IWMI Working Paper

172

Mapping Irrigated Areas in the Limpopo Province, South Africa

Xueliang Cai, James Magidi, Luxon Nhamo and Barbara van Koppen

IWMI International Water Management Institute

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LIMPOPO PROVINCIAL GOVERNMENT
DEPARTMENT OF AGRICULTURE AND RURAL DEVELOPMENT

CGIAR RESEARCH PROGRAM ON Water, Land and Ecosystems

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Project

This study, *Irrigated Area Mapping in the Limpopo Province,* is part of the DAFF-supported project *Revitalization of Smallholder Irrigation in South Africa.* It is a component of the Global Irrigated Area Mapping (GIAM) initiative of the International Water Management Institute (IWMI), and is a part of the CGIAR Research Program on Water, Land and Ecosystems (WLE).

Collaborators

This research study is a collaboration of the following organizations:

International Water Management Institute (IWMI)

Department of Agriculture, Forestry and Fisheries (DAFF)

Limpopo Department of Agriculture and Rural Development (LDARD)

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Acronyms

CAADP	Comprehensive Africa Agriculture Development Programme
CGIAR	A global research partnership for a food-secure future
DAFF	Department of Agriculture, Forestry and Fisheries
GDP	Gross Domestic Product
GIAM	Global Irrigated Area Mapping
GIS	Geographic Information System
GPS	Global Positioning System
GT	Ground Truth
ICT	Information and Communication Technology
IWMI	International Water Management Institute
LDARD	Limpopo Department of Agriculture and Rural Development
LULC	Land use/Land cover
MODIS	Moderate Resolution Imaging Spectroradiometer
MVC	Maximum Value Composite
NASA	National Aeronautics and Space Administration
NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NLC	National Land Cover
ODK	Open Data Kit
SDG	Sustainable Development Goal
USGS	United States Geological Survey

Summary

Recent studies reveal that there are many differences in reported numbers of irrigated areas, especially in developing countries, and that significant knowledge gaps and uncertainties remain to inform investment decisions and policy making. This is particularly relevant in South Africa, where the National Development Plan (NDP) envisages to increase irrigated areas; yet there are uncertainties in reported information on irrigated areas, especially on informal irrigation. This report summarizes the findings of a collaborative effort by the International Water Management Institute (IWMI), Department of Agriculture, Forestry and Fisheries (DAFF) and the Limpopo Department of Agriculture and Rural Development (LDARD) to map and assess irrigated areas in the Limpopo Province, South Africa. An assessment based on remote sensing was carried out to map agricultural areas in 2015 using a combination of Landsat and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. The mapping process was supported with data from previous irrigated area mapping exercises by DAFF and three field ground truthing (GT) surveys jointly conducted with the partners. A literature review and analysis of irrigated area statistics showed gaps and inconsistencies in different government reporting lines to comprehensively include irrigated areas. The mapping based on remote sensing estimated in total 1.6 million hectares (Mha) of cropland in the province, with only 262,000 ha actually irrigated in the 2015 winter season. The center-pivot irrigation systems, usually with high capital inputs, were underutilized with only 47,000 ha (29%) actually irrigated out of 164,000 ha equipped with center pivots.

INTRODUCTION

Agriculture is a relatively small but important sector in South Africa as it accounts for about 3% of national gross domestic product (GDP) and 7% of formal employment. The South African National Development Plan (NDP) (NPC 2012) sets to stimulate the country's economic growth in multiple sectors including agriculture with special emphasis on irrigation. The typology of agriculture in South Africa is however interesting with successful commercial farming on one side, a large number of small subsistence farming on the other, and a range of out-growers in between (Pienaar 2013). This mosaic in South Africa's agriculture entails a pathway for the growth of emerging farmers as the government has set to improve the smallholder farmers' lot and reduce their vulnerability. However, it also poses challenges for targeted agricultural policies and investment in a dynamic environment where changes are constantly occurring and water resources management for the agriculture sector for all-inclusive and pro-poor interventions is hotly debated.

Irrigation is a key player in the terrestrial ecosystem concerning water, food, and eventually, the well-being of people and the environment. Irrigation is also the single largest abstractive water user in many countries (Johansson 2005). National and regional food security targets are often built on irrigation development. For example, the Comprehensive Africa Agriculture Development Programme (CAADP) sets a target to expand area under irrigation on the continent by at least 5 million ha (Mha) by 2025 (NEPAD 2014). There are renewed efforts to ensure food and water security as set out by many countries, development agencies and, globally, the United Nations' Sustainable Development Goals (SDGs), specifically Goals 1, 2 and 6 on poverty alleviation, zero hunger and provision of clean water and sanitation, respectively.

While policies and investment often focus on irrigation in many African countries, there is a general lack of data and information on the status of existing irrigation on the continent. Ali (2016) analyzed the reported irrigated areas for ten Asian countries and found that there are large variations in the reported numbers depending on their sources. The coefficient of variations of the ten countries ranges from 27 to 90%, rendering associated policies and investment plans which base their analyses on uncertain numbers, much less effective. The reason for the misapprehension is that there is a general lack of an accurate, up to date and comprehensive information set for a baseline, timely reporting of changes in irrigated areas and the corresponding production. Existing country reporting systems on which global data sets on irrigated areas, such as the Food and Agriculture Organization of the United Nations (FAO) AQUASTAT database, are based, are often estimates and aggregates coming through layers of national administrative systems. These results are often subject to errors and biases.

Remote sensing is a useful tool for mapping irrigated areas to better support water resources and agricultural development in developing countries where reliable reporting and monitoring systems are yet to be established. Valid for application at multiple scales such as global scale (Thenkabail et al. 2007), regional scale (Xiao et al. 2006), and basin scale (Cai and Sharma 2010), the remote sensing approach can map large areas within a short period of time and at low cost. More importantly, remote sensing can map the areas actually irrigated instead of areas equipped for irrigation. There can be profound differences between the two: sometimes the actual irrigated area is larger than the areas equipped, especially in regions where agriculture is more fragmented with informal irrigation, as in Africa and Asia. Sometimes, the actual irrigated area is much smaller, mainly in the case of large public irrigation systems where the actual command areas often shrink due to lack of maintenance. Remote sensing can overcome these problems and provide a "picture" of the real situation to the mapping period. It will further help understand the ecological footprint of food production, assess the potential of agricultural development within the planet's boundaries with limited land and water resources, and achieve a balance between the agricultural and natural ecosystems.

This report describes research outcomes to map irrigated areas using medium-resolution images of Landsat 8 in the Limpopo Province, South Africa. The activity was carried out in collaboration with DAFF and LDARD. The results based on remote sensing were compared with existing information from national and provincial sources. The gaps in current reporting lines were identified and alternative approaches through remote sensing to improve decision making for future investment were analyzed. Capacity-building and partnership were also part of the study.

In 2012, the International Water Management Institute (IWMI) embarked on an initiative to use satellite imagery to map irrigated and rain-fed areas to assess how agricultural water management practices are expanding in traditionally rain-fed areas across Asia and Africa. The resultant product is obtainable from IWMI's Water Data Portal (available at www.waterdata.iwmi.org/applications/irri_area). This initiative builds on IWMI's previous attempt at Global Irrigated Area Mapping (GIAM) (Thenkabail et al. 2007) which was the first of such maps, globally. In 2014, 2015 and 2016 these activities were coordinated from IWMI's regional office in South Africa, based in Pretoria, in close collaboration with DAFF and LDARD.

As IWMI's mapping activities attracted interests from DAFF and LDARD, they agreed to provide support to further refine IWMI's continental mapping methodology at local scale in the Limpopo Province, South Africa. The activity was further supported by the CGIAR Research Program on Water, Land and Ecosystems (WLE). DAFF and LDARD received on-the-job training during the course of the project and a training workshop was also conducted at the end of the project. The staff also participated in various project activities, including the identification, collection and analysis of existing reporting lines on irrigation and rain-fed agriculture; field surveys using Information and Communication Technology (ICT) Android global positioning system (GPS) and tablets; and geographic information system (GIS) analysis.

1. DESCRIPTION OF THE STUDY AREA

The Limpopo Province in South Africa is the northernmost province of the country, sharing international boundaries with Botswana, Mozambique and Zimbabwe (Figure 1). This province covers an area of 125,755 km^2, accounting for 10.4% of the total national area of South Africa with a population of about 5.4 million (Stats-SA 2015). The topography of the province is very contrasting ranging from bushveld to majestic mountains rich in indigenous forests and unspoilt savanna wilderness. The topography is divided into three distinctive regions which define the climate and vegetation of the province (Vincent et al. 2010). These include:

(a) Lowveld region (arid and semiarid)

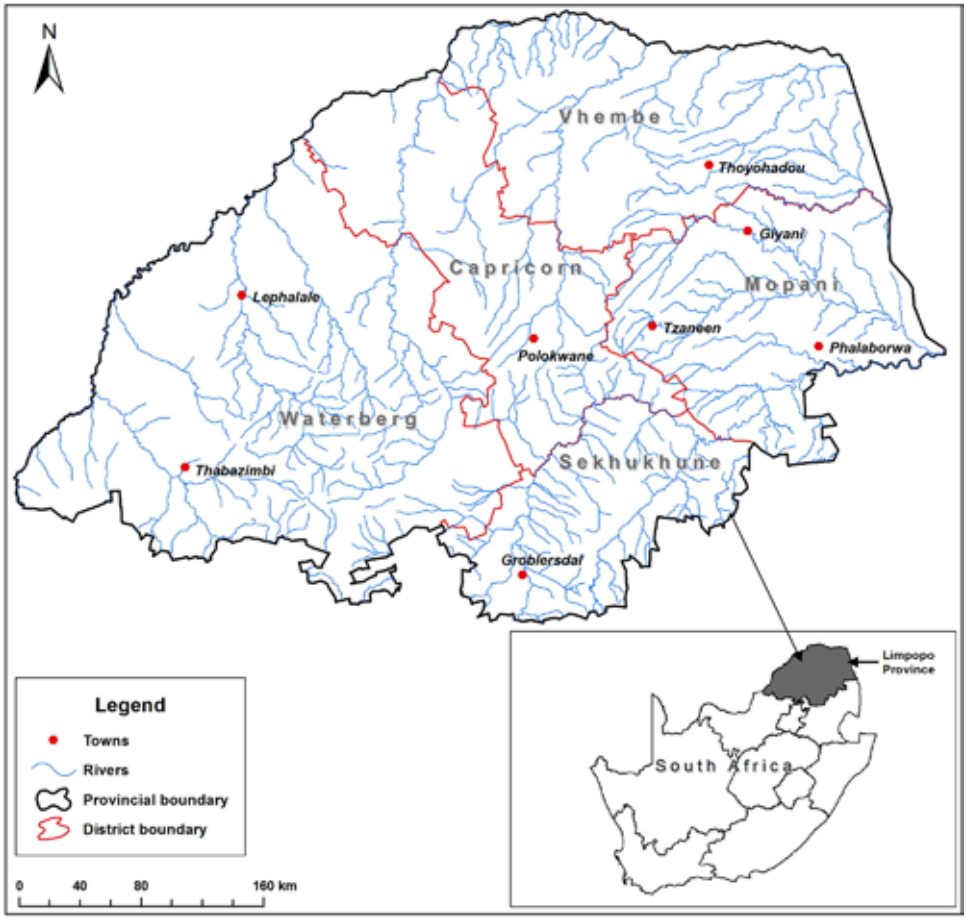
(b) Middle-veld region (semiarid region)

(c) Escarpment region (sub-humid climate with rainfall of over 700 mm per annum).

