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Cotton Mapping in Kenya: GPS-Based Data Collection – A Cost Comparison with High Resolution Satellite Imagery Mapping

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ABSTRACT

The main objective of this study was to carry out farm size auditing (verification) and provide a baseline data for a strategic information management system for mapping cotton in Kenya. It aimed to establish an accurate, updated and detailed database for all the cotton farmers working with Rift valley Products Limited (RVP). This study demonstrates the use of Global Position System (GPS) data collection methods and Geographic information system (GIS) to provide accurate, key and important information for decision making and planning. GIS based spatial analysis was conducted and the best locations for harvest collection centres were determined, based on the shortest and least cost path of delivery by the farmer. The maps produced have proven to be critical tools for the field officers for route planning when conducting field visits. This has led to a considerable cut in the cost of production. A cost comparison between GPS field data collection and use of a high resolution satellite image is given, implying that field data collection is still the most cost effective method of collecting accurate information, especially if the land parcels under consideration are small and segregated.

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1. Introduction

Cotton was introduced in Kenya in 1901 by the British colonial administration and promoted as a suitable cash crop in areas where other crops did not fare well (Waindi and Njonge, 2005). About 350,000 hectares in the country are suitable for cotton production and have the potential to yield an estimated 260,000 bales of lint annually. However, cotton is only being cultivated on about 25,000 hectares at present, with an annual lint production of 20,000 bales (Bartoo, 2009). The lack of certified seed has also been culminating to low production of the cotton crop (Obare, 2009).

Since independence, Kenya's cotton-textile-apparel industry has gone through major phases. At independence private ginners dominated the industry. Over the next ten years the Government helped cooperative societies buy the private ginneries from the colonialists and instituted a regime of controlled margins and fixed farm-gate cotton prices. In addition, it invested in a number of textile mills, which supplied the largely private apparel (garment) manufacturers. Under this regime (which was also characterized by large donor support), land under cotton expanded by 180% and processing capacity by 60% in the 1970s. However, Government and donor assistance started declining in the mid-1980s, which saw lint production drop by 57% between 1984/85, and 1992/93 (Ikiara and Ndirangu, 2002).

According to a recent report by the Institute of Economic Affairs, a non-governmental body based in the Kenyan capital, Nairobi, "continued synthetic competition, diminishing world prices, introduction of cheap imports of second hand clothes and diminished cotton profitability" were amongst factors that dealt a blow both to cotton production, and the textile and clothing industries (Mulama, 2009). Cotton farming has been on the decline for the past two decades. However, it is slowly picking up after years of neglect and disillusionment among farmers. The revival of the Salawa Cotton Ginnery in Baringo district has played a great role in revitalizing farming activities in the Kerio Valley region (African Agriculture, 2008).

Cotton is one of the few cash crops suitable for marginal, low rainfall areas, which cover about 87% of the country's landmass, and are home to about 27% of the population. The crop is, additionally, grown by small-scale farmers. Another source of motivation are the enormous market prospects presented by the African Growth and Opportunity Act (AGOA) passed by the United States of America (USA) Congress in 1999, the African Caribbean Pacific-European Union (ACP-EU) Cotonou Agreement ratified in 2000, and the expected freer textiles trade with removal of quota restrictions in year 2005 under the World Trade Organization (WTO) framework. (Ikiara and Ndirangu, 2002).

Reliable crop information is vital to the functioning of grain markets. It is used to make informed decisions on planting, marketing, and policy. A GIS combines geographic mapping capabilities with a database management system. A GIS database consists of a set of data layers, usually referencing a common coordinate system, which describe different thematic or quantitative information. A GIS offers many advantages for spatial data management and presentation, including a structured representation for data, data management functions, and most importantly, visualization of data. Spatial simulations can take advantage of large quantities of data previously digitized as GIS layers. Data analysis functions and mapping queries, such as area statistics and image processing techniques, provide methods of analyzing the inputs and results of the spatial simulations (Mccauley, 1999). Applying GIS to the process of preparing crop estimates has improved accuracy while lowering costs (Fourie, 2008). High spatial resolution satellite imagery has the potential for mapping crop growth variability and identifying problem areas within fields (Yang *et al.*, 2006).

Several studies have been done to assess the applicability of GIS and remote sensing in precision farming. For example, Yang *et al.*, (2006) compared QuickBird satellite imagery with airborne imagery for mapping grain sorghum yield patterns. They concluded that QuickBird imagery can be a useful data source for mapping variability in crop growth and yield. Drysdale and Metternicht, (2003) applied remote sensing in monitoring crop variability and weeds in paddocks and concluded that remote sensing can be very useful in crop growth models. However other researchers have a different view on this applicability, for example, in their research, Walter *et al.*, (2008) noted that Satellite remote sensing has not been practical for agronomic research conducted using small plots due to spatial resolution issues. Their conclusion however, indicates that QuickBird multispectral images show promise for estimating agronomic parameters from small plot research. A significant barrier to implementation of most satellite remote sensing techniques for multi-temporal analysis of

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seasonal crop changes in near real time is the conversion of image digital numbers (DN) of each spectral band to spectral reflectance at the surface by correcting for atmospheric effects (Moran *et al.*, 1997).

This paper seeks to demonstrate the application of Global Positioning System (GPS) and GIS in mapping cotton farming in Kerio valley. In particular it outlines the findings of an auditing exercise which partly was conducted to verify the information provided by farmers with regards to farm sizes and location, as well as provide a basic understanding of the crop condition at the time of survey. This has a direct impact on planning, planting and harvesting the cotton product whilst minimizing cost; maximizing the use of manpower and other available resources. An attempt has been made to compare the cost of utilizing high resolution satellite imagery to cost of field-based method of data collection.

