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Adoption of GIS, GPS and RS Techniques in the Sudanese Sugarcane Industry: Part 1- Kenana Base Map Establishment

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Abstract: The objective of this study is to explore the adoption of Geographical Information System (GIS), Global Positioning System (GPS), Remote Sensing (RS), and related techniques in the Sudanese sugarcane industry for agricultural production management as a response to the feedback from the academia on sugar industry. Framework on the adoption of the initiative program included techniques capacity building, base map establishment, and crop monitoring and assessment. Extensive in-house training and attended seminars were carried out by the academia to targeted personnel to highlight the opportunities pertinent to the success planning, implementation and management of these techniques on sugarcane industry. High resolution Satellite image data and GIS technique were used to establish Kenana Sugar Company (KSC) base map. Various map layers such as field layout, irrigation network, soil type, roads network, civil work were prepared using remotely sensing data along with the existing maps. Twelve ground reference points were established. The field layout map layer is divided into six areas and each area is divided into two farms having three sections for each. The soil map layer is qualitatively classified into four soil categories based on the tonnage produced. The irrigation network map layer consisted of six pump stations, main canals, primary canals, field canals, regulators, and drainage network. The road network map layer showed the major and minor roads that had been used as a platform for Vehicle Tracing System (VTS) for hauling sugarcane, while the civil work layer located the factory, administrative and residential area. Based on the obtained results, this study provides sample evidence that sugar industry could use GIS, GPS, RS and related techniques to enhance the management of sugarcane production.

Keywords: Sugar Industry; GIS; GPS; Remote sensing; Precision agriculture.

1. INTRODUCTION

Rapid advancements in Geographic Information System (GIS), Global Positioning System (GPS), Remote Sensing (RS), and related techniques have increased the productivity, quality, and efficiency of all aspects of industry. These cutting edge techniques have only been recently applied to sugar industry. Worldwide pressures on the sugar industry include much greater competition in production and the need to produce sugar in an environmentally sustainable manner. These constraints together with the need to maintain or improve profitability require that the industry constantly improves sugar production efficiencies which in turn necessitate access to better information upon which the decision making is based. Better information implies that up-to-date, accurate, reliable, and relevant data being captured, existing information being easily accessed, maintained, and made available to the relevant decision makers within the industry. This necessitates that information is digitally available, not paper based. The data need to be kept in one place and maintained by one person/group to prevent the duplicate data entry and management.

Past research has shown that a significant progress had been made in the adoption of precision agriculture (PA) and related spatial information techniques to crops such as maize, soybean and wheat. In sugar cane, progress has been slow even in countries known to be at the forefront of these new emerging techniques, such as Australia, South Africa, Brazil and Mauritius. Much of the early work in adoption of these techniques to sugarcane production was undertaken in Australia in the mid-late 1990s [1]. Other early work was initiated in Mauritius [2]. However, a collapse in the world sugar price towards the end of the decade, along with the perceived high cost of precision agriculture mitigated against the Australian industry taking advantage of the early learning. Whilst much of the work done in Australia in remote sensing applications in sugarcane production have been much more targeted at issues associated with harvest management than PA [3,4], such technology along with GPS harvester tracking, logging of harvester performance, electronic consignment and GIS-based data management has left the industry well placed to integrate PA into existing systems. The recent adoption of controlled traffic and guidance is consistent with this view [5]. Following the early Australian research, the Mauritius

Sugar Industry Research Institute embarked on a program of evaluating the potential application of PA to their cane production system [2,6]. Given the relative lack of mechanisation in the South African sugar industry, mainly as a consequence of an abundance of cheap labour, the major focus has been on the use of satellite-based remotely sensed imagery [7,8], and the appropriate sampling and analysis of both soil and plant tissue [9]. However, the Indian industry has been exploring the use of satellite-based remote sensing and GIS in sugarcane production [10], no doubt drawing on the abundant IT expertise in India. Repeat image acquisition matched to key growth stages enabled variety discrimination in addition to assessment of planted acreages. Similar work has been done in Thailand to assess spatial relationships between soil property variation and variation in sugarcane yield [10].

Sugar industry in Sudan has received great attention and progress. In this context, Kenana Sugar Company (KSC) is the world's largest integrated sugar company. The company is a joint venture of Arab, Sudanese and foreign capital. The company utilizes an area of 42000 ha and has average sugar cane production of 114 MT/ha. All activities related to sugar industry do not need only update maps but also accurate information about the schemes. Although these new emerging techniques can solve the problem of getting the data, none of the local companies tried to use this technology. Fortunately, KSC scheme enjoy excellent, successful and unique track record of information. Example of information records include field blocks and numbering, yield production and cane quality data, field records of variety, soil type, and agronomic inputs, pest and disease status, irrigation scheme data, and various infrastructure. Recently, KSC launched an initiative program on the adoption of spatial information techniques in the scheme for agricultural production management in collaboration with academia.

