumeni (7 337 ha, 4.56%), Emadlangeni (6 006 ha, 1.70%), Ulundi (4 978 ha, 1.53%), Emnambithi/Ladysmith (9 552 ha, 3.22%), Dannhauser (4 357 ha, 2.87%), Msinga (3 396 ha, 1.36%), Nongoma (3 329 ha, 1.53%), Umtshezi (3 194 ha, 1.62%), Indaka (2 489 ha, 2.51%), Ingwe (2 006 ha, 1.01%) and Imbabazane (1 481 ha, 1.50%). Each of these municipalities has more than one percent of the total area directly affected by gully erosion. Other municipalities with severe gully erosion include Okhahlamba (2 822 ha, 0.81%), Umzimkhulu (1 672 ha, 0.69%) and Newcastle (1 511 ha, 0.81%). Each of these municipalities has more than a thousand hectares of land directly affected by gully erosion. Overall, 87 522 ha (0.94%) of the total land in Kwazulu Natal Province is directly affected by gully erosion.

Table 3.9: Gully erosion information for each local municipality in KwaZulu-Natal Province (after Le Roux *et al*., 2010).

Local municipality name (and code)	Area (ha)	Gullied area (m^2)	Gullied area (ha)	Gullied area (%)
Umdoni (KZN212)	25106	0	0	0.00
Hibiscus Coast (KZN216)	83493	0	0	0.00
Mtubatuba (KZN275)	49635	0	0	0.00
Maphumulo (KZN294)	89606	11600	1	0.00
KwaDukuza (KZN292)	66411	17400	2	0.00
Mandeni (KZN291)	53720	25900	3	0.00
Vulamehlo (KZN211)	95994	36600	4	0.00
Umhlabuyalingana (KZN271)	361867	42000	4	0.00

uMshwathi (KZN221)	181810	51400	5	0.00
Ndwedwe (KZN293)	115711	51800	5	0.00
Richmond (KZN227)	125563	70800	7	0.01
uMhlathuze (KZN282)	77810	72200	7	0.01
Mthonjaneni (KZN285)	108582	73800	7	0.01
Ntambanana (KZN283)	108284	87400	9	0.01
The Msunduzi (KZN225)	63398	112300	11	0.02
The Big 5 False Bay (KZN273)	106060	112500	11	0.01
Mkhambathini (KZN226)	89067	114600	11	0.01
Ezingoleni (KZN215)	64786	119400	12	0.02
Mbonambi (KZN281)	120972	158900	16	0.01
uMlalazi (KZN284)	221150	203200	20	0.01
Ethekwini (ETH)	227994	245300	25	0.01
Umzumbe (KZN213)	125863	252200	25	0.02
Jozini (KZN272)	304729	278100	28	0.01
uMngeni (KZN222)	156660	405500	41	0.03
Kwa Sani (KZN432)	113131	969300	97	0.09
Ubuhlebezwe (KZN434)	160402	1157800	116	0.07
UMuziwabantu (KZN214)	108976	1407000	141	0.13
Conservation areas	549267	1433900	143	0.03
Greater Kokstad (KZN433)	267991	1984300	198	0.07
Hlabisa (KZN274)	141753	2147300	215	0.15
Impendle (KZN224)	104535	5170300	517	0.49
Mpofana (KZN223)	165135	5497200	550	0.33
Nkandla (KZN286)	182756	6170500	617	0.34

UPhongolo (KZN262)	323922	8309600	831	0.26
eDumbe (KZN261)	194251	8485700	849	0.44
Umvoti (KZN245)	251565	9615900	962	0.38
Imbabazane (KZN236)	98525	14811600	1481	1.50
Newcastle (KZN252)	185501	15110300	1511	0.81
Umzimkhulu (KZN435)	243543	16724500	1672	0.69
Ingwe (KZN431)	197636	20055800	2006	1.01
Indaka (KZN233)	99148	24890400	2489	2.51
Okhahlamba (KZN235)	347559	28217000	2822	0.81
Umtshezi (KZN234)	197248	31940400	3194	1.62
Nongoma (KZN265)	218192	33288200	3329	1.53
Msinga (KZN244)	250119	33964800	3396	1.36
Dannhauser (KZN254)	151599	43569000	4357	2.87
Ulundi (KZN266)	325055	49777800	4978	1.53
Emadlangeni (KZN253)	353934	60064700	6006	1.70
Endumeni (KZN241)	161021	73369300	7337	4.56
Emnambithi/Ladysmith (KZN232)	296487	95517500	9552	3.22
Abaqulusi (KZN263)	418463	123837000	12384	2.96
Nqutu (KZN242)	196207	155186000	15519	7.91
KZN Province	**9328192**	**875216000**	**87522**	**0.94**