Most of the rainfall in the Limpopo Province occurs during summer (October to March), averaging 500 mm.year^{-1} whilst the other three seasons are generally dry. The eastern and northern parts are subtropical, with humid and hot summers. The average temperatures in summer are around 27 °C. In winter (May to September), the nights are cold and mostly frost-free, with chilly mornings and dry and sunny days (Vincent et al. 2010). However, in the Lowveld it can get very hot with temperatures reaching between 45 and 50 °C.

In terms of agriculture, the Limpopo Province is described as the "Garden of South Africa" because of its rich production of fruits and vegetables (Oni et al. 2012). The province is endowed

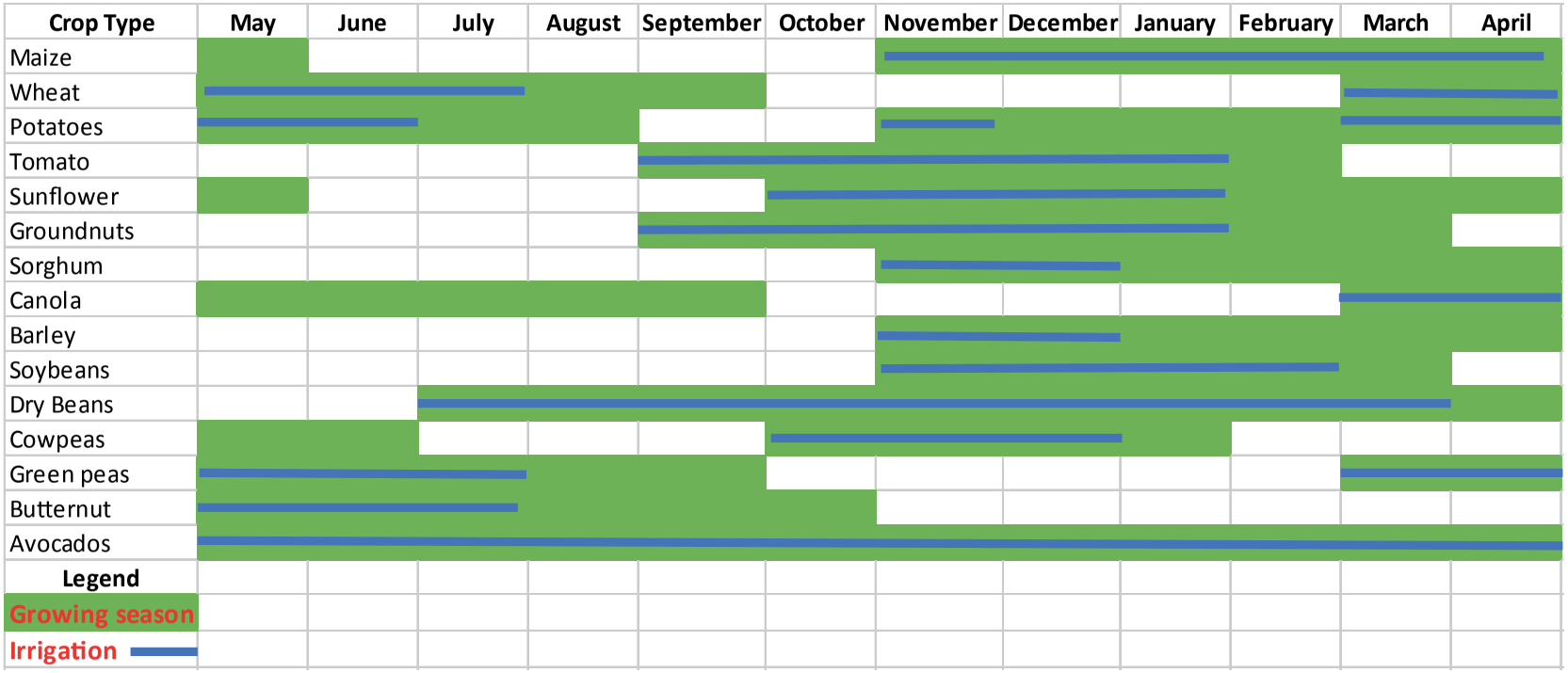
FIGURE 1. Map of the Limpopo Province in South Africa showing its districts and major towns.



with abundant agricultural resources and is one of South Africa's prime agricultural regions. According to the Department of Trade and Industry's provincial economies report (DTI 2003), the province produced the following in South Africa: mangoes (75%), papaya (65%), tea (36%), citrus, bananas, and litchis (25%), avocados (60%) and tomatoes (66%). Other major crops grown in the province include coffee, nuts, guavas, sisal, cotton, sunflower, maize, wheat and tobacco and timber (more than 170 plantations). Grapes are also successfully cultivated in the Waterberg District. The largest tomato farm in South Africa lies between Tzaneen and Makhado. Crop production is done by both commercial and smallholder farmers. Many of the rural people still practice subsistence farming. Cattle ranching is practiced mainly in the bushveld region and is often combined with controlled hunting. Figure 2 gives the cropping calendar of some of the irrigated crops in the Limpopo Province. There is cultivation throughout the year in the province, which promotes the garden status of South Africa.

However, according to previous studies, the most limiting resource in the province is water and most of the smallholder farms are under rain-fed agriculture (Oni et al. 2012). Approximately 70% of the prime agricultural land in the province is occupied by commercial farmers and the rest is occupied by smallholder farmers located mainly in the former homelands.

FIGURE 2. Cropping calendar of some of the irrigated crops grown in the Limpopo Province.



Source: Developed by Luxon Nhamo from different sources on cropping guidelines of crops for the Limpopo Province.

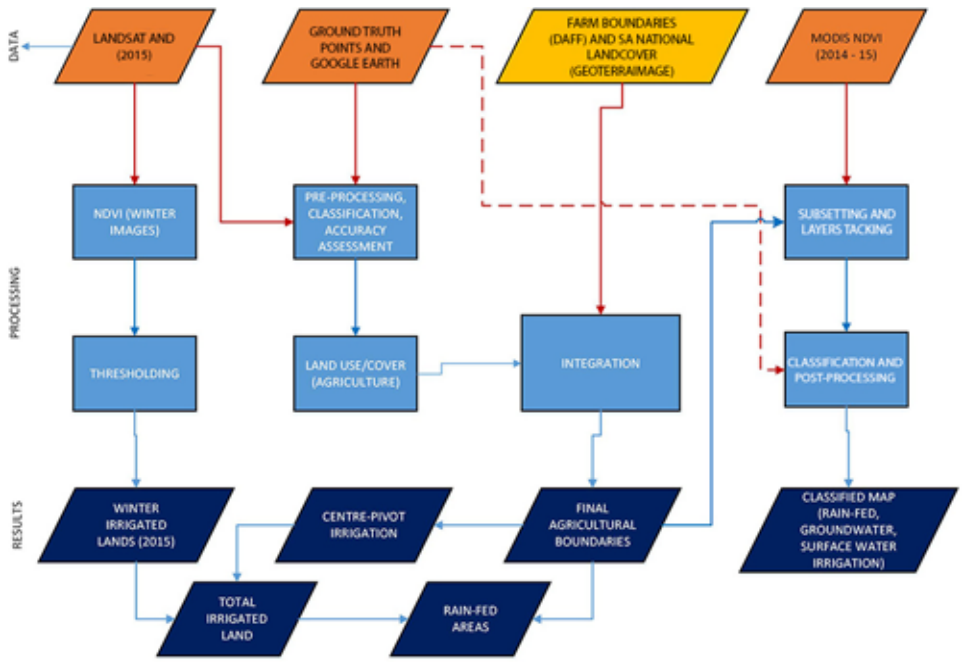
2. METHODOLOGY

2.1. Delineation of Croplands Using Remote Sensing

A series of data sets were collected and used to come up with the final map of croplands of the Limpopo Province. These include Landsat 8 and the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) time series images, ground truth (GT) points, existing national Land use/Land cover (LULC) maps, statistics and government surveys of the agricultural areas.

The mapping procedure included data collection, data processing and map generation (results) as indicated in the methodological flow-chart shown in Figure 3. It needs to be noted that the delineation of the agricultural area is based on one time Landsat 8 image for 2015. The identification of plots/fields that are cultivated throughout the year (so including winter irrigation) was achieved through the NDVI analysis. Area equipped with center pivots highlighted in this study refers to all areas equipped with pivots whether irrigated or not. Center pivots are highly mechanized irrigated areas and are easily identified by their circular shape.

FIGURE 3. Flow-chart of the data inputs, key procedures and outputs of the irrigation mapping.



2.2. Satellite Data Download and Analysis

The primary data used to map agricultural areas in the Limpopo Province is the cloud-free Landsat 8 imagery of 2015, with a spatial resolution of 30 m and temporal resolution of 16 days. The province requires eight (8) Landsat 8 scenes (Figure 4) to cover the entire area. About 247 Landsat scenes from 2014 to 2015 were downloaded from the United States Geological Survey's (USGS) Earth-explorer website, 137 scenes had a cloud cover less than 10% and 110 scenes had cloud cover above 10%. The visibility of most summer Landsat scenes was hampered by clouds, making it impossible to make up a cloud-free mosaic for the summer season. The most suitable images for classification were found between May and September, and for this study July and August images were used (Table 1).

FIGURE 4. Landsat scenes that cover Limpopo Province. The numbers are the paths/rows of respective image tiles.