The main objective of this study work was to explore the adoption of Geographical Information System (GIS), Global Positioning System (GPS), and Remote Sensing (RS) techniques in Kenana scheme for agricultural production management. The detailed objectives were:

- To conduct comprehensive trainings and seminars for sugar industry targeted personals on GIS, GPS, RS and related techniques.
- To establish various KSC state areas GPS control points using Real Time Kinematic (RTK),
- To establish various KSC base map layers such as field layout, irrigation and drainage network, soil type, roads network, residential areas and factory

2. MATERIALS AND METHODS

2.1 Base Map Establishment

The following guidelines were considered on the base map establishment:

i. Extensive and thorough discussions with base map steering committee about strategic concepts and processes for establishing the initiative program.
ii. A desk top review was held with the company trainees in checking and reviewing the data collection, manipulation and analysis using GIS, GPS and RS techniques.
iii. A presentation for the progress of the program was held by the local expert in the presence of agricultural administration managers and staff at the end of three training programs. Feedback from the presentation was also considered in this report.

The evaluations criteria or steps were based on three levels: planning; implementation; and management.

Appropriate planning of a GIS is essential for the success of the initiative program. The planning involved GIS awareness, identifying the requirements and the type of analysis needed data source and spatial link to satisfy the requirements. The Agricultural Administration Department revealed that a primary requirement of sugar industry is access to accurate information, both present and past including field maps and associated data. The identified information included the following:

i. Area under cane and individual field area in hectares.
ii. Cane yield production MT/ha and sugar quality production MT/ha.
iii. Field records soil types, terrain contour, cane varieties and agronomics inputs.
iv. Irrigation information such as pumps, canals, drainage, regulators, and water required for irrigation.
v. Pest and diseases status.
vi. Forest area in hectare.
vii. Transport distance to mills and scheduling of hauling cane.

The GIS expert together with trained staff investigated and documented information requirements such as type of analysis, data sources, and methods for collecting data into a single format database, database design, and spatial links.
The implementation of the program involved the inputs of the GIS expert together with trained staff to design a database that will be linked to mapped GIS data. The second phase of implementation involved linking of the mapped data in the GIS to the database. Consequently the system will provide solutions in forms of maps, tables and report.
Management of the project is important as the system must be maintained and updated to meet any new requirements. The functional information system would be constantly re-evaluated and fine-tuned to insure that it is able to meet current and newly defined objective. This will ensure that problems are addressed and that an optimally accurate database will be maintained.

2.2 Description of Study Area

Kenana Sugar Estate, situated in the Sudan (East Africa), is considered to be one of the largest single estates in the world covering an area of 42000 ha. The scheme is irrigated from the White Nile water by lift irrigation. The potential yield of the estate is about 3.3 million MT of cane. The Estate is situated 300 km South of Khartoum and 30 km South of Rabak town on the east bank of the White Nile. The scheme is located geographically at 13˚ North of the latitude and 30˚ East of the longitude. Fig. 1 shows Kenana location map while Fig. 2 shows a satellite image covering the project area.

Climate: The Estate is situated in an arid continental climatic zone. The climate is broadly divided into two seasons, the dry season from November to the end of March and summer season from April to the end of October. About 90% of the total rainfalls occur during the June-September period. Most of it is in July and August, the mean annual rainfall is about 300mm. The mean annual temperature is 28.7^{o}C. The mean maximum temperature is over 40^{o}C in April and May with absolute maximum of about 45^{o}C in these months. The mean minimum temperature is 17.6^{o}C in December with an absolute minimum of 10^{o}C. The daily evaporation rate varies from 5mm/day in August to 16 mm/day in March-April.

Topography: The Estate area slopes downwards the river with an average land slope of 0.5 meter per kilometer. From it's Western boundary to the river elevations range from 390 m to 429 m above sea level. The Estate area is divided into two parts by a ridge running from North-East to South-West from elevation 424 m to 410 m and is deeply incised by two drainage channels which are separated by a ridge. The governing slopes are about 45^o to the direction of the drainage channels. The cross contour grades range from 1:25 to 1:1000 with the majority of areas around 1:500.