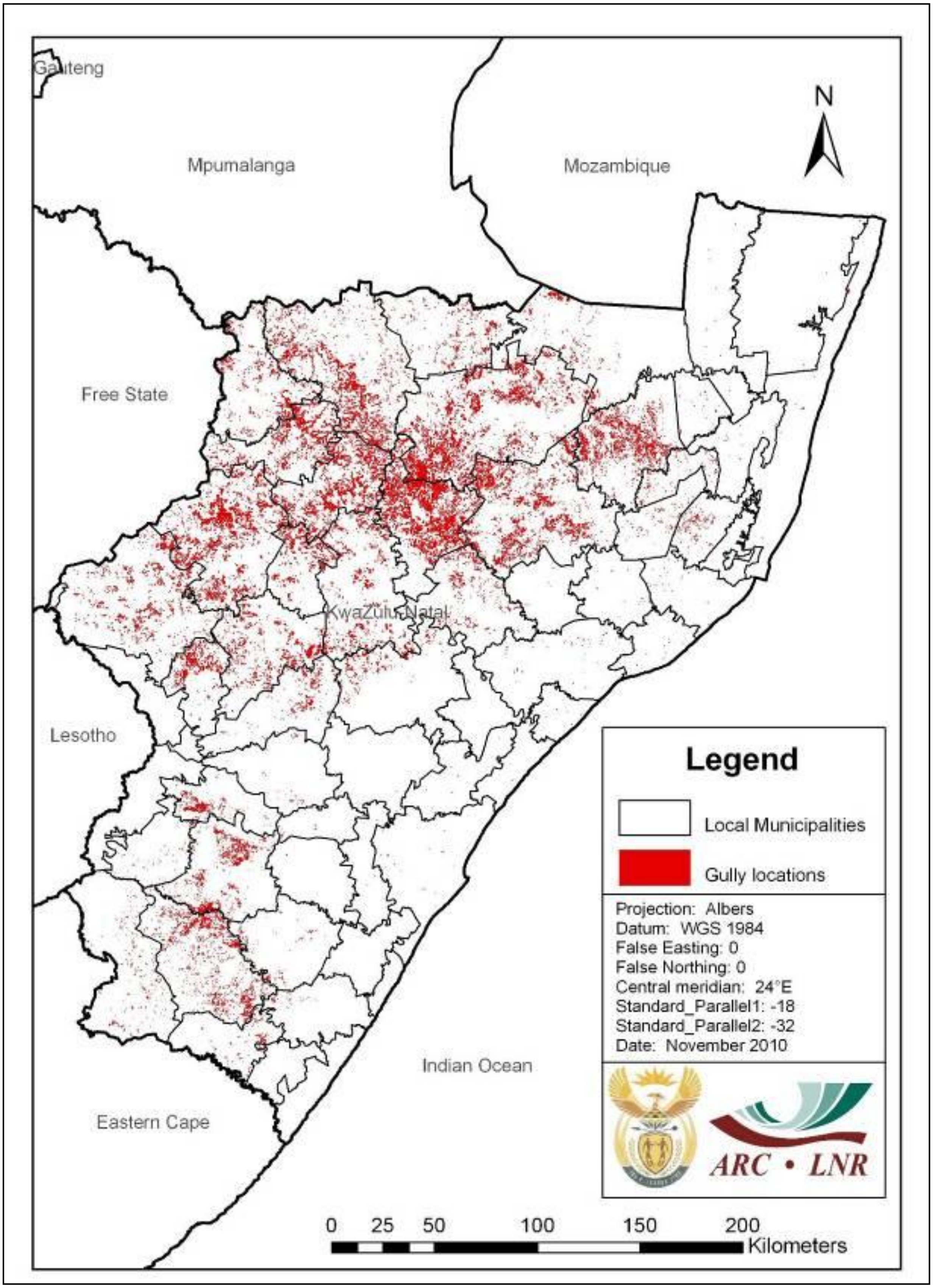

Figure 3.9: Gullies location map of KwaZulu-Natal Province (after Le Roux *et al*., 2010).