2. Methodology

2.1. Study area

Kerio valley is located in Kenya's rift valley province and covers an area cutting across several administrative districts. It is a warm and hot climate suitable for cotton growing. The area experiences low rainfall and high temperatures. Kerio Valley lies between the Tugen Hills and the Elgeyo escarpment at an elevation of about 1,000 meters. The valley lies in a narrow, long strip approximately 80 km by 10 km wide at its widest, through which the Kerio River flows (Muchemi *et al.*, 2008). Lake Kamnarock lies in the middle of Kerio valley, the lake was gazetted in 1984, and it saw the creation of the Lake Kamnarock Game Reserve, which is the home to about 500 elephants (Omondi *et al.*, 2002). The lake is threatened with extinction, mainly caused by encroachment by farmers. As established by reports from farmers and local residents, wildlife – Human conflict is prevalent as was witnessed by crop destruction courtesy of the wild animals (especially Elephants).

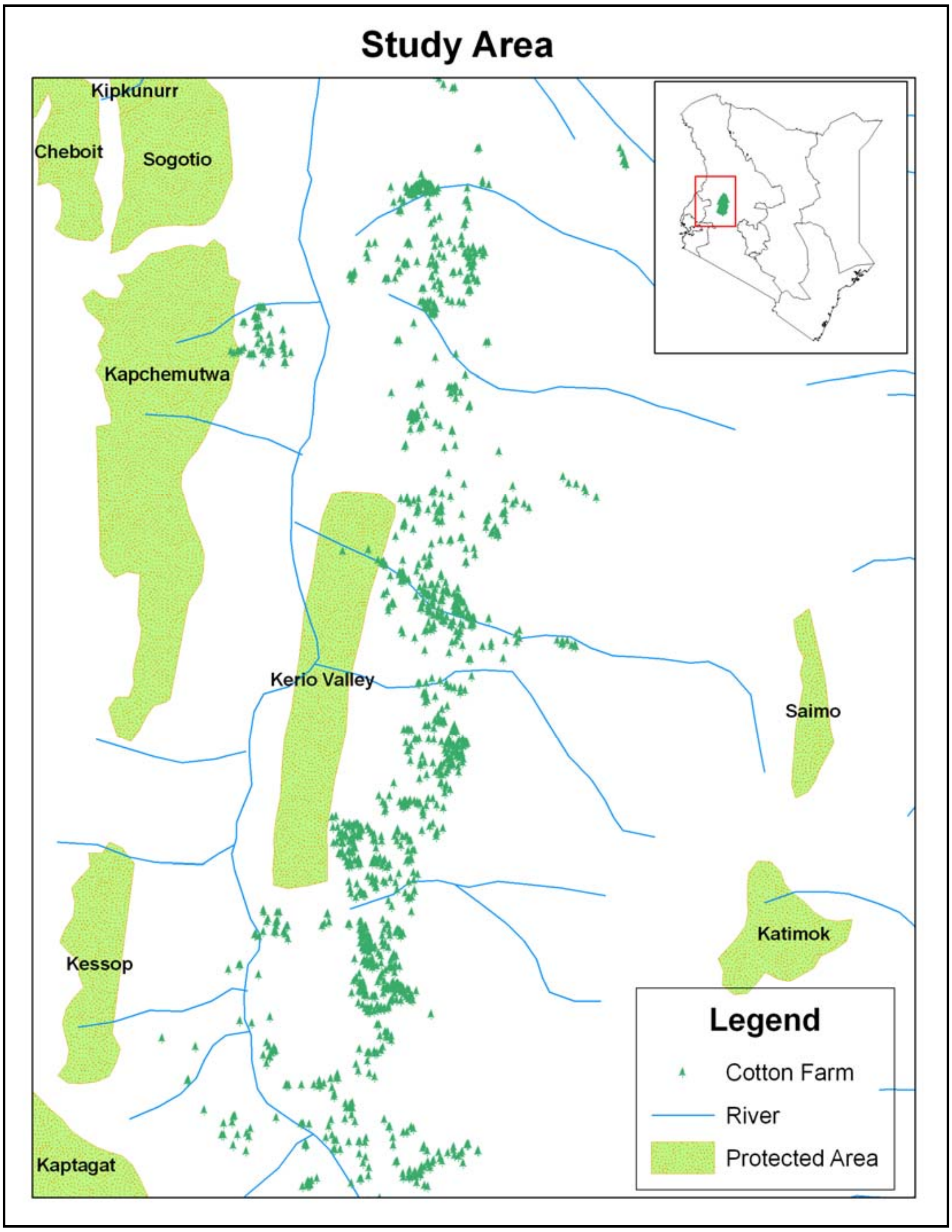

Figure 1: Kerio Valley, Study area.

2.2. Datasets and data collection

2.2.1. Parcel information / Cotton farm Characteristics

A standard data questionnaire was developed to collect specific information regarding