Extension: The estate total area is 63,000 ha out of which 39,480 ha is designated for cane growing. The first crushing season started in 1980 while planting was, at that time, done in new areas targeting 35,280 ha to produce 3.0 million MT of cane. The factory continued crushing cane harvested from this area until the need had arise to have fallow land to improve the production and avoid excess cane after cane planting. About 2,100 ha used to be left fallow for the above purpose at the expense of the area for crushing. The crushing then reduced to 32,340 ha for the last few years. The extension of 4,200 ha therefore was thought of and now became a reality. Planting in this new extension, which is named Area 6 has started since (1996/97) and the cane produced on it had crushed in season 1997/98.The cane area, then, became 39,480 ha broken down to crushing cane seed area and fallow area of 34,650 and 4,200 ha, respectively. Area 6 has added one more division in cane production department which will, in turn, need to be fully equipped as a separate area in the estate. The department is adopting the decentralization of the work facilities among the different sections and these facilities are moved from one section to another whenever necessary.

2.3 Methodology

Various software and hardware were used in the establishment of Kenana's capacity building and base map using GIS software (ArcGIS 9.2), remote sensing software (ERDAS imagine 9.1), RTK GPS *Leica* 520 for collecting the coordinates reading from the field. Map source for processing GPS data and Microsoft office (Word and PowerPoint) were used for reporting and presentation. In addition, computer System, Microsoft Windows® XP, Professional, Version2002, Service pack 2, Registration number, 00045-136-724-167 was used also for this study.

To create the feature data for the study area, high resolution satellite image from IKONOS Satellite of one meter spatial resolution with three bands was used. Details specifications of the Satellite and image were shown in Table 2. The IKONOS image with the size of 4 GB and (img) format was exported to (MSRI) format which minimized the size of the image to 2 GB using Erdas Imagine 9.1. The steps followed to process the raw image could be shown as follows: (a) Geometric correction of the satellite data using the GPS control points, (b) Adjustment of drawing scale 1:1.5 and (c)

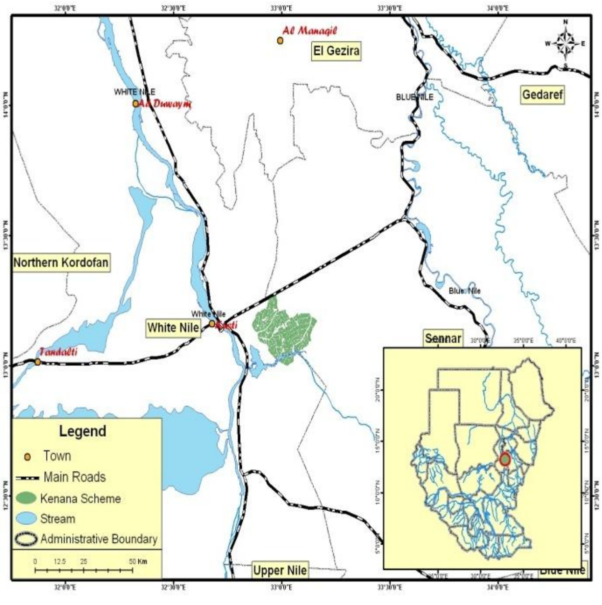

Fig. 1. Kenana (KSC) location map

Fig. 2. Kenana (KSC) from space (high resolution image)

Table1. IKONOS satellite and image specifications

Name	IKONOS
Date of launch	Sept. 24, 1999
Altitude	681 km
Orbit	98.1 degree, Sun synchronous
Swath Width (km)	11
Dynamic Range	11-bits Per Pixel
Image Bands	Panchromatic, Green, Blue Red, and near infrared.
Projection	UTM_Zone_36
Datum	WGS1984

Tracing the features which contained the fields based on area (area1, 2, 3, 4, 5 and 6), irrigation network (main canals, primary canal, canal design, pumps station, etc..), roads network map (major and minor roads), and civil work (factory, administrative and residential area).

3. ANALYSIS APPROACHES AND RESULTS

3.1 Capacity Building Program

To exploit GIS, GPS, RS, and related techniques successfully awareness must be created at all levels of decision makers, administrators, agriculturalists, and engineers on sugarcane industry. The involved staff must realize the potentials and benefits derived from these techniques. Intensive short training courses, workshops and seminars on these emerging techniques were held. At the first step University of Khartoum staff (with collaboration of Departments of Geography and Agricultural Engineering) as local GIS experts engaged in precision farming and agricultural database design and development were employed by sugarcane industry to conduct training. The main objective was to help the company staff for document the GIS information and design the database, which would contained the relevant information in sugar industry. The program was started with three training courses for selected staff (10 candidates) from Agricultural Administration Department so as to educate them and make them aware with GIS, GPS and RS techniques. The main focused of the three training courses were:

i. Introduction to GIS, GPS and RS techniques: The main objectives of this introductory course: (a) To address the importance of these technologies to the sugar industry. (b) To train the staff on the basic principles and practice in the technology.

ii. Intermediate GIS and related technologies: This course included intermediate GIS, technical issues in GIS, training in GIS software, training on GPS application in the field and image processing techniques.

iii. Advance GIS and related technologies course: The topics of this course were conducted in parallel with sugarcane scheme base map production developed by the company trained staff.