3.10. Limitations

Foremost, vectorizing gully erosion from SPOT 5 imagery at a scale of 1:10 000 by hand is exceedingly laborious and time-consuming. Furthermore, capturing gullies this way requires subjective interpretation from the gully erosion interpreters. As already mentioned above, it was especially difficult to distinguish between gullies and natural river beds/channels, floodplains, landslides, other erosion forms and bare soil. Although conventional mapping techniques were time-consuming and susceptible to subjectivity of the gully interpreters, much higher accuracies were achievable compared to automated techniques, e.g. supervised classification, support vector machines and segmentation (e.g. Le Roux *et al*., 2008a; Taruvinga, 2008; Pirie, 2009, Mararakanye, 2011).

Another limitation is that it was not possible to visually delineate different categories of eroded lands (e.g. active or non-active gullies). For example, it is postulated that many erosion features in the Northern Cape Province are of considerable age and may not be contributing to current sediment yields (e.g north of Graaff-Reinet) (Boardman *et al*., 2003). In contrast, observations in the field and several other sources of literature indicate that several gullied areas in the Eastern Cape are active and contribute to current sediment yields. Therefore, erosion in these areas is as yet poorly understood and needs further investigation. Furthermore, only a qualitative appreciation of the factors influencing gully behaviour has been obtained and the processes behind gully erosion remain poorly understood. The reason for this is that several factors contribute to gully developments which are site and scale specific. This problem is coupled with South Africa's diverse set of climate, soil, land tenure, socio-economic conditions and farming practices. Fortunately, the degree of erosion can be estimated in conjunction with collateral information obtained by ground truthing and classification techniques in future research (see Le Roux and Sumner, 2011).

PART 4: CONCLUSION AND RECOMMENDATIONS

4.1. Summary

In this report, the ability to map erosion features, especially gullies, based on SPOT 5 imagery is illustrated. Previous studies (Le Roux *et al*., 2008a; Taruvinga, 2008; Pirie, 2009, Mararakanye, 2011) and the current study indicate that much higher accuracies are achievable by conventional mapping techniques compared to automated techniques. Therefore, mapping of erosion features was done by visual interpretation and vectorization from SPOT 5 imagery from various acquisition dates between 2006 and 2008 for the whole country.Results shows that Northern Cape (160 885 ha), Eastern Cape (151 759 ha), Kwazulu Natal (87 522 ha), Free State (64 674 ha), Limpopo (58 669 ha), Western Cape (25 403 ha), Mpumalanga (17 420 ha) and North West (10 782 ha) Provinces are most severely affected by gully erosion. The Gauteng Province is not severely affected by gully erosion (110 ha).

4.2. Challenges and Recommendations

The limitations of this study include subjectivity during interpretation by the gully erosion interpreters, it was not possible to visually delineate different categories of eroded lands (e.g. active or non-active gullies), and only a qualitative appreciation of the factors influencing gully behaviour was obtained with the processes behind gully erosion remaining poorly understood. For example as mentioned above, it is postulated that many erosion features in the Northern Cape Province are of considerable age and may not be contributing to current sediment yields. In contrast, observations in the field and several other sources of literature indicate that several gullied areas in the Eastern Cape are active and contribute to current sediment yields. Therefore, erosion in these areas is as yet poorly understood and needs further investigation.