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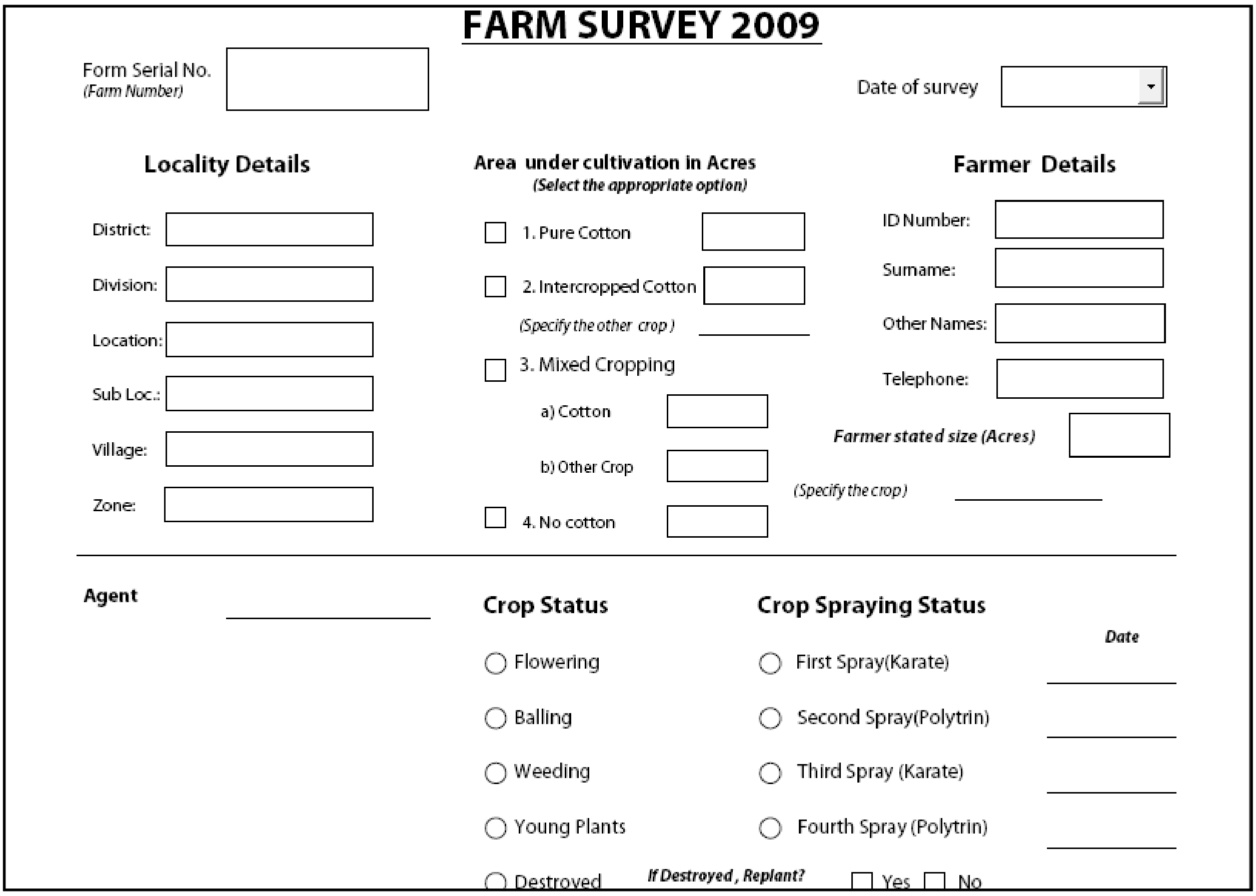
each parcel of land under cotton. GPS coordinates defining all the corners of the parcel were recorded. In addition, the extent of the parcel was "tracked" using a Handheld GPS unit to compute the area as well as to provide the spatial extent of the parcel. The following information was collected: Farmer details, Locality details, area under cotton (Pure, Mixed or Intercropped), crop growth status and the spraying status. A unique identifier was assigned to each parcel. The figure below shows a sample of the data sheet used to collect the farm / farmer details.



FARM SURVEY 2009

Form Serial No. *(Farm Number)*

Date of survey

Locality Details

District:

Division:

Location:

Sub Loc.:

Village:

Zone:

Area under cultivation in Acres *(Select the appropriate option)*

1. Pure Cotton

2. Intercropped Cotton

(Specify the other crop)

3. Mixed Cropping

a) Cotton

b) Other Crop

4. No cotton

Farmer Details

ID Number:

Surname:

Other Names:

Telephone:

Farmer stated size (Acres)

(Specify the crop)

Agent

Crop Status

Flowering

Balling

Weeding

Young Plants

Destroyed

If Destroyed, Replant? Yes No

Crop Spraying Status

Date

First Spray(Karate)

Second Spray(Polytrin)

Third Spray (Karate)

Fourth Spray (Polytrin)

Figure 2: Questionnaire.

2.2.2. Spatial Component: Area under cotton

In addition to the information collected in (2.2.1) above with the aid of a handheld GPS, the area under cotton was mapped and a polygon feature captured with the aid of the GPS. This was coupled with the computation of the individual areas under different types of cropping systems (Pure, Mixed or Intercropped). Using the data collected from the questionnaire and the GPS, a database was developed to store this information. The attribute information was stored in an MS Access® database and the spatial component stored in the ESRI® shapefile format. An Open Database Connectivity Connection (ODBC) linkage was created to link the two datasets for display on a map and for statistical analysis. The database was designed such that functionalities for querying, reporting and integration could be added later if needed.

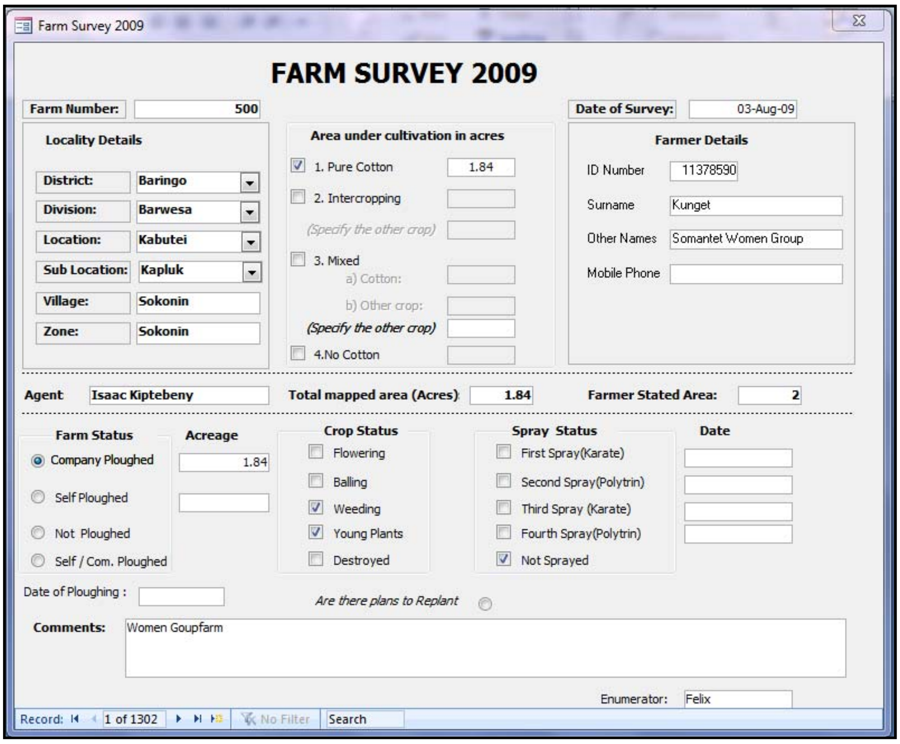


Figure 3: The database.