3.2 Ground Reference Points (GFP)

The RTK GPS *Leica* 520 was used to collect the coordinates reading from the field. A total of twelve points distributed through the estate area were located. The main point was located in the agricultural department head office. Table 2 shows the GPS readings for each point. These points will be used as a base for any application inside the field such as harvesting, transportation, land preparations ...etc. Fig. 3 shows the distribution of the GPS reference points within the estate area.

3.3 Fields Layout Layer

Kenana Sugar scheme is divided into six areas each of about 6,720 ha (Fig. 4). Each area is subdivided into two farms and each farm is irrigated by a separate primary canal with very rare exceptions of shared canals, the phenomenon which will ease the water management along the irrigation channel. The farm is also divided into three sections each of about 1260 ha. These divisions are headed by Area Manager, Farm Manager and Section Manager, respectively. In each Area an Irrigation Controller in the Section Manager level is appointed to order and monitor the water along the area canals. A Cultivation Manager per Area at the Farm Manager level is responsible for all the cultural operations pre and post harvest in addition the manger is responsible for the mechanical operations in the plant cane. The Area is a separate unit having the identity of the independent

Table 2. GPS Point coordinates in meters for each point

Point	Easting (m)	Northing (m)
area33	500698.775	1443836.551
office c1	491680.017	1445256.425
D1	514063.082	1447211.866
area4	500611.618	1448505.692
ps3	491592.680	1448661.377
ps2	488098.078	1449338.782
area2	493381.688	1450960.806
ps4	497612.504	1452824.276
area55	508088.746	1454837.275
area1	490958.858	1456296.927
ps6	503641.765	1456795.411
D10	498069.598	1461201.823