In this context, recommendations include estimation of the degree of erosion in conjunction with collateral classification techniques and the quantification of the influence of factors in gully development. This can mainly be achieved by quantifying the influence of different gully contributing factors by correlating existing gully maps with other available spatial datasets in a GIS (e.g. Geology, Land Types, DEMs, Land Cover etc.) (see Le Roux and Sumner, 2011). Quantifying the influence of factors in gully development will facilitate the selection of suitable alternatives for preventing or reducing soil loss, especially at municipal and provincial levels.

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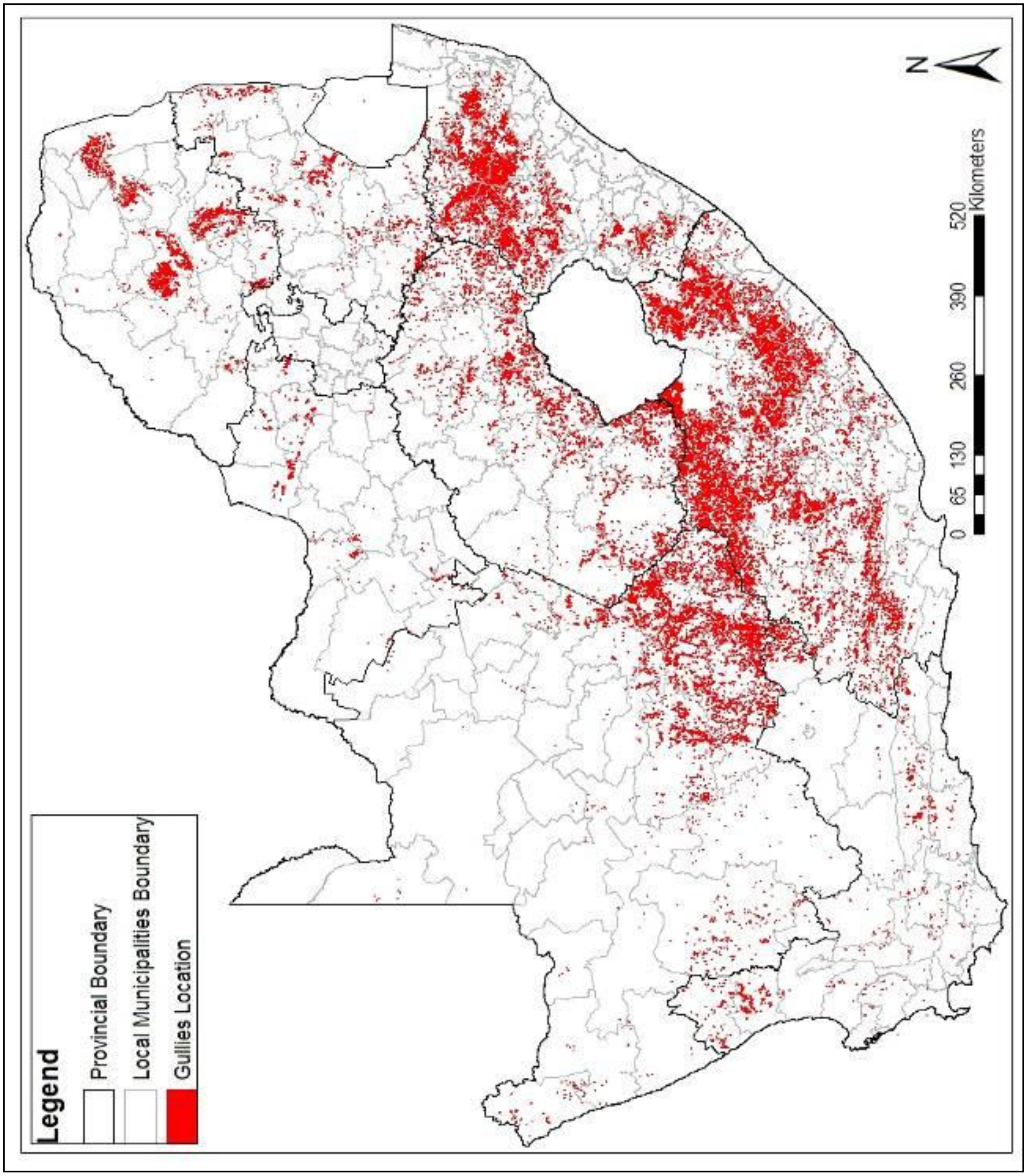
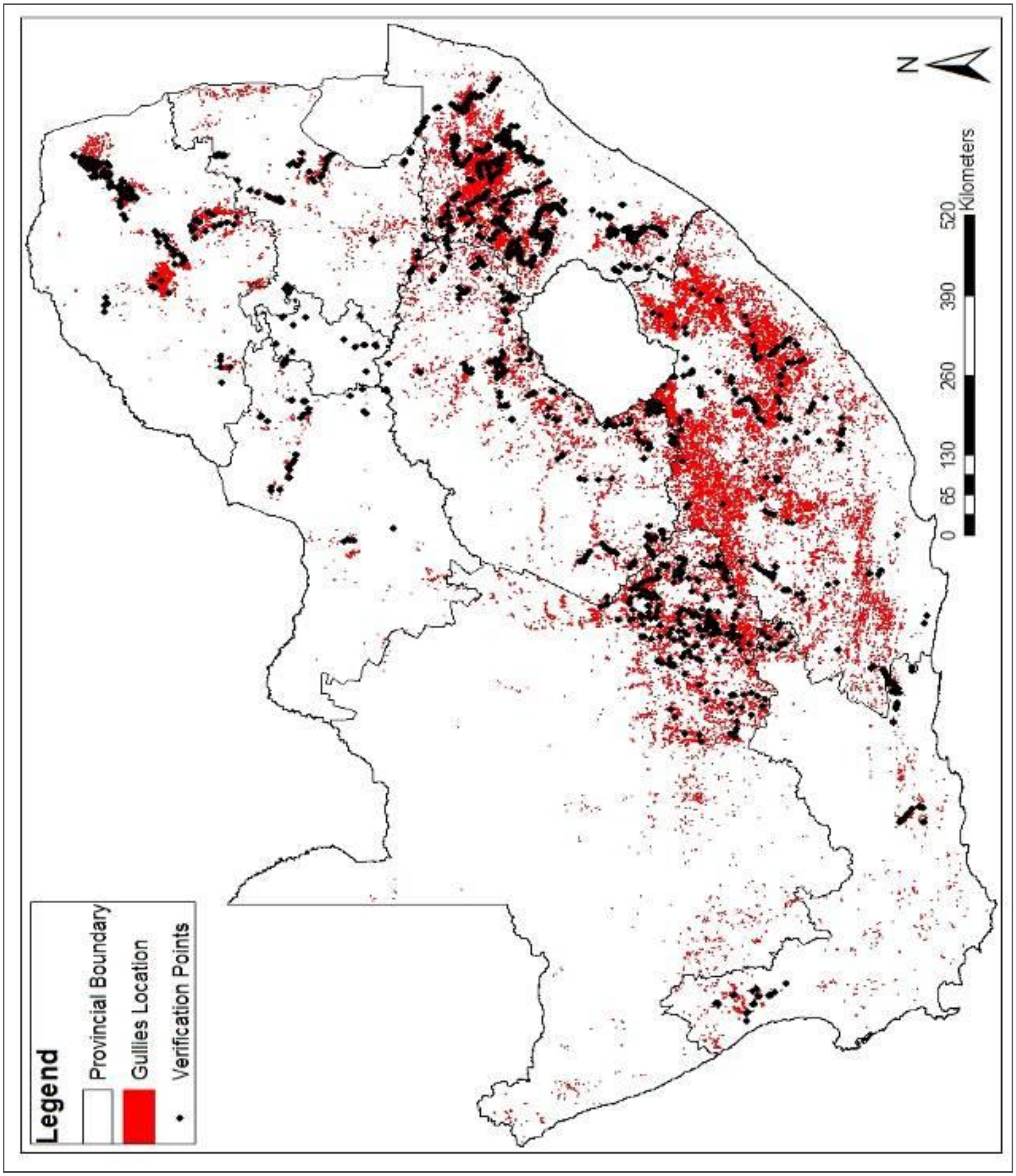
APPENDICES