3. Analysis and Findings

3.1. Proposed harvest collection centres

All the market centres in the Kerio valley were mapped for use in selection of the best collection points for the harvested cotton. Selection was based on close proximity to farms and also the likelihood of the centre serving more farms at the shortest distance possible. In addition, these centres should be easily accessible by foot and vehicle. This was achieved by using the proximity analysis functionality in the ArcGIS 9.2® environment. A threshold of 8 kilometers was chosen as the maximum distance a farmer should transport their product. This threshold was chosen as a reasonable distance based on terrain and accessibility, in order to keep transport cost at a minimum. The following is a list and map of the selected collection

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centres.

Table 1: Proposed collection centres.

No.	Collection Point(Mkt. Centre)	Latitude	Longitude
1	Barwesa Market	0.70340	35.70043
2	Kampi Nyasi Market Centre	0.76675	35.70747
3	Kui Kui market Centre	0.80936	35.69143
4	Maregut market Centre	0.86189	35.69467
5	Chemitany Market Centre	0.89692	35.69049
6	Konowa market Centre	0.68087	35.68315
7	Kiturwo Market Centre	0.66492	35.69048
8	Ketkor Market Centre	0.64624	35.68692
9	Katibel Market Centre	0.62289	35.66909
10	Muchukwo Market Centre	0.59902	35.66964
11	Kapluk Market Centre	0.56918	35.66479
12	Kaptara Market Centre	0.54897	35.64710
13	Salawa Market Centre	0.49622	35.66057

The following is a table showing some of the farms (see Table 2), the collection centres they are near to, and the distance between them. The Near tool® calculates the distance between different spatial features and is a fundamental tool of proximity analysis. Near distance is calculated by evaluating the shortest separation between an input feature and a near feature (ESRI, 2007).

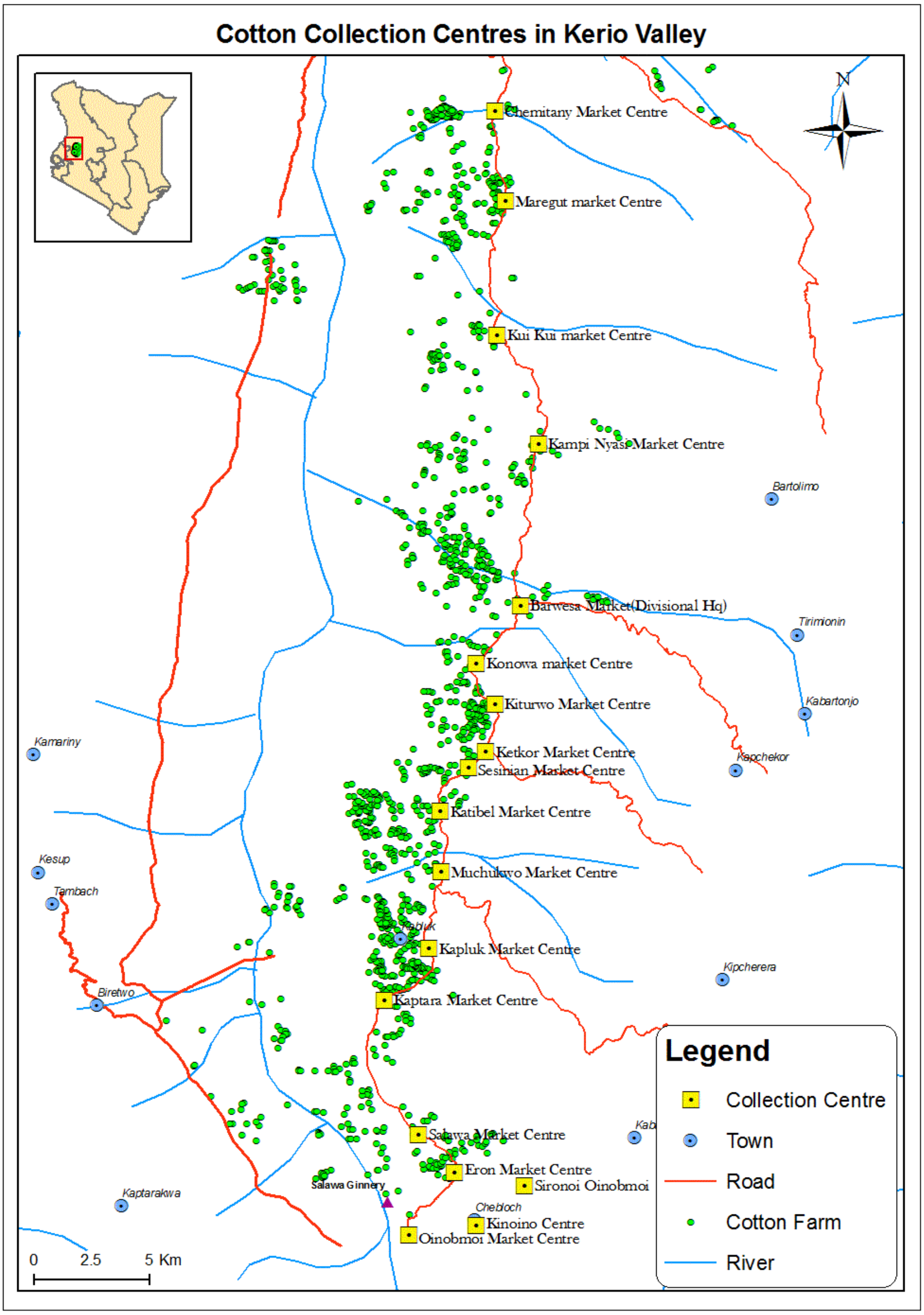

Figure 4: Proposed collection Centres.