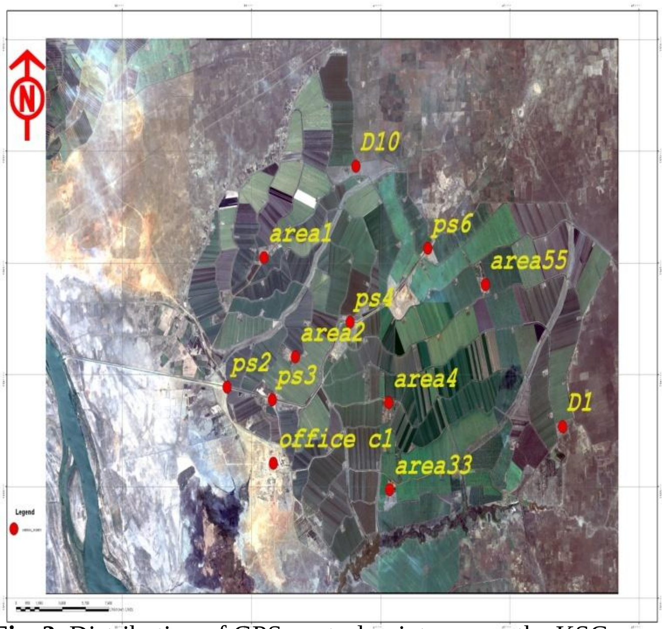

Fig. 3. Distribution of GPS control points across the KSC

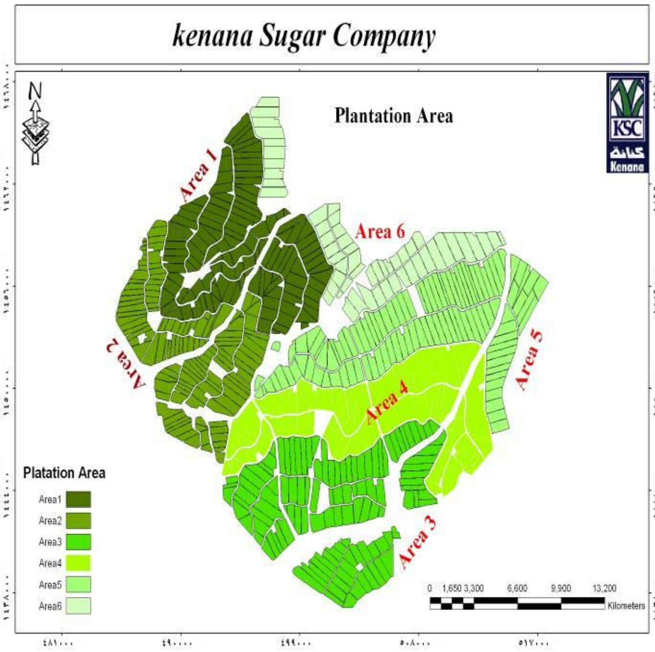

Fig. 4. Kenana plantations areas

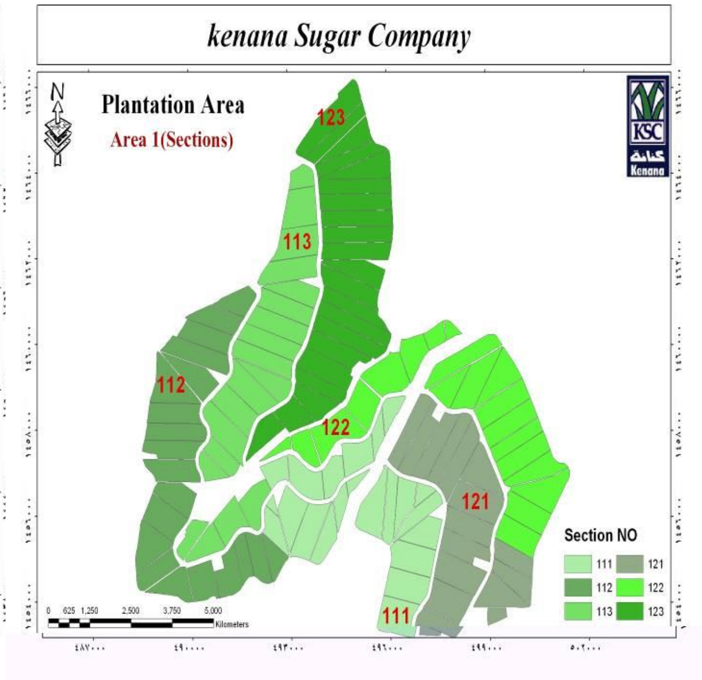

Fig. 5. Sections of Area 1

scheme equipped with it is own machinery, tractors, implements, vehicles, workshops, chemicals, services, staff, irrigation water, and headquarter. A typical sample plantation area with sections is presented in Fig. 5.

3.4 Irrigation Network Layer

Water supply in Kenana is performed by the irrigation section headed by the assistant field manager for water supply. This section is responsible for pumping operation, water conveyance from the White Nile and distribution to the primary canals, and the irrigation system maintenance. The water application is performed by the field management section. Fig. 6 shows the irrigation system layout as it was drawn from the high resolution image. The water supply is done by lifting water from the White Nile through six pumping stations to an elevation of 45 meter from the White Nile level. The six pumping stations are connected in series to irrigate 35280 ha for the period between April to September. However, this area is increased for the period of October to March due to the commencement of the fallow land planting.

The main canal No. 1 is a carrier of water to the pumping station No. 2 as no water diversion is made to the primary canals from the main canal. The other main canals 2, 3 and 4 have diversion of water to the primary canals on both sides. Pumping stations 1 and 2 in the series are designed to pump maximum of 42 M^3/s each, with an extra pump bay to meet future extension. The maximum demand of the estate at the peak is 36.4 M^3/s i.e. Seven pump units, out of 8 pump units installed in each of the pumping station (No.1and 2), with a discharge capacity of 5.25 M^3/s/unit to irrigate 35280 ha. These seven pump units are the maximum practically allowed. The other four stations are designed with lesser capacities because of diversions of water to the primary canals as the water flows uphill. The main canals which are the main arteries have been designed as hydraulic conveyance, as distinct from the primary canals which have been designed to command the land. Series of primary canals, which constitute the main delivery system, take off from the main canals forming a network of about 200 km and following the contour to serve the agricultural fields. The primary canals were designed to store water at night which has not passed to the field. However the night storage system was lately dispensed, and has been replaced by continuous flow system. The regulating structures of the primary canals incorporate movable weirs which control the flow into the canals with reasonable accuracy and thus ensure sufficient water to the fields. The canals are divided into reaches not exceeding five km. The intermediate regulators are night storage weirs which consist of a pipe controlled by a gate and concrete weir with brickwork forming the sill. The sill of the weir is at the level which allows full discharge of the canal to flow over the weir when the water level upstream of the regulator is at the night storage level. The pumping stations operated continuously for 24 hours to meet the continuous siphoning to the furrows. All primary canals are provided with escape to weirs draining any excess water flow.