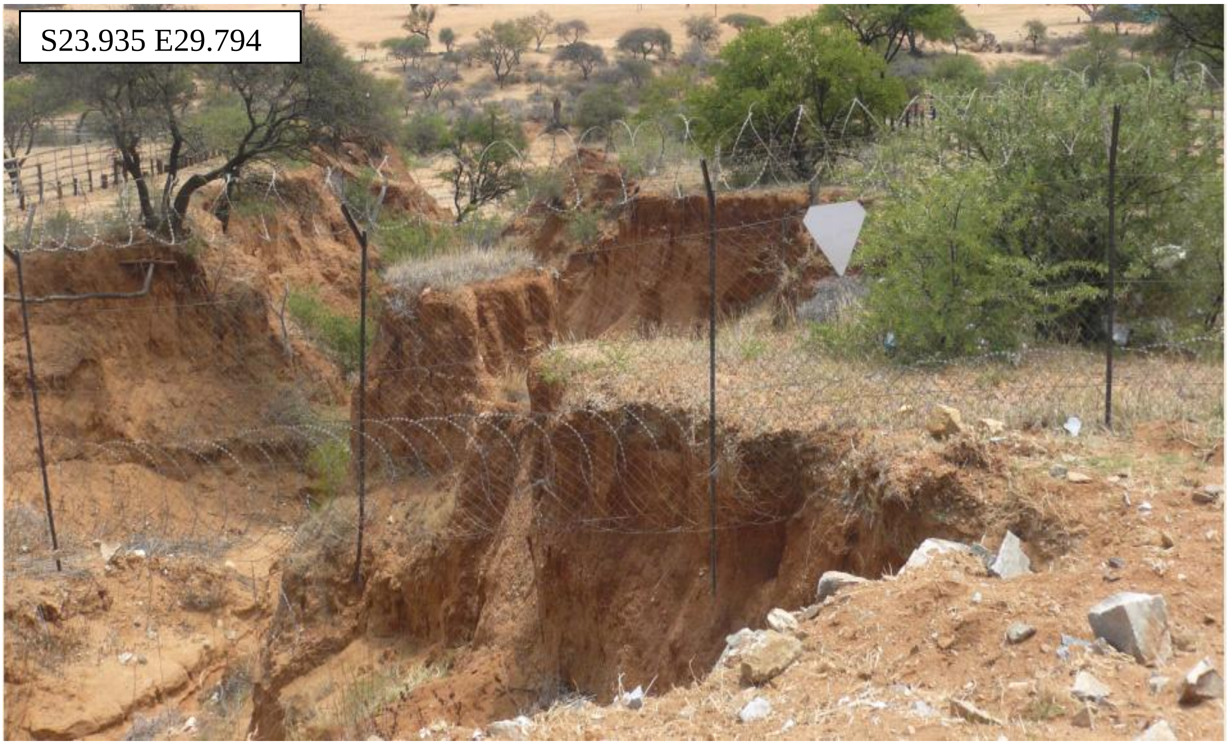
Appendix A: Gully Erosion Location Map of South Africa