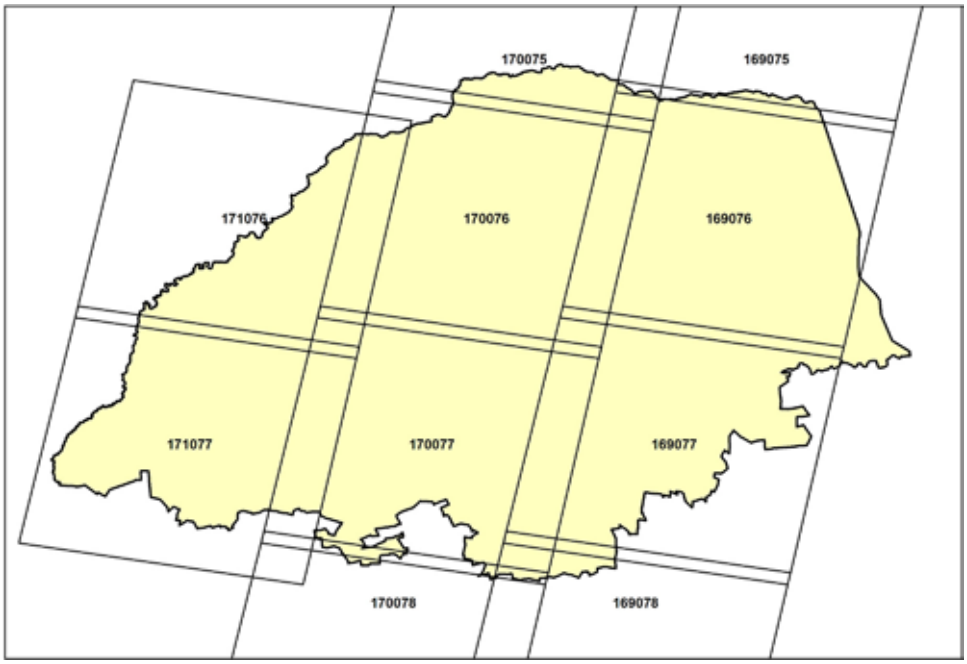


TABLE 1. Landsat scenes used in the classification and extraction of winter irrigation.

Image ID	Path/Row	Date acquired	Sun azimuth	Sun elevation
LC81690762015220LGN00	169/076	2015/08/08	41.37094039	39.80762522
LC81690772015220LGN00	169/077	2015/08/08	40.83829258	38.5734537
LC81690782015220LGN00	169/078	2015/08/08	40.35146455	37.33107129
LC81700752015211LGN00	170/075	2015/07/30	40.1789006	39.09253599
LC81700762015211LGN00	170/076	2015/07/30	39.67319419	37.84354791
LC81700772015211LGN00	170/077	2015/07/30	39.21111909	36.58690461
LC81710762015202LGN00	171/076	2015/07/21	38.1777553	36.30092157
LC81710772015202LGN00	171/077	2015/07/21	37.7700256	35.02597225

The MODIS NDVI 250 m resolution with 16 days of maximum value composite (MVC) from October 2014 to March 2016 was downloaded from the United States Geological Survey's (USGS) website for temporal profiling of GT points. This NDVI 250 m is derived from bands 1 and 2 of the MODIS on board the National Aeronautics and Space Administration's (NASA's) Terra satellite. They are useful to fill gaps in temporal data sets due to cloud-affected Landsat images.

2.3. Ground Truth (GT) Data Collection

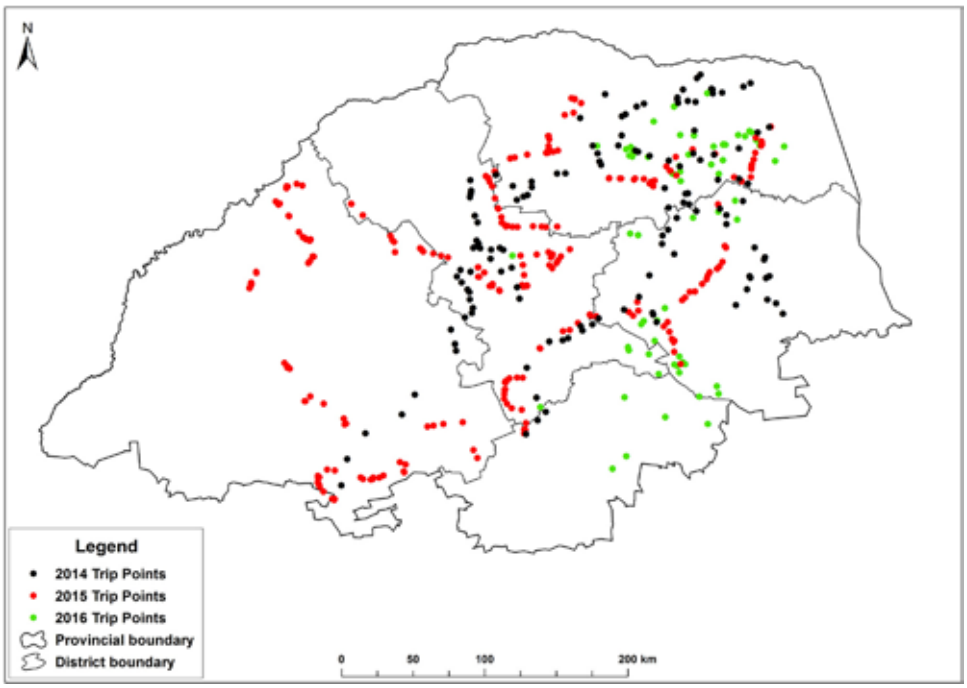
Detailed GT points (or ground verification) data were collected from field visits in the province in 2014, 2015 and 2016. GT points were captured using an application based on an Android tablet called Open Data Kit (ODK) Collect. The ODK application allows the surveyor to travel in the field with fewer carry-ons to record field observations as well as pictures on site by a few clicks

and text inputs. One important advantage of the ODK is that data recorded in the field are sent to a server through an Internet connection, which the surveyor can choose through either mobile data collection immediately in the field, or through WiFi when the device is connected to a WiFi hot spot at a later stage. Sending collected data to the server from the field or in the evenings, when reaching an accommodation with WiFi, is an important data safety feature to prevent losses. A more detailed description of the survey is attached in Annex 1.

GT points were used to both gain an understanding of what is happening on the ground and accurately assess the final product. At each GT point the following information was recorded during the field trip: spatial location of the field visited, land cover, irrigation water source (surface water or groundwater, or rain-fed), and crop type and dominance. There were also some remarks attached to each GT point. Google Earth high resolution (0.61-4 m) data were also used to generate more "GT points" in the office. The "zoom-in" views of Google Earth provide information on whether the land is an agricultural area, and sometimes even evidence on whether it is irrigated, rain-fed or fallow.

The three years' survey yielded a total of 455 GT points in the Limpopo Province. The GT points focused on irrigated areas and especially small-scale irrigated areas. Figure 5 is a map of the GT points taken during the three years of field visits. The surveys of 2014 and 2015 (both conducted in November) focused on collecting irrigation information through rapid field assessment, which totals 375 points. These 2014 and 2015 points were mainly for field verification and accuracy assessment of the final products. The 2016 survey was however largely questionnaire-based with extensive interactions with farmers. The survey covered a large range of topics including demographic, economic, farming, marketing, types of crops grown, challenges, and water source (both surface water and groundwater). The total number of 2016 survey points is 80, and it covered mainly smallholder irrigation schemes. The analysis of the broader questions is reported separately (Van Koppen et al. 2017).

FIGURE 5. GT points visited in 2014, 2015 and 2016.



2.4. Other Secondary Data Sets Used

Existing similar mapping products which include the South Africa National Land Cover (NLC) map developed in 2013-14, DAFF's 1999 and 2015 maps of field boundaries, map of the crop estimate committees and IWMI's global irrigated area mapping (GIAM) were also used to compare and complete the final product of this study.

The NLC map was generated using multi-season Landsat 8 imagery of 2013 and 2014 by GEOTERRAIMAGE (GEOTERRAIMAGE 2015). The map contains 11 agricultural classes which are listed below. It is evident that the classification does not separate irrigated versus rain-fed area, except for center pivots.

1. Cultivated Commercial Fields
2. Cultivated Commercial Pivots
3. Cultivated Orchards
4. Cultivated Vines
5. Cultivated Permanent Pineapple
6. Cultivated Subsistence
7. Cultivated Cane Pivots
8. Cultivated Cane Commercial - Crop
9. Cultivated Cane Commercial - Fallow
10. Cultivated Cane Emerging - Crop
11. Cultivated Cane Emerging - Fallow

In 1999 and 2015, DAFF developed the maps of field boundaries. These maps were digitized from SPOT 5 imagery (2.5 m resolution) at a scale of 1:10 000 for the whole country. These data sets included annual crops, horticulture and viticulture, old fields, center pivots, shade nets, subsistence farming and plantations. As in the previous case, the data sets do not specifically identify irrigation and rain-fed areas, except for center pivots.

2.5. Mapping Agricultural Areas

Maps of South African National Land Cover (SANLC) and DAFF field boundaries have shown a good level of accuracy and they are reasonably up to date. The current irrigated area mapping initiative used the two data sets for comparisons, verification and completion of the gaps that might have been left out by the remote sensing exercise. The irrigated area mapping exercise mainly used Landsat 8 images of 2015 to plot out croplands.

The delineation process started with processing of cloud-free Landsat 8 data which were layer-stacked and mosaicked into three segments for the entire Limpopo Province. The maximum likelihood supervised classification method was used to separate different LULC types in the province. In supervised classification, the user recognizes classes in the available images as shown in Figure 6, based on the prior knowledge (personal experience, GT visits, and Google Earth zoom-in views). Prior knowledge of the area allows the user to select and set up discrete samples for each LULC class and assign names to them. These samples are called training sites and spectral signatures (mean values and variance of digital number--DN) of each training site will be computed. Using statistical processing, every pixel on the images will be compared with the signatures on the

training sites and will be assigned to the classes it resembles. In this study, the maximum likelihood supervised classification was run for the whole province and training sites were created.

The focus of the current classification and analysis is on delineating agriculture areas. Training samples of four sets of LULC classes which led to the general land cover classification were used in the present classification. These four classes included water, urban and bare areas, natural vegetation and agriculture. The description of each class is shown in Table 2.

FIGURE 6. Developing training samples for supervised classification.