The scheme is provided with a drainage network to drain off excess irrigation water and rainfall of 130 mm in 24-hrs time. Each primary canal irrigates 2500-3800 ha. The standard unit of the layout is 420 ha which is called sub-section. The field canal takes water off from the primary canal to irrigate a field of 60-84 ha on average. Fig. 7 describes a typical example for areas irrigation system layout. Water in the primary canal is diverted into field canals running parallel to it. Long furrows of 1.5 km average length run across the contour of average slope 0.2% (1:250-1:500). Because of the

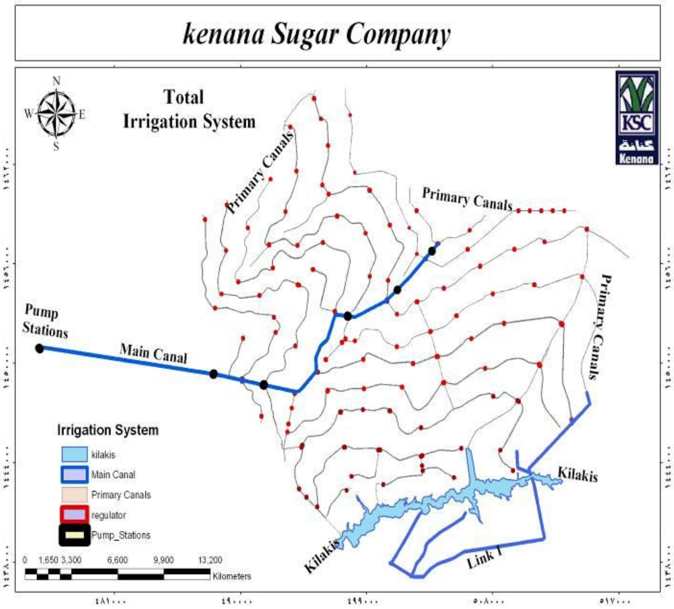

Fig. 6. Kenana irrigation system

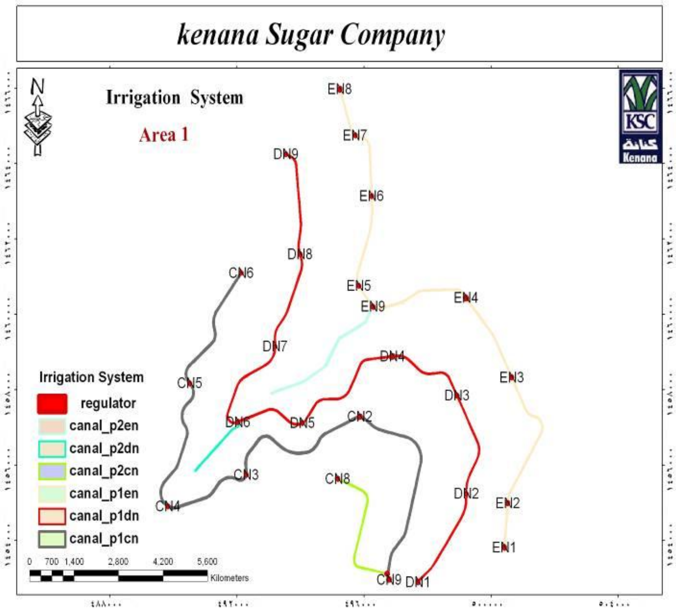

Fig. 7. Area 1 irrigation system

longer time needed to irrigate long furrows, the night storage system of irrigation was replaced by continuous irrigation which requires full attendance to ensure perfection and water saving. The drains for each area are also drawn separately.

3.6 Soil Classes Layer

The soil of the Estate consists mainly of sediments of the Blue Nile and mostly derived from the basic rocks of the Ethiopian highlands forming part of the extensive central clay plain of the Sudan. The soil is classified as vertisols i.e. soils that crack widely, have a high content of montmorilinitic clay and have a high base-exchange capacity. The soils are fairly uniform, cracking, and self mulching clays. The surface cracking is developed with cracks up to 5 cm. wide down to about 60 cm. A massive horizon below 60 -75 cm. deep has fewer cracks compared to the top layer. Irrigation and rain water enter the soil through the cracks resulting in the swelling of the soils and closing of the cracks after saturation. Very little further water can gain entry and thus development of water table does not arise easily. The topsoil is alkaline clay, containing 40% to 60 % clay and 10% to 30% sand, with somewhat heavier sub-soils. Over 90 percent of the soil has a pH value in the range of 7.5 to 8.5. About 97 percent of the topsoil (0-25 cm) has low EC (electric conductivity) values of less than 2 mm hos/cm increasing to 4 mm hos/cm in the sub-soils (75-100 cm).