Appendix B: Distribution of Verification Points

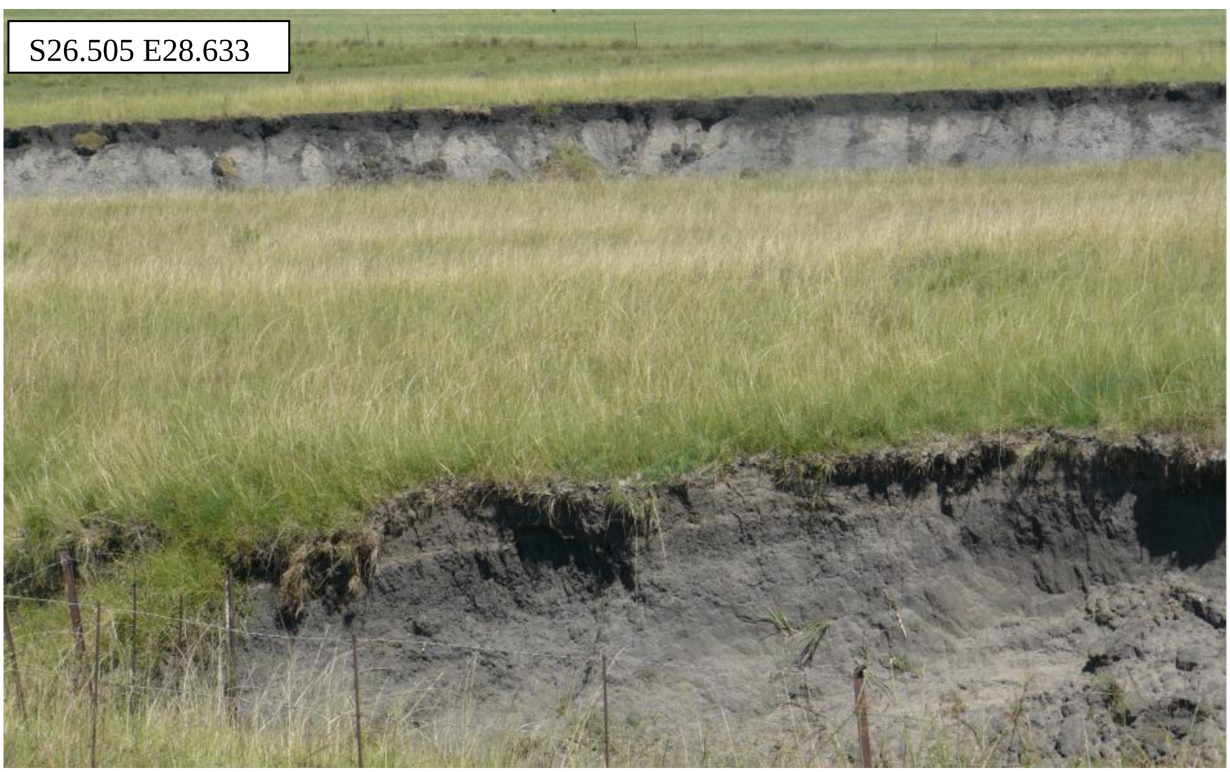


Appendix C: Selected Gully Erosion Photos in Limpopo Province



Appendix D: Selected Gully Erosion Photos in Mpumalanga Province

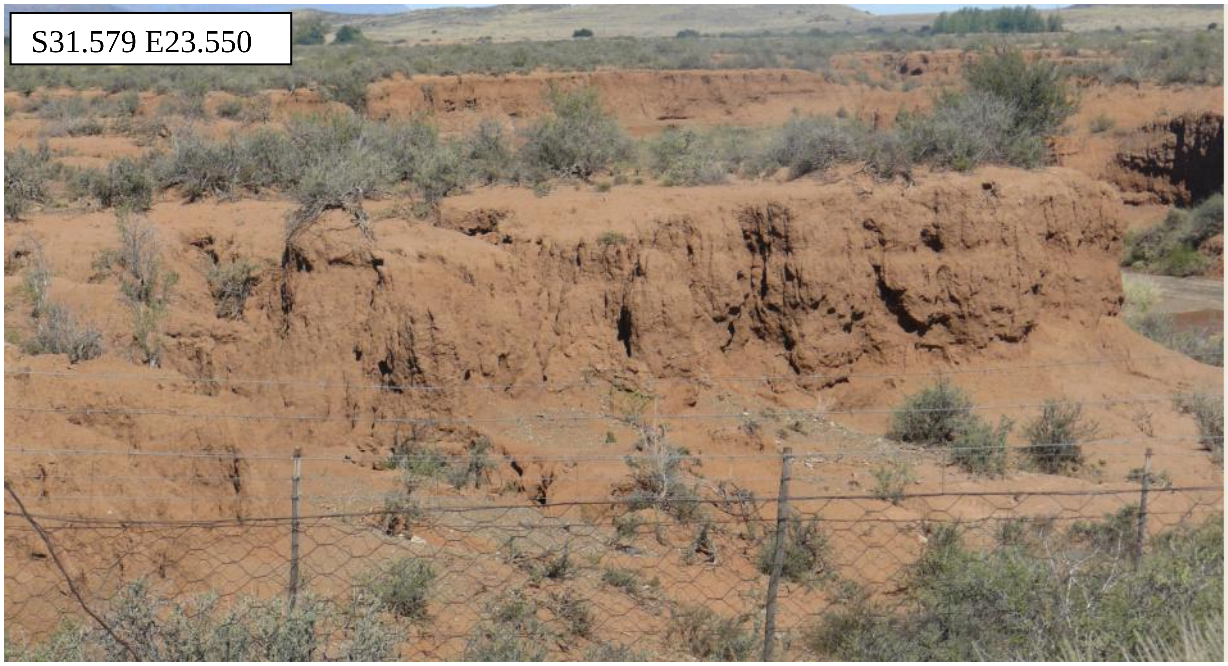
Appendix E: Selected Gully Erosion Photos in Gauteng Province