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Table 2: Some selected farms showing the nearest collection centre and distance between.

Farm ID	Nearest Collection Centre ID	Distance (Kilometers)
500	10	1.43
501	10	1.25
502	10	1.30
503	10	1.29
591	9	3.52
592	9	2.98
881	12	2.57
882	12	2.29
883	12	1.38
884	12	1.54
885	11	2.70
886	11	2.52
887	11	1.95
960	5	1.19
961	5	0.78
966	1	2.90
967	1	2.90
…….	…….	……..

3.2. Area under cotton Cultivation

One of the primary objectives of this study was to determine the area under cotton. It was established that; 592 hectares were under pure cotton, 18 hectares under intercropping while 71 hectares were ploughed, but did not have any cotton. The significance of this information is that, Rift Valley Products Limited (RVP) would be able to identify farmers who have intercropped or practiced mixed farming. This is important in estimating productivity because some crops are detrimental to cotton if intercropped. Additionally, this information was used for disciplinary actions and cost reimbursement for the cases where cotton was not planted but land had been ploughed for.

3.3. Area auditing (Farmer stated Vs. Mapped Area)

At the commencement of the cotton farming project, due to time limitations, cost and unfavorable weather conditions, it was not possible to determine the areas of parcels that would be put under cotton cultivation. As such, farmers were requested to state the areas that they would provide for cultivation. Part of this study was to cross-check the stated areas against the measured areas (using GPS). A comparison between the mapped area and the initially stated area was done. The results were quite intriguing: for 86 farms, the initial stated farm sizes were not available and hence a comparison could not be done. However, the remaining 1,216 farms were analyzed and the following is a list of some of the farms and their discrepancies.

Table 3: Auditing, farmer stated versus GPS mapped area.

Farm No	Mapped Area(acres)	Farmer Stated Area(acres)	Difference
500	1.84	2	0.16
501	0.53	0.5	-0.03
502	1.1	1	-0.1
503	1	1	0
506	0.97	1	0.03
507	1.13	1	-0.13
508	0.5	0.5	0
509	0.74	2	1.26
511	2	2	0
512	1	1	0
513	0.55	0.5	-0.05
514	1.22	1	-0.22
515	1.3	1	-0.3
516	0.9	1	0.1
517	0.76	1	0.24
518	1.44	1.5	0.06
520	0.76	0.75	-0.01
521	1.35	1	-0.35
522	0.74	1	0.26
523	1.24	1	-0.24
…..	…….	…..	……..

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As it can be seen from table 3, the estimated sizes by the farmers were quite accurate as compared to the mapped. In fact, the cumulative difference in area between the mapped and estimated area is only 25.75 acres. This finding satisfies the primary objective of the study in confirming that; the initially stated total acreage is close to the mapped (true) area. This is an interesting finding, as this level of accuracy of estimation from the local farmers was not expected.

3.4. Crop Status

Part of the research was to assess the basic condition of the crop. From the field observations, it was found that out of the total area, 173 hectares were reported to have been destroyed, majority of them being attributed to drought. Other factors of destruction were livestock and a few cases of wildlife. A total of about 430 hectares were likely to be productive; for the plants were either flowering or balling. This excluded the 76 hectares of young plants whose success would depend on the availability of rainfall.

Table 4: Crop status.

Crop Status	Total Area(hectares)
Balling	73.40
Flowering	103.00
Flowering and Balling	213.46
Weeding	41.04
Young Plants	76.37
Destroyed	173.71
Total	680.77

3.5. Maps, Visualization and Presentation of results

A map is a useful tool in communicating spatial information; it can be used in the dissemination of various attributes of the phenomenon under consideration. One of the key products of this study was zonal and overall maps that would be used by the extension officers in farm management. Several maps were produced including:

- Indicator maps : showing the various findings e.g. distribution of farms by cropping type
- Harvest Collection Point maps : showing the areas they serve

- Crop Status

The following are some of the maps produced:

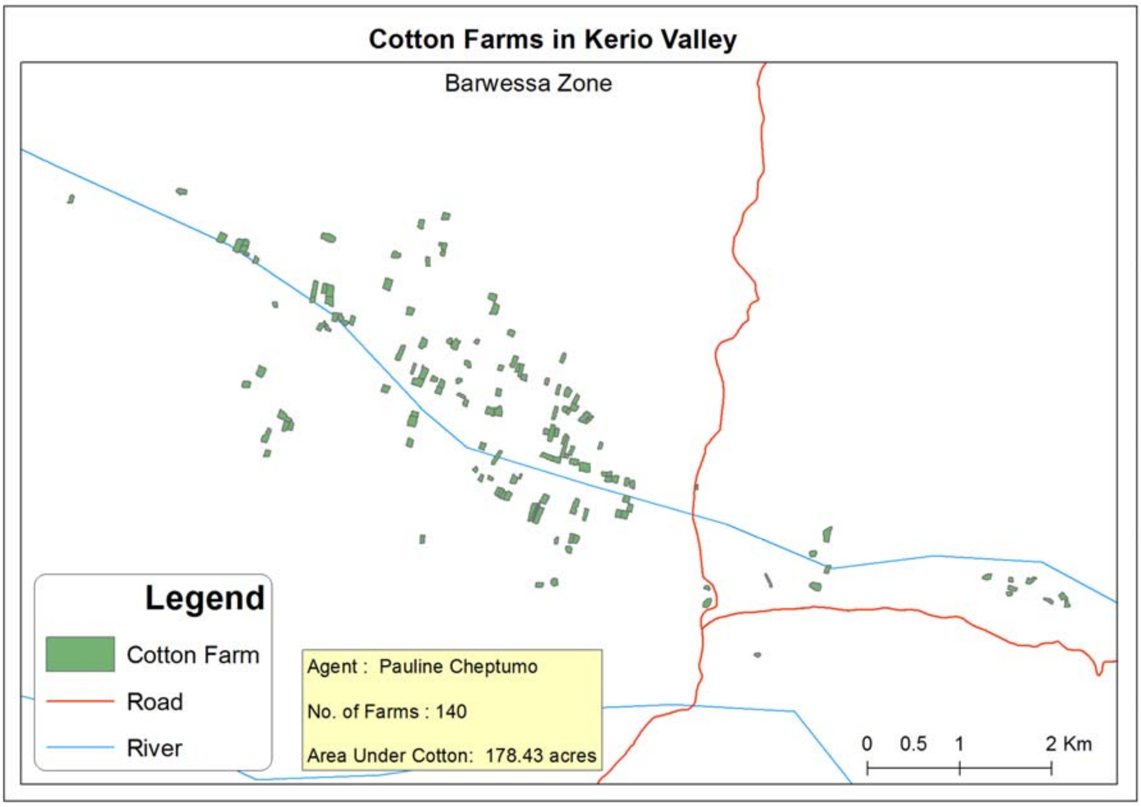

Figure 5: Zone map

A zonal map was produced for each zone. The map shows the area covered by the agent as well as the location of all farms under his/her jurisdiction. They maps were used in redistribution of farms to agents to aid in administration and cost reduction.

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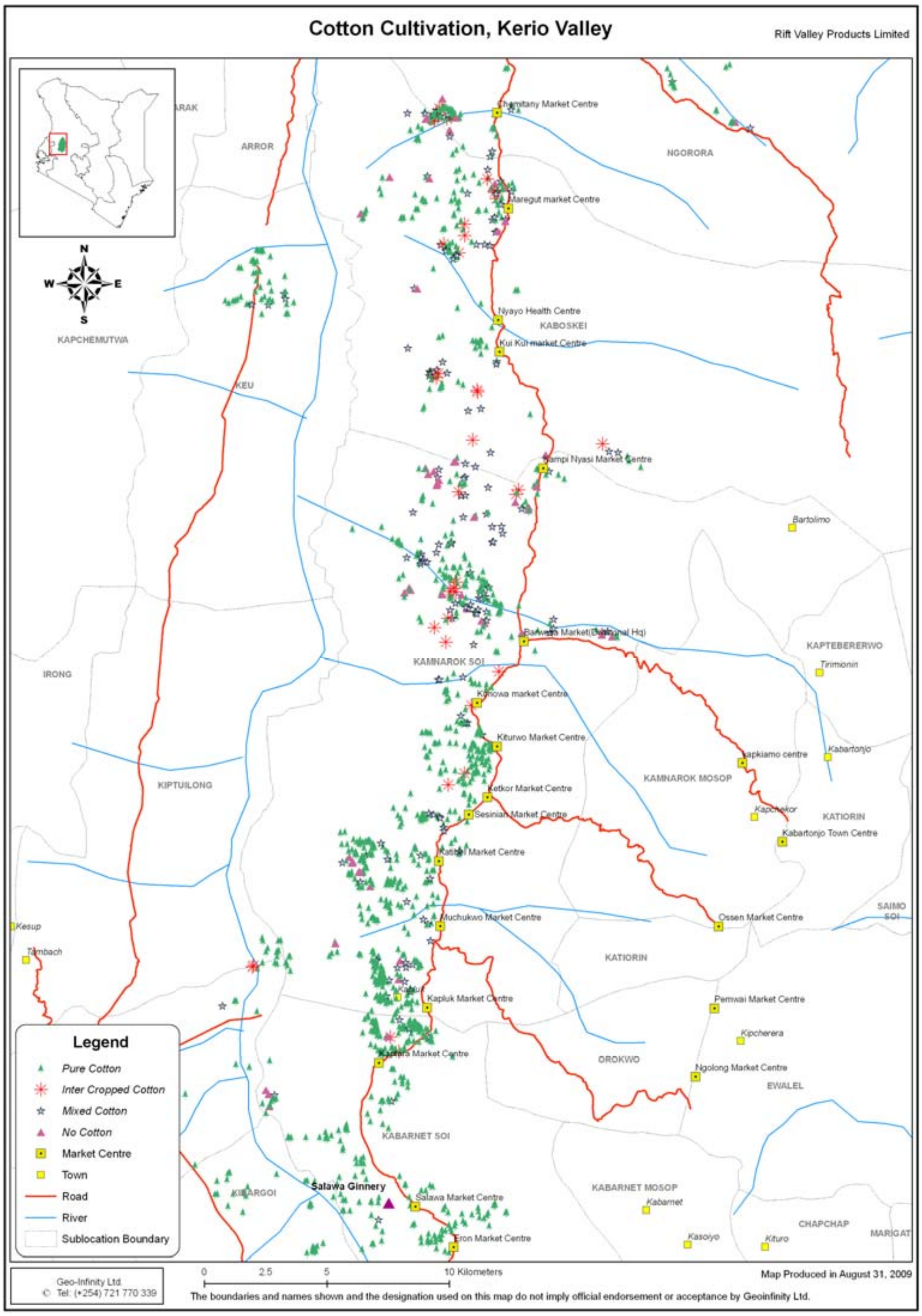

Figure 6: Cropping Type.

The map (Figure 6) shows the distribution of how farmers cultivated cotton. It shows regions where mixed cropping was done and also the regions where cotton was not cultivated.