The soil of the estate is classified according to its potentiality into 4 categories marked (A1, A2, B1, and B2) on the soil classes' map. The maps have been drawn for sample sections on each class based on the tonnage produced in each of these sections for the period between 85/86 and 95/96. Kenana soil classes and a sample area soil classes is presented in Figs 8-9, respectively. It is clear that the soil classes have a noticeable effect on the yield, but it is, of course, not the only factor. Other factors are, of no doubt, have a great effect on the section yield among them, the management of inputs (irrigation, weeding, fertilization, cultivation), this in addition to the effect of the cane crop cycle, the time of planting which determines the quality of germination, the variety and the time of harvest.

3.7 Road Network Layer

*Road Layer Preparation***:** A feature of the datasets was created within the personal geo-database. In addition, the feature class and topology layer were built in line with spatial referencing of the image. Using Arc GIS 9.2, the road layer was drawn and the topological error was edited during the drawing at the scale of 1:1500. The final product was a Shape-file. This was obtained from personal geo-database. The Shape-file is a vector data storage format for storing the location, shape, and attributes of the geographic feature. A Shape-file is stored in a set of related files contained one feature class. The Shape-file is composed of three main files that contain spatial and attribute data. The Shape-file can optionally have other files with index information. All of the files that comprise a Shape-file appear as one feature class in the catalogue [12].

Attribute Table Editing: The final product was a Shape-file. This was obtained from personal geo-database with attribute table which contains these fields. The table input included FID, SHAPE, OBJECT ID, LENGTH, and ID. The VTS requires standard attribute table which has descriptive fields for Roads such as AREA_NAME, RD_CLASS, COMM NO., RD_DIRECTION, DISPLAY, RD_NUM, INTERCHAN, RD_WIDTH, LANDMARK, ROAD_TYPE, NO_LANE, RESOURCE, ROAD_NAME and SPEED. After reprojecting the shape-file using Arc Tool Box (converted the projection to geographic) the attribute table was edited (adding fields) and the administrative boundary was established as required by the system. After attributes edit the final layer which is required by the system. Kenana had road network layer, the scheme contained two types of roads (major and minor roads) each of which has its own specifications. The major roads are 20 m in width, open in both directions having lane number of 2, and its speed is limited to 60 km/h. The minor roads are 10 m in width, one direction is opened having lane number of 1 and its speed was limited to 40 km/h. Fig. 10 presents the digitized Kenana road network map layer. Furthermore, there were some specifications found in the attribute field of the road network layer, such as area name, road number and land marks which represented the familiar places that found in the area. All these descriptions are very important for the analysis which can be performed by the vehicle tracking system. Presently, there are ninety four trucks moving in the fields, transporting the sugar cane to the plant and about seven trucks used for supplying the others with fuel. The management of these trucks in this large area was very difficult, because of many managerial problems like the irregularities in cane delivery to the plant caused by old style of communication, traffic jams, misconduct of the personnel, and poor supervision of the fleet logistics. Kenana roads