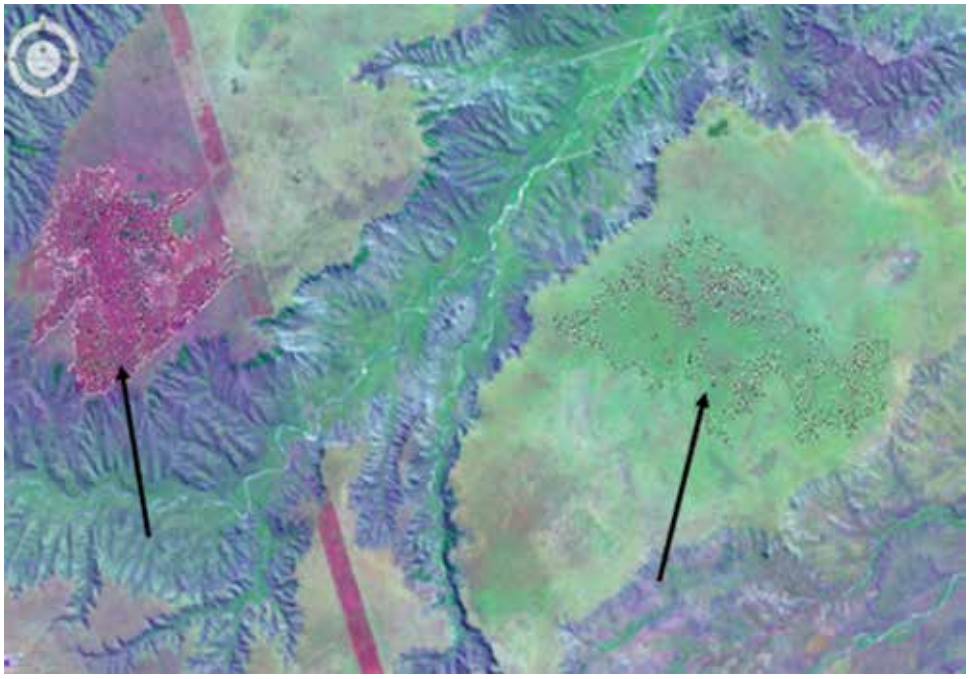


TABLE 2. Land cover classes derived from the Landsat 8 image classification.

Class	Description
Water	Dams, rivers, wetlands
Natural vegetation	Natural vegetation, shrubs, bush encroachment, mountains
Agriculture	Irrigated, non-irrigated croplands and orchards
Urban and bare areas	Formal and informal residential areas, administrative areas, industrial areas, transport networks, excavations, construction sites, open spaces and bare ground

The resulting map derived from the above procedures was then compared with existing LULC maps. Direct comparisons of the three maps -- IWMI, DAFF and NLC 2014 (GEOTERRAIMAGE 2015) show discrepancies in agricultural boundaries. The differences were especially significant in smallholder farming areas, particularly in former homelands. The DAFF and NLC 2014 maps tended to exclude more areas where the field plot is small, and where plot demarcations are less visible. Confusions are also observed for perennial crops such as fruits with timber plantations. Google Earth zoom-in views were used extensively to verify the discrepancies. When a fruit-tree plot with clear boundaries that was not a timber plantation was identified, preference was given

for it to be classified as an agricultural land, even though it may have not been cultivated in the past few years. Tree plantations such as eucalyptus and pine trees were classified as forests; so, they were not included as agricultural land.

2.6. Mapping 2015 Winter Irrigated Areas

The Normalized Difference Vegetation Index (NDVI) was used to map irrigated areas. NDVI is a slope-based vegetation index derived from the reflectance values of near-infrared and red portions of the electromagnetic spectrum, and is used to quantify photosynthetic capacity, moisture stress, and vegetation productivity. NDVI is calculated as follows:

$$NDVI = \frac{NIR\text{-}R}{NIR+R} \tag{1}$$

where, NIR represents the spectral reflectance in near-infrared band and R represents the red band. Chlorophyll, which is the primary photosynthetic pigment in the plant absorbs visible light (0.4-0.7 µm) bands but reflects infrared light (0.7-1.1 µm) wavelengths. Healthy vegetation reflects more infrared and absorbs more red and blue portions of the electromagnetic spectrum. The blue portion is affected by atmospheric scattering; hence the use of red and near-infrared bands to calculate NDVI and other vegetation indices. In arid areas and dry seasons there is less absorption of the visible light and low reflection of the infrared light, resulting in a low NDVI value; and the opposite applies in humid areas and wet seasons. NDVI values range from -1 to +1 where 0 to1 represents high plant productivity, and -1 to 0 represents no vegetation cover, presence of clouds, water or glaciers. NDVI was calculated from the Landsat 8 cloud-free 2015 winter images.

The NDVI threshold was used to separate the irrigated and non-irrigated lands between July and August 2015 during the dry season, which falls during the winter season in South Africa. Pixel values above the threshold value of 0.14 were selected and classified as winter irrigated areas and those below were classified as non-irrigated areas. This is based on the assumption that in the Limpopo Province, no crops could have healthy conditions (represented by NDVI) during the dry winter season without irrigation. So any crops within agricultural areas with NDVI above certain thresholds should be irrigated.

3. RESULTS

3.1. Irrigation Status from the Field Survey

The results from the GT surveys undertaken in 2014, 2015 and 2016 show that most of the surveyed lands are owned by smallholder farmers and cultivated under rain-fed agriculture. However, it has to be noted that the design of the 2014, 2015 and 2016 field surveys was to capture more smallholder farming and, hence, it is not representative of the province. The pie-chart shown in Figure 7 indicates that of the 455 points surveyed, 50% of the cultivated land is under smallholder farming (small-fragmented and small-relatively dense), 16% is under emerging commercial farmers (medium-relatively dense), 16% is under large commercial farming (large-contiguous) and 18% comprises smallholder irrigation schemes.

The surveys also showed that there is significant groundwater irrigation as indicated by the pie-chart given in Figure 8. Of the agricultural land sites surveyed 27% is irrigated from groundwater sources, 26% uses surface water sources and 10% is under conjunctive use (uses both groundwater and surface water). However, 37% of the agricultural land still depends on rainfall.

FIGURE 7. Distribution of agriculture types by scale.

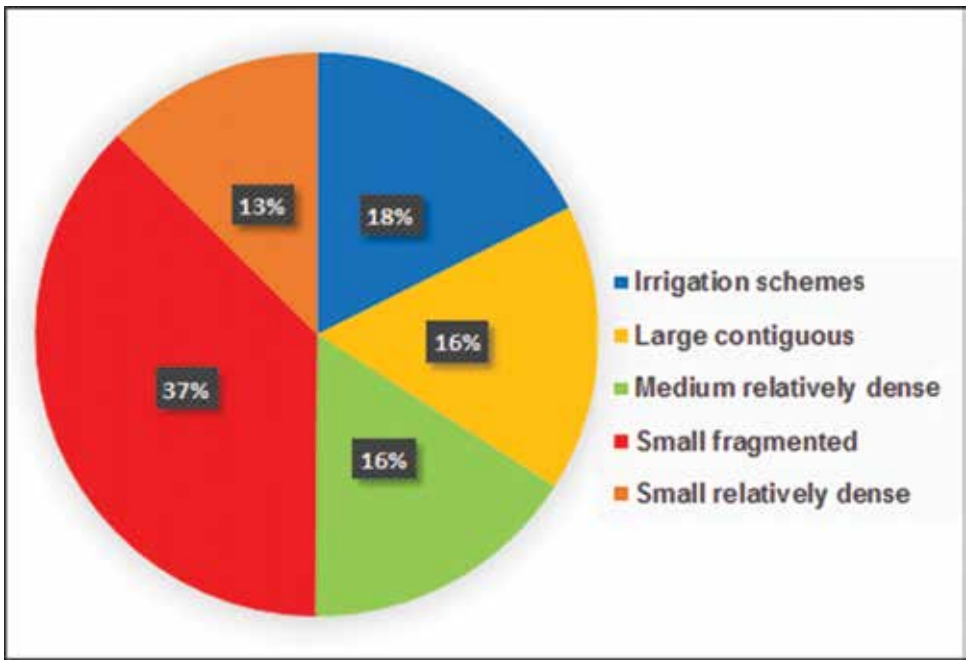
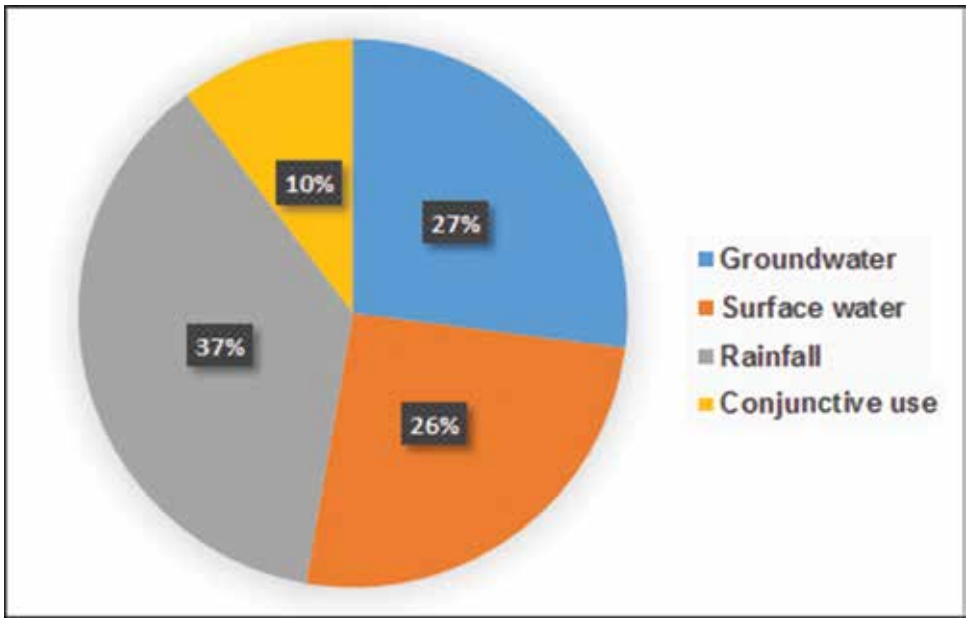


FIGURE 8. Distribution of agricultural systems by water sources.



The surveys also revealed that irrigation is differently distributed among the types of farming systems as shown in Table 3. The large contiguous, medium, relatively dense and small farm types are mostly irrigated with groundwater with a very small proportion under rain-fed agriculture. The conjunctive use of water is mainly common in farm types that are large contiguous and irrigation schemes. Groundwater is the dominant water source supplying 76% of large- to medium-scale farming while only 13% is supplied with surface water.