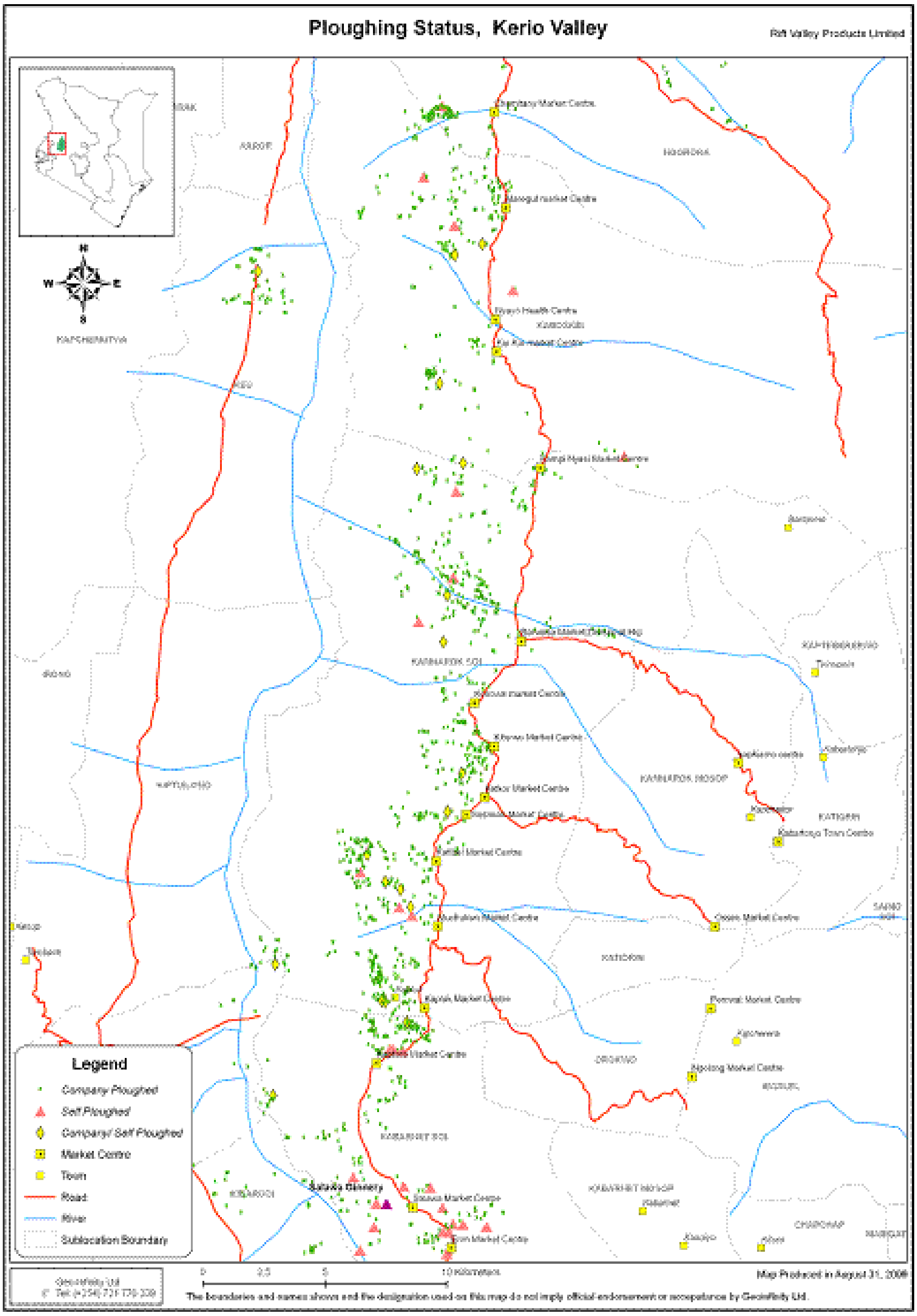

Figure 7: Ploughing Status.

The map shows the distribution of farms that RVP ploughed as well as farms which farmers ploughed for themselves.

3.6. Cost Comparisons

The following table shows the breakdown of all the costs involved in the mapping exercise. A team of five people was recruited to participate in the exercise and took 30 days to complete the mapping. The undertaking was structured such that each person would cover a zone (as defined by the farmers, a zone is an area covering about 100-300 farms). It took a GIS / data specialist five days to enter, compile, and analyze the data. It took a further five days to produce 22 maps that would be used by the field officers for their day to day use.

Table 5: Field based data collection and processing costs.

Quantity	Cost Description	Unit Price	Total
30	Field Data Collection (estimate 20 days for 5 personnel)	$350.00	$10,500.00
	(30 days x $70 per day x 5 people)		
30	Meals and accommodation for the 5 personnel	$150.00	$4,500.00
30	Car Hire and Fuel Expenditure	$100.00	$3,000.00
5	Database development, Data processing, Data Cleaning (5 days x $250 per day x 1 person)	$250.00	$1,250.00
5	Map Production (14 zone maps, 3 overview maps)	$250.00	$1,250.00
	(5 days x $250 per day x 1 person)		
5	Purchase of Garmin GPS 60	$445.00	$2,225.00
1	Miscellaneous cost (Communication, repairs, Data devices etc.)	$1,000.00	$1,000.00
		Total	**$22,750.00**

The QuickBird satellite is the first in a constellation of spacecraft developed by DigitalGlobe® and offers highly accurate, commercial high-resolution imagery of Earth. QuickBird's global collection of panchromatic and multispectral imagery is designed to support applications ranging from map publishing to land and asset management to insurance risk assessment. Today, DigitalGlobe's QuickBird spacecraft is able to offer sub-meter resolution imagery, high geolocational accuracy, and large on-board data storage. The satellite can provide high resolution images both multi spectral and panchromatic at resolutions of 61 cm and 2.4 m respectively (DigitalGlobe Inc., 2010). In this study, comparison was done with the cost of acquiring and analyzing a high resolution multispectral QuickBird image.