Appendix F: Selected Gully Erosion Photos in North West Province

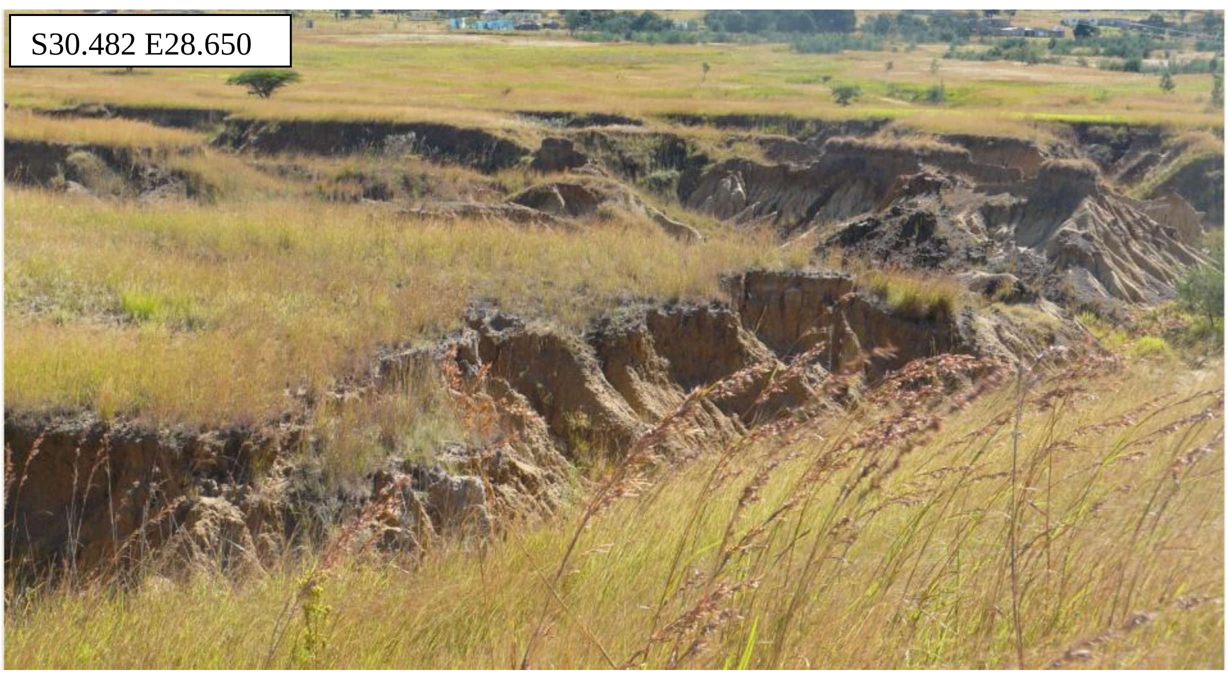
Appendix G: Selected Gully Erosion Photos in Free State Province

Appendix H: Selected Gully Erosion Photos in Northern Cape Province



Appendix I: Selected Gully Erosion Photos in Western Cape Province

Appendix J: Selected Gully Erosion Photos in Eastern Cape Province



Appendix K: Selected Gully Erosion Photos in Kwazulu Natal Province