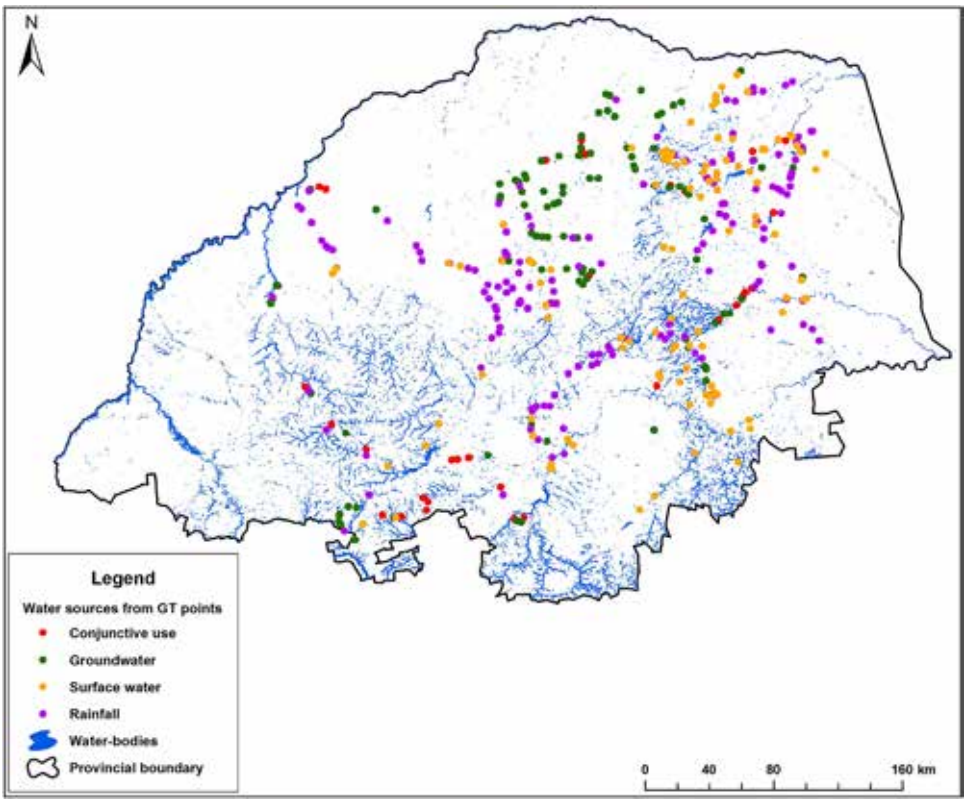
TABLE 3. GT points among small- to large-scale farming with different water sources.

Farm type	Groundwater	Surface water	Conjunctive use	Rainfall	Sum
Large, contiguous	0	29	42	4	75
Medium, relatively dense	61	1	0	11	73
Small, relatively dense	39	18	0	0	57
Small, fragmented	20	0	0	152	172
Irrigation schemes	3	69	6	0	78
Sum	123	117	48	167	455

On the other hand, the smallholder farming sector surveyed relies heavily on rain-fed agriculture. About 88% of the small fragmented farming is rain-fed (Table 3). Only 12% of this farming is irrigated and mostly from groundwater. Irrigation schemes generally use surface water for irrigation. Overall, the farm types under irrigation generally use more surface water than groundwater.

Generally, the spatial distribution of irrigation with different water sources has hardly any relation to the distribution of water bodies. Figure 9 is a map showing the surface water bodies from NLC 2013-14 map and the irrigated and rain-fed areas in the Limpopo Province identified during the three field trips. A significant amount of groundwater irrigation was found in areas with dense surface water bodies, while the surface water irrigation tends to be more closely related to the distribution of surface water. But, generally most cropland areas were under rain-fed agriculture, especially in smallholder farming areas.

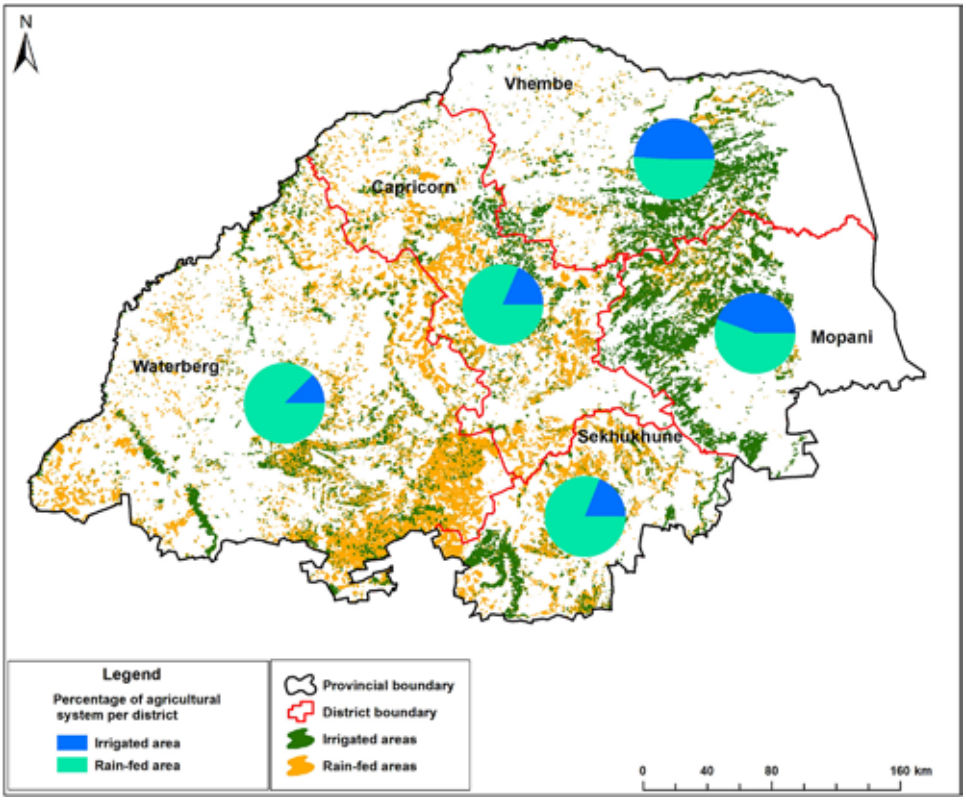
FIGURE 9. The distribution of 2014, 2015 and 2016 GT points of different irrigation and rain-fed farming systems along with surface water bodies.



3.2. Delineated Agricultural Areas in the Limpopo Province

The agricultural areas in the Limpopo Province by agricultural systems (rain-fed and irrigated), shown in the map in Figure 10, are mapped for the year 2015. The rain-fed areas were derived by subtracting winter irrigated areas, areas equipped with center pivots and areas under irrigation schemes as obtained from the 2016 field survey. Winter irrigated fields were identified by their plant richness during the winter season (July to August) using NDVI, as vegetation is expected to be dry during winter. The remaining agricultural fields were then designated as rain-fed.

FIGURE 10. Agricultural areas by system (rain-fed and equipped for irrigation) showing proportion of agricultural systems in each district in the Limpopo Province.



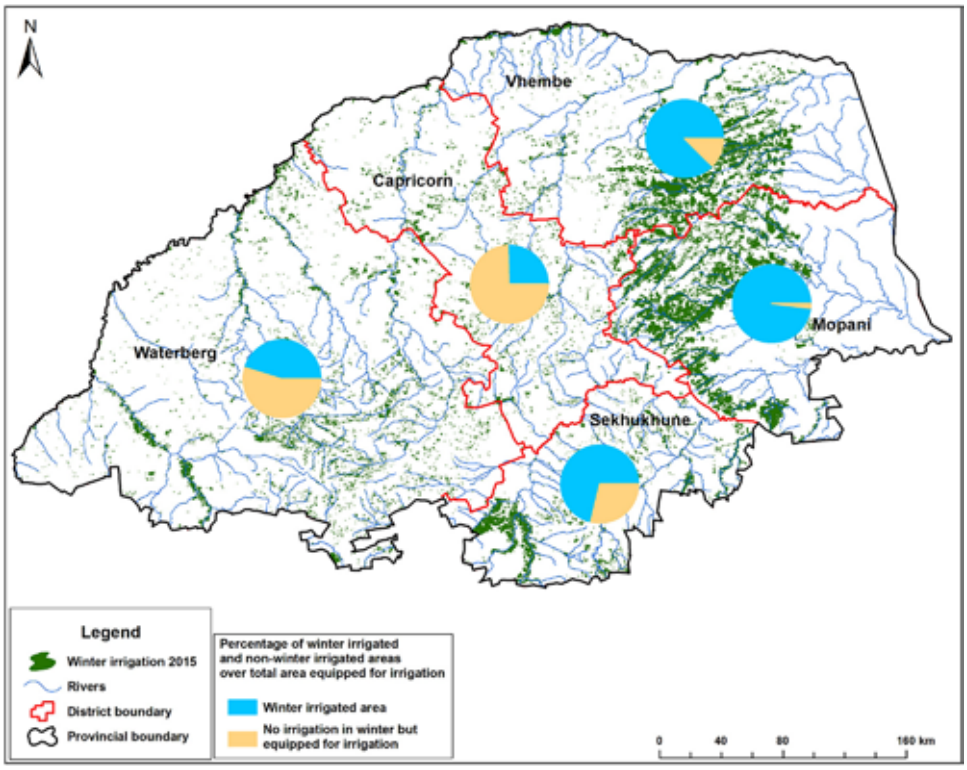
The total cropland area in the Limpopo Province, according to the IWMI-derived 2015 map of the Limpopo Province, was 1.6 million ha, whilst DAFF field boundaries map has a total of 1.4 Mha, giving a difference of 200,000 ha between the two sets of map products. The area equipped for irrigation in the province occupies 380,000 ha representing 23% of the cropped area while rain-fed areas occupy 1.3 Mha equalling 77% of the total cropped area. The map also gives the proportion of agricultural systems (rain-fed and irrigated) per district in the province shown by means of the pie-charts. The highest proportion of area equipped for irrigation occurs in Vhembe and Mopani districts; this is very low in Capricorn, Waterberg and Greater Sekhukhune. But, generally, agriculture in the province is rain-fed. A complete list of land cover area by type of agriculture per district and municipal levels and former homeland boundaries is presented in Annex 2.

3.3. The Winter Irrigated Areas in the Limpopo Province

The IWMI 2015 winter irrigated areas that are actually irrigated (Figure 11) were derived from NDVI analysis using Landsat images. As mentioned, when NDVI indices are high on an agricultural land from July to August, it would mean that there is actual irrigation in the particular plot/field as the winter season is dry in Limpopo. Map of winter irrigated areas shows that there is a high concentration of winter irrigation in Mopani and Vhembe districts which are to the east of the province. Most of the irrigated areas are generally concentrated in areas where there is a predominance of bodies of surface water. Total winter irrigated areas in 2015 derived from the Landsat data set totalled 262,000 ha; yet the total cropland area for the province for the same year was 1.6 Mha. Therefore, only 16% of cropland and 69% of the area equipped for irrigation in the Limpopo Province were irrigated throughout the year in 2015 and the rest was probably irrigated only during the summer or never at all. It should also be noted that the severe 2015 El Niño-induced drought in southern Africa could have affected winter irrigation.