The cost of acquiring 1 square kilometer is $32 (USD). However, a minimum 64 square kilometers is required for any order. In this study, the area covered by the segregated cotton farms covers an extent of about 1,700 square kilometers. This translates to 32*1500 = $54,400. In addition, analysis would be required to identify, digitize and classify the cotton farms. Further field work would be needed to provide groundtruthing to verify and asses the accuracy of the image interpretation. Assuming the engagement of two GIS experts for 15 days to work on this at standard rates as used in the actual field work, their labor cost would be about $3,000. This exercise would cost in excess of $60,000; more than three times the cost of the field-based GPS data collection method.

4. Discussion

The study demonstrates the practical applicability of GIS in cotton farming as a decision making tool. It provides a clear picture on the location, size and distribution of cotton farms. The study provides concise information about the farmer as well as the area under cultivation which acts as firm baseline information for other applications with regards to cotton farming, e.g. input distribution, Micro-financing and payments. This study has achieved the target of determining the exact areas under cotton, hence providing critical information for the cotton project management. The database created by this information will be very useful in future automation of the management practices at the Salawa ginnery.

The maps produced have proven to be critical tools for the field officers who are now using them for navigation and route planning when conducting field visits, distributing farm inputs and coordinating harvesting. This has led to a considerable cut in the cost of production in terms of delivery time and fuel consumption. The analytical selection of the best sites for collection centres has also led to a reduction in the delivery times of the product and a reduction in transportation cost. In terms of cost, the ground based method using GPS proved very useful and extremely cheap when compared to the use of QuickBird imagery. This was confirmed by the actual cost incurred ($22,750) as compared to the cost that would have been incurred if the option high resolution imagery was considered ($60,000). Lower resolution imagery was not considered because the cotton parcels in the area under study were small (~ 1.00 – 2.500 acres) and would not be discernible.

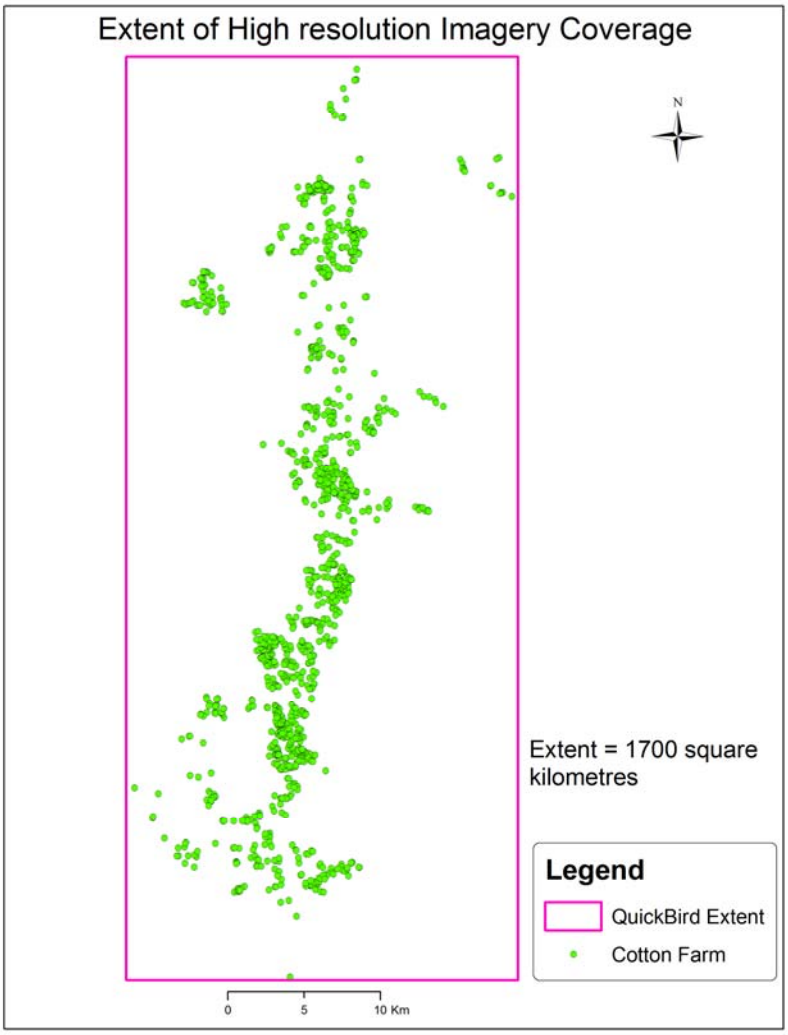

Figure 8: Extent of Kerio valley cotton farms.

5. Conclusions

The study has demonstrated that GIS and GPS are powerful tools in precision farming for providing timely and accurate information for decision-making. Farms' size auditing was conducted and this provided interesting results, most of the farmers provided accurate information. Further, the best sites for collection centres were identified based on spatial analysis.

With respect to cost, the use of handheld GPS in the field has proven to be a cost effective method of collecting spatial data in a small scale farm scenario. The cost incurred during this study as compared to the approach of mapping from high resolution imagery is lower. The field-based GPS mapping provided the researchers with an opportunity to ground-truth and verify the existence of the farms which would have not been possible in the case of using High resolution imagery. In addition, the collection of other critical information relevant to the assessment of crop status, verification of farmer details as well as cropping system was only possible through the field-based approach. In conclusion, for small segregated parcels as in this case, field-based methods have been shown to be cheaper and efficient as compared to satellite based mapping methods.

In future, considerations can be put in place to apply the technology of GPS / GIS in detail site analysis and selection for cotton farming. This would involve detailed soil studies combined with other ecological requirements for cotton. Replication of the same study in other areas of Western and Nyanza provinces would provide a concise detailed database of cotton farms in Kenya.

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