The map presented in Figure 11 also gives the proportions of the areas equipped for irrigation that are irrigated during the winter season and those not irrigated in the same season in 2015. Most of the areas equipped for irrigation in Vhembe and Mopani districts are irrigated throughout the year. But in Capricorn and Waterberg districts more than half of the area equipped for irrigation is not irrigated. In Greater Sekhukhune District more than half of the area equipped for irrigation is irrigated throughout the year.

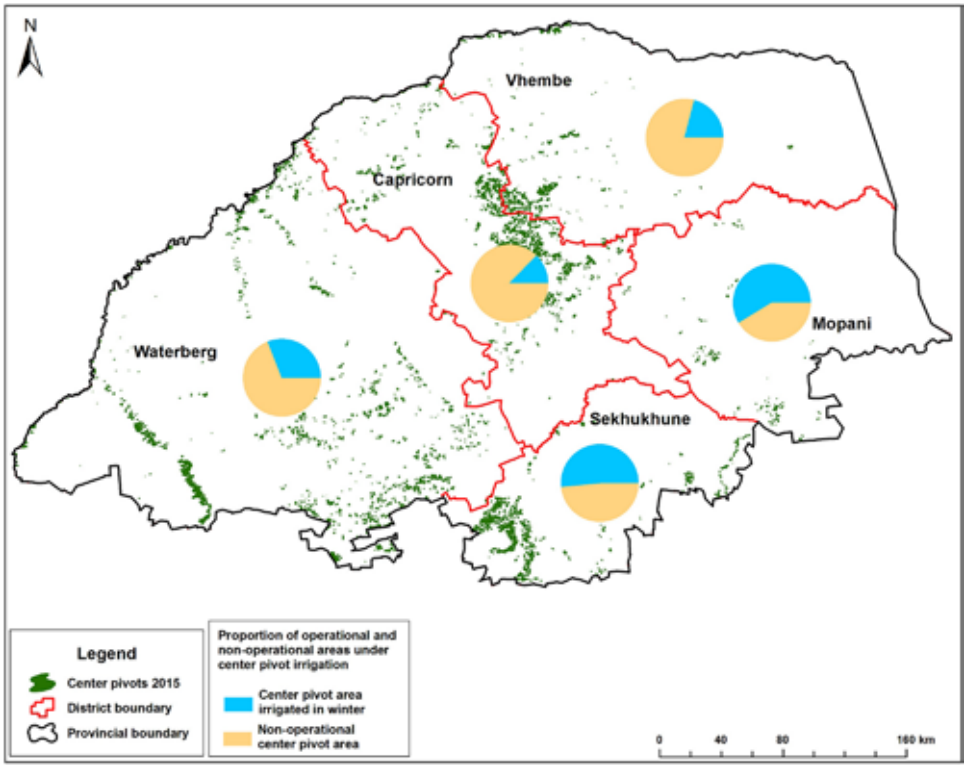
FIGURE 11. 2015 winter irrigated areas in the Limpopo Province (July to August), showing proportion of winter irrigated areas and those not irrigated but equipped for irrigation.



3.4. Center-Pivot Irrigation Areas in the Limpopo Province

The center-pivot irrigation areas of the province were also mapped and are shown in the map given in Figure 12. The pie-charts represent the proportion of the operational and non-operational center-pivot areas per every district in the province. Surprisingly, a comparison between the winter irrigation and the center-pivot maps (Figures 11 and 12) shows that a large part of the area under center pivot was not irrigated in the 2015 winter season. This is evident mainly in Capricorn District where there is the largest concentration of center pivots. Figure 12 also shows a high concentration of center pivots in Capricorn District, but a comparison of the same district as shown in Figure 11 which presents areas that are irrigated only in winter shows that most center pivots are not irrigated. More than three quarters of the center-pivot area in Capricorn District was not operational in the winter of 2015. Generally, more than half of center-pivot areas in all districts are not operational, except in Mopani and Greater Sekhukhune districts. Most irrigated areas in the Limpopo Province that are irrigated throughout the year are therefore not necessarily center pivots. Center pivots in the province cover an area of 164,000 ha. Of the total area equipped for irrigation, which is 380,000 ha, almost half is under center-pivot irrigation, and the rest under other forms of irrigation.

FIGURE 12. The mapped center pivots of the Limpopo Province in 2015. The pie-charts represent the proportion of operational and non-operational center-pivot irrigated areas.



3.5. Difference between Mapped Cropped Areas and Other Existing Data Sets

A comparative analysis of cropland and irrigated areas was made for the Limpopo Province between IWMI maps and other existing similar data sets. Table 4 shows that the cropland area mapped in this study is slightly higher than that reported by DAFF in 2015 (1.6 Mha compared with 1.4 Mha, respectively). The area equipped for irrigation as reported by DAFF is 273,000 ha, which is about

18% of the total cropland. The DAFF map was produced from digitizing of Spot 5 satellite images. The center-pivot irrigation from DAFF map accounts for nearly half of the total areas equipped. In the 2015 winter irrigation season (July to August) as mapped by IWMI, the area actually irrigated was 262,000 ha, which is 95% of the reported equipped areas by DAFF (2015). However, of the total winter irrigation, only 47,000 ha, or 18% of the center pivots are actually irrigated. It means the current reported area equipped for irrigation by DAFF is underestimated.

TABLE 4. Total cropland area and irrigated areas of the Limpopo Province.

District	Total cropland area: IWMI (ha)	Total cropland area: DAFF 2015 (ha)	Area equipped for irrigation: IWMI (ha)	Total area equipped for center-pivot irrigation (2015): IWMI (ha)	2015 winter irrigation: IWMI (ha)	2015 winter center-pivot irrigation: IWMI (ha)
Capricorn	314,268	275,830	58,670	49,995	15,040	6,365
Mopani	206,284	170,378	92,220	4,258	90,464	2,501
Sekhukhune	243,217	219,391	46,430	27,627	33,066	14,263
Vhembe	197,254	182,472	97,717	15,363	85,568	3,214
Waterberg	672,408	573,939	84,652	67,215	38,262	20,825
Total	1,633,433	1,422,010	379,692	164,459	262,403	47,170

The low usage of center pivots in the 2015 winter season also points to interesting questions. Center pivots are usually considered as a well-equipped type of irrigation. The fact that such well-equipped irrigation is also underutilized means that there are serious environmental or social factors behind this underutilization, including the 2015 El Niño drought.

3.6. Accuracy Assessment of the Mapped Agricultural Areas

Accuracy assessment is a way of determining the measure of agreement between the reference image and the classified one of unknown quality. It evaluates how the classification results represent the real world. In accuracy assessment, the kappa index of agreement can be used to measure the degree of agreement between the classified and reference data. In this study, accuracy assessment was done using the GT points acquired from 2014 to 2016 field visits. The overall classification accuracy for the agricultural areas was 96%.

4. DISCUSSION AND CONCLUSIONS

In spite of the importance of irrigation for food production and water security, data and information are scarce in most parts of the developing world including South Africa. The Limpopo Province has seen reasonable efforts of various mapping activities including general LULC mapping and agriculture-focused surveys. However, a comprehensive data set is still missing in the provinces of South Africa to summarize the irrigation status and development and track trends. This information is significant, especially when the province is inhabited by large groups of a formerly disadvantaged

population that still rely on agriculture, and when the country has clearly set out targets in agriculture and irrigation development.

The province has a total of 1.6 Mha of cropland, with only 262,000 ha irrigated in the 2015 winter season. Large amounts of investments have been made in center-pivot irrigation systems. The center-pivot usage is however low with only 47,000 ha, out of a total of 164,000 ha being equipped and irrigated in the winter of 2015. Further studies are needed to understand the reason for such low utilization of irrigation systems.

There is also a general lack of technical capacity and institutional arrangement within DAFF and LDARD to produce periodic, consistent reports on the status and development of irrigation. Open source, dense, temporal remote sensing data sets provide a new opportunity to achieve this goal at lower costs and to assess agricultural development and production in near real-time. The challenges are however within the departments to build up capacity, and monitor agricultural production and productivity at regular intervals and update on irrigation development. The task becomes easier now that a basis on which to build on is available, especially with necessary capacity-building of relevant DAFF and LDARD staff. One advantage of the remote sensing methodology used in this study is that it can be replicated at other provinces to assess the national irrigation scenario and can also be applied at regular intervals.

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ANNEX 1. TECHNICAL GUIDE ON ODK FIELD SURVEY

This note lays out the detailed methods and requirements for a field survey to determine LULC and information on crops and irrigation. Two options were included for the survey: 1) paper- and GPS-based survey and 2) Android smart phone-/tablet-based survey.

It is important to note that before commencement of the survey, careful planning is required for logistics as well as communications with concerned parties to ensure smooth and successful field trips. Familiarization with the areas to be surveyed will help learn better about the crops, the irrigation systems, and the people.

1. ROUTE PLANNING

As an example, suppose the Asian Development Bank (ADB) water investment sites are the target areas of field surveys. The water point (WP) assessment focuses on irrigation systems identified by individual countries and the ADB. These areas usually fall in one Landsat image tile or more. While the image processing will automatically include all the tile areas, WP assessment is only carried out for the target areas.

The route planning is therefore a process to optimize the field travel routes within each project site, and from one site to another. Within each site, the travel routes need to cover diverse conditions within the planned time frame. These usually include lower, middle, and upper reaches of canal command areas, and areas irrigated with different sources (groundwater, surface water, main canals, and tertiary canals). An example of such a route is starting from the source, traveling clockwise towards the tail end of the irrigation system and returning to the source, completing the survey with an oval shaped route. If the irrigation system is a long strip along a valley, then a zig-zag route will also be a good option. Field adjustment may be necessary to adapt to crop-growing conditions in order to have main crops well captured, but other crops are also well represented in the GT points.

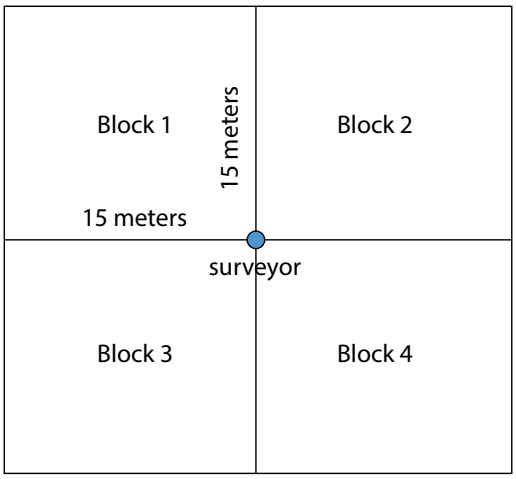
2. THE FIELD SURVEY METHOD

The field survey needs persons to travel around in the study area along a planned route, and stop regularly (every 1-2 km) to record field info on land use, crop type, crop conditions, and crop yield (by asking farmers). If the crop is already harvested, the same info can be collected by interviewing famers who own the plots.

Detailed recordings are made at each stop point. It is preferred that at each stop, the surveyor will walk a few hundred meters off the main road into the fields. He/she may then choose a square area of 30 X 30 m^2, with himself/herself in the center from where coordinates and pictures are taken and other recordings are done. This needs to be practiced by the field team before the actual exercise to familiarize with the procedures. Once the area is chosen, percentage crop and other land cover can be estimated for each block and then added up. Pictures and other observations can also be made and recorded following filling of the survey form.

The data recording can be done using two methods. The first method requires printing out of paper survey forms (attached) and hand filled for each point visited together with hand-held GPS readings. The second method uses Android phones with an application ODK Collect (downloadable for free) to record and upload the info electronically. Both forms are identical in content. It could

take three to five days to survey an irrigation system depending on size and travel mode. The summaries of the requirements for the two methods are listed in the next section.



How to survey a point – percentage land cover is estimated for each block and then added up.

2.1. Android phone-/tablet-based method

This method uses smart phones or tablets to record info on a field survey which is then uploaded to a server through an Internet connection. The GT form is built into an Android-based App ODK Collect. The App is freely available through Google Play Store©.

The main user interface of ODK Collect

2.1.1. Setting up the server and user name

After downloading the App, the first step is to set up server access and fetch GT survey template forms. Users can use the default server on http://opendatakit.org a server set up by International Water Management Institute (IWMI), or set up their own server. This guide uses the server set up by IWMI, a common survey GT form they developed:

- Launch the ODK Collect
- Go to “General Settings”

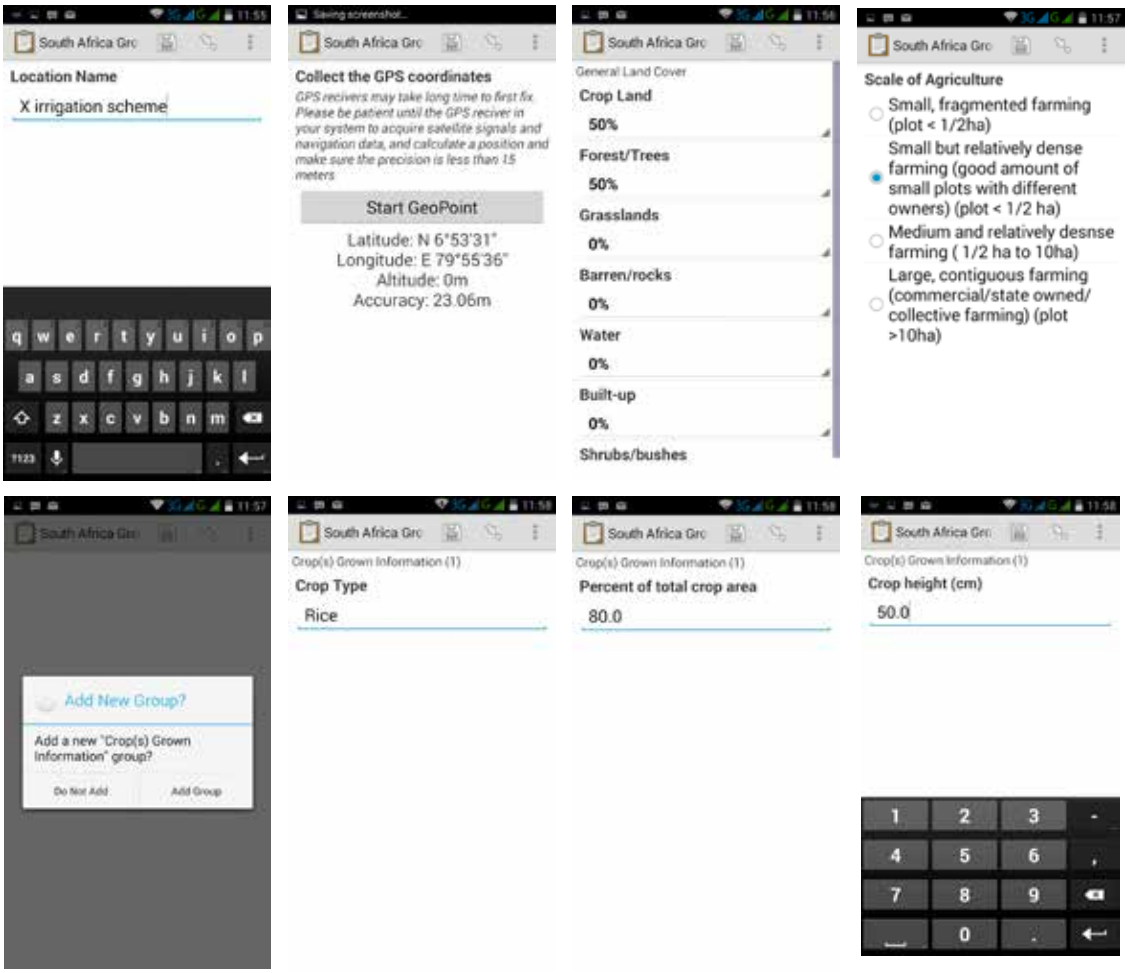
- Select “Configure Platform Settings”
- Enter following ODK aggregate settings
- URL: http://mdn.iwmi.org
- User Name: AS PROVIDED
- Password: AS PROVIDED

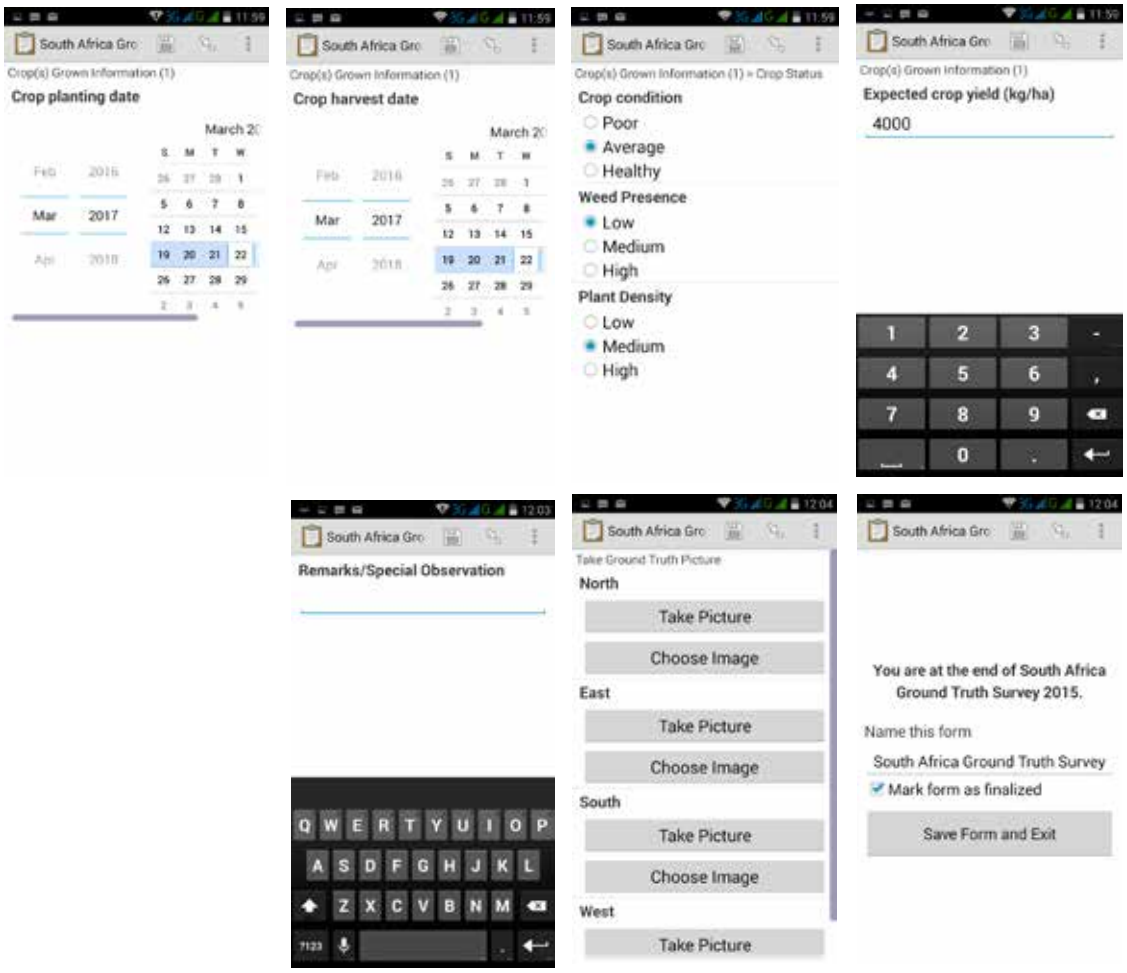
2.1.2. Fetching blank form/template

On the main menu press “Get blank form” to download the GT template. There are several options available. Users can download the form “Ground Truth Survey China Modified”. The App is ready to be used for field survey.

2.1.3. Surveying your first point

- Press “fill blank form”
- Choose the form you downloaded earlier
- Follow step by step instructions as shown below:





ODK Collect GT survey interfaces and the survey content

2.1.4. Uploading to the server

The GT points are uploaded to server automatically as soon as the device is connected to a WIFI hot spot. It can also be sent through mobile 3G/4G connections in the field. The settings for automatic sending can be changed in the general settings.

2.1.5. Browsing/downloading GT points from the server

The server can be accessed using the same URL address, user name and password through a computer. All the points uploaded can be viewed in table format or map format. They can be downloaded and converted into a GIS layer or Excel table.

2.1.6. Requirement for method 2 Android phone/tablet

- Two persons (one is the driver and the other is the data collector who knows some English, how to operate an Android device, and a bit of agriculture in the study area that he needs to be able to identify main crops and irrigation types in the field).
- One car or motor bike or tuk.

- An Android phone/tablet which has an Internet connection in the field, a camera, and a minimum of 8 GB storage space, and backup battery/power bank.
- Cash for fuel, meals, and overnight accommodation in small towns (that the team will travel roughly a circle/oval to cover one irrigation system).
- Other personal care items.

2.2. Method based on paper printouts

The contents of the forms are the same as those of the Android-based method. Instead of filling up in a smart phone/tablet, the surveyor has to fill up the one page form on paper, and take GPS coordinates and photos using separate devices. When taking photos, Photo ID needs to be noted down on the GT form to keep track of their location.

2.2.1. Requirement for the survey, based on paper printouts

- Two persons (one is the driver, and the other is the data collector who knows some English and a bit of agriculture in the study area that he needs to be able to identify main crops and irrigation types in the field)
- One car or motor bike or tuk.
- A hand-held GPS with spare batteries.
- A digital camera with spare batteries.
- Paper GT forms.
- Cash for fuel, meals, and overnight accommodation in small towns (that the team will travel roughly a circle/oval to cover one irrigation system).
- Other personal care items.

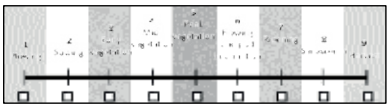
This method requires the data form to be input into the computer after the survey.

GT form for crop type mapping of ADB water productivity assessment areas

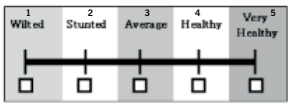
LOCATION PARAMETERS		LULC PARAMETERS			AGRICULTURAL / CROP PARAMETERES					
1. GT Point No.		***7. Land cover***		***Cover [a] (%)***	***7.1 Farmland***		***Area [b] (%)***	***Canopy cover [c] (%)***	***Growth stage [d]***	***Health [f]***
1.1 Country		7.1 Farmland	☐		7.1.1 Wheat	☐				
		7.2 Home gardens	☐		7.1.2 Corn	☐				
1.2 Province		7.3 Trees/Forest	☐		7.1.3 Rice	☐				
		7.4 Shrubs	☐		7.1.4 Millet	☐				
2.1 Latitude		7.5 Scrublands	☐		7.1.5 Orchards	☐				
		7.6 Herbs/Weeds	☐		7.1.6 Soybean	☐				
		7.7 Grass	☐		7.1.7 Rape seed	☐				
2.2 Longitude		7.8 Barren land	☐		7.1.8 Cotton	☐				
		7.9 Built-up	☐		7.1.9 Groundnut	☐				
		7.10 Water	☐		7.1.10 Weeds/grasses	☐				
2.3 Date of collection (MM/DD/YY)		7.11 Others	☐		7.1.11 Vegetables	☐				
					7.1.12 Sugarcane	☐				
					7.1.13 Tobacco	☐				
3. Crop calendar					7.1.14 Farm fallow	☐				
Season	***Period***	***Crop type***			7.1.15 Others	☐				
3.1 season 1	( ) – ( )									
3.2 season 2	( ) – ( )									
3.3 continuous	( ) – ( )									
4. Crop Intensity (%)		***5. Topographic position***			***6. Photo ID****	***8. Irrigation scale***			***9. Watering method***	
		5.1 Valley	☐			8.1 Major (Major andmedium surface water irrigation)	☐		9.1 Surface water	☐
		5.2 Upland	☐			8.2 Minor (Groundwater, small reservoir or tank)	☐		9.2 Groundwater	☐
(Circle what is appropirate)		5.3 Plain	☐						9.3 Conjunctive use	☐
0 20 40 60 80 100									9.4 Rain-fed	☐

LEGEND:

d: Crop growth



f: Crop health



Note: a, b = The land cover types/crop types should add up to 100%; c = All the cs should sum up to 100% for each crop (for each b).

d: Choose from 7.1 (only last number required, e.g., number 3 for rice) or specify if not listed.

ANNEX 2. STATISTICS FROM IWMI 2015 IRRIGATED AREA MAPPING

Limpopo agricultural areas

District level

District	Area in ha
Mopani	206,284.09
Vhembe	197,254.95
Capricorn	314,268.03
Waterberg	672,408.33
Greater Sekhukhune	243,217.73
Total	1,633,433.16

Municipality level

Municipality	Area in ha
Aganang	52,299.04
Ba-Phalaborwa	16,221.42
Bela-Bela	108,639.31
Blouberg	62,648.58
Elias Motsoaledi	60,456.33
Fetakgomo	23,595.88
Greater Giyani	49,029.71
Greater Letaba	45,964.96
Greater Marble Hall	48,924.33
Greater Tubatse	45,972.47
Greater Tzaneen	65,971.33
Lepele-Nkumpi	37,231.68
Lephalale	122,542.57
Makhado	90,784.47
Makhuduthamaga	64,191.00
Maruleng	29,092.03
Modimolle	111,471.27
Mogalakwena	84,675.70
Molemole	63,420.47
Mookgopong	178,938.47
Musina	22,325.99
Mutale	26,236.51
Polokwane	64,477.71
Thabazimbi	95,505.76
Thulamela	62,811.40

Former homelands

Name	Area in ha
Gazankulu	127,237.514
Lebowa	412,213.74
Venda	110,609.61

Winter irrigation

District level

District	Area in ha
Capricorn	15,040.651
Greater Sekhukhune	33,066.879
Mopani	90,464.604
Vhembe	85,568.393
Waterberg	38,262.983
Total	262,403.51

Municipality level

Municipality	Area in ha
Aganang	557.07
Ba-Phalaborwa	7,353.07
Bela-Bela	3,803.78
Blouberg	3,199.28
Elias Motsoaledi	10,781.20
Fetakgomo	394.90
Greater Giyani	11,443.97
Greater Letaba	9,981.69
Greater Marble Hall	13,568.32
Greater Tubatse	6,688.01
Greater Tzaneen	39,286.21
Lepele-Nkumpi	2,112.79
Lephalale	120,730
Makhado	30,998.81
Makhuduthamaga	1,634.45
Maruleng	22,397.47
Modimolle	7,260.83
Mogalakwena	2,949.51
Molemole	3,562.04
Mookgopong	2,650.90
Musina	10,696.77
Mutale	9,172.77
Polokwane	1,577.16
Thabazimbi	12,869.04
Thulamela	35,388.28

Former homelands

Name	Area in ha
Gazankulu	32,008.67
Lebowa	15,035.95
Venda	50,426.17

Areas equipped for irrigation

District level

District	Area in ha
Capricorn	58,670.40
Greater Sekhukhune	46,430.74
Mopani	92,220.99
Vhembe	97,717.77
Waterberg	84,652.40
Total	379,692.31

Municipality level

Municipality	Area in ha
Aganang	732.8042092
Ba-Phalaborwa	7,485.46
Bela-Bela	11,295.51
Blouberg	9,104.40
Elias Motsoaledi	16,804.62
Fetakgomo	657.08
Greater Giyani	11,791.55
Greater Letaba	9,981.69
Greater Marble Hall	19,121.61
Greater Tubatse	8,042.45
Greater Tzaneen	40,041.23
Lepele-Nkumpi	2,283.20
Lephalale	26,005.30
Makhado	44,216.46
Makhuduthamaga	1,804.97
Maruleng	22,918.89
Modimolle	16,496.19
Mogalakwena	5,120.41
Molemole	31,935.25
Mookgopong	10,664.47
Musina	12,266.67
Mutale	9,172.77
Polokwane	4,161.42
Thabazimbi	21,961.36
Thulamela	35,624.38

Former homelands

Name	Area in ha
Gazankulu	32,643.40
Lebowa	17,209.02
Venda	50,516.83

Rain-fed areas

District level

District	Area in ha
Mopani	116,279.17
Vhembe	101,355.33
Capricorn	255,798.57
Waterberg	588,197.68
Greater Sekhukhune	197,147.64
Total	1,258,778.38

Municipality level

Municipality	Area in ha
Makhuduthamaga	62,428.930
Fetakgomo	22,945.93
Greater Marble Hall	29,886.96
Elias Motsoaledi	43,753.98
Greater Tubatse	38,054.14
Greater Giyani	37,721.29
Greater Letaba	36,292.84
Greater Tzaneen	26,814.23
Ba-Phalaborwa	8,887.50
Maruleng	6,560.58
Musina	10,206.35
Mutale	17,308.17
Thulamela	27,976.75
Makhado	47,209.94
Blouberg	53,585.42
Aganang	51,575.40
Molemole	31,538.06
Polokwane	60,350.51
Lepele-Nkumpi	34,979.40
Thabazimbi	73,644.59
Lephalale	96,685.70
Mookgopong	168,300.36
Modimolle	95,099.48
Bela-Bela	97,372.46
Mogalakwena	79,596.61

Former homelands

Name	Area in ha
Gazankulu	95,705.86
Lebowa	395,351.08
Venda	61,215.39

Area equipped with center pivots
District level

District	Area in ha
Mopani	4,258.06
Vhembe	15,363.39
Capricorn	49,995.54
Waterberg	67,215.00
Greater Sekhukhune	27,627.19
Total	164,459.18

Municipality level

Municipality	Area in ha
Aganang	190.05
Ba-Phalaborwa	556.68
Bela-Bela	10,130.60
Blouberg	7,275.96
Elias Motsoaledi	11,428.77
Fetakgomo	506.42
Greater Giyani	386.81
Greater Marble Hall	12,035.20
Greater Tubatse	3,313.25
Greater Tzaneen	1,340.56
Lepele-Nkumpi	219.40
Lephalale	20,383.16
Makhado	15,002.58
Makhuduthamaga	343.55
Maruleng	1,974.00
Modimolle	12,211.29
Mogalakwena	2,676.45
Molemole	30,446.39
Mookgopong	9,033.33
Musina	3,384.57
Polokwane	3,098.63
Thabazimbi	18,281.29
Thulamela	240.2384

Former homelands

Name	Area in ha
Gazankulu	828.14
Lebowa	2,990.48
Venda	102.074

Winter center-pivot irrigation
District level

District	Area in ha
Mopani	2,501.67
Vhembe	3,214.02
Capricorn	6,365.797067
Waterberg	20,825.59
Greater Sekhukhune	14,263.33
Total	47,170.39

Municipality level

Municipality	Area in ha
Aganang	14.32
Ba-Phalaborwa	424.30
Bela-Bela	2,638.87
Blouberg	1,370.84
Elias Motsoaledi	5,405.35
Fetakgomo	244.25
Greater Giyani	39.23
Greater Marble Hall	6,481.91
Greater Tubatse	1,958.81
Greater Tzaneen	585.54
Lepele-Nkumpi	48.98
Lephalale	6,450.86
Makhado	1,784.92
Makhuduthamaga	173.02
Maruleng	1,452.59
Modimolle	2,975.93
Mogalakwena	505.55
Molemole	2,073.19
Mookgopong	1,019.78
Musina	1,814.67
Polokwane	514.36
Thabazimbi	9,188.97
Thulamela	4.14

Former homelands

Name	Area in ha
Gazankulu	193.42
Lebowa	817.40
Venda	11.41

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