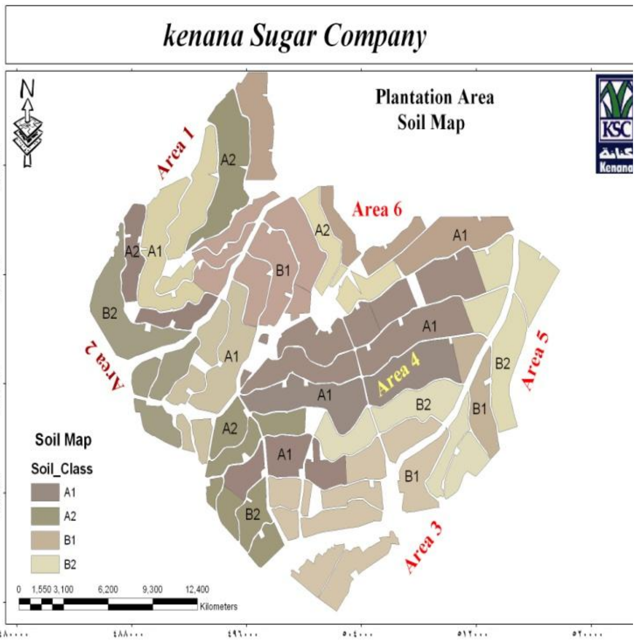

Fig. 8. Kenana soil classes

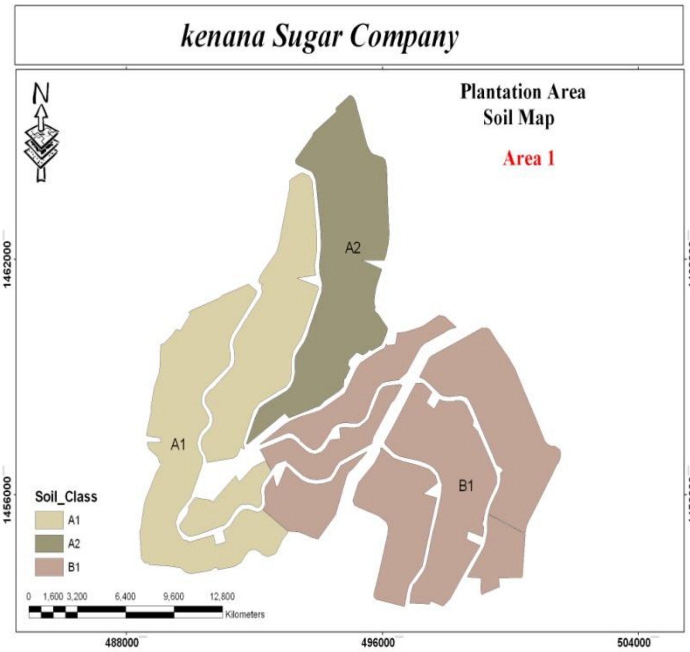

Fig. 9. Area 1 soil classes

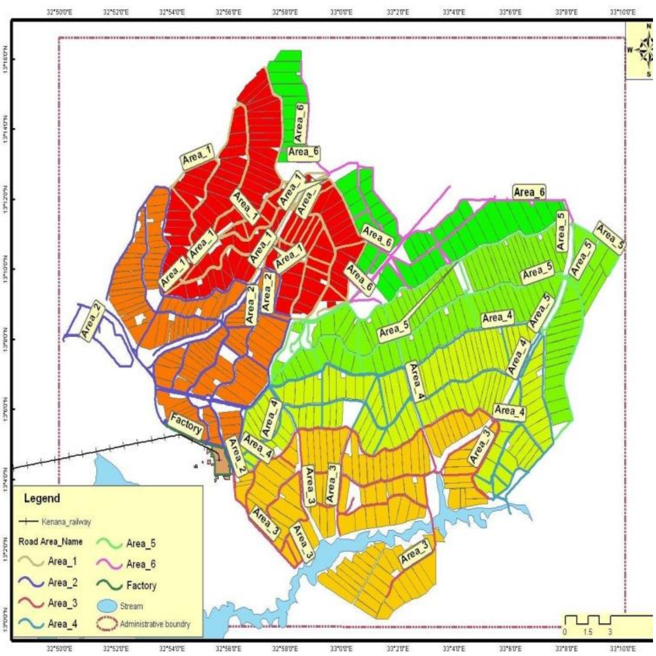

Fig. 10. Kenana road network

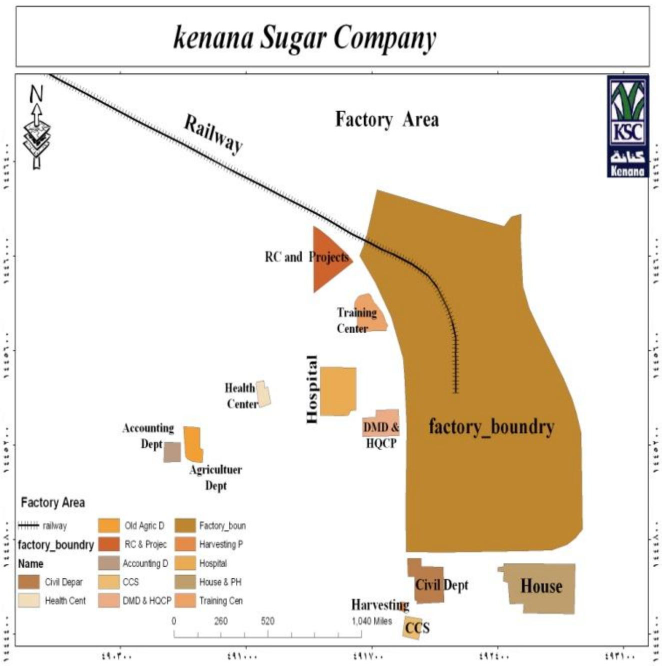

Fig. 11. Kenana factory and residential area

network and areas GIS database have been successfully digitized and developed in order to be linked with Kenana's Vehicle Tracking System. The VTS had been successfully developed in Kenana Sugar Company for hauling and transportation of sugar cane [13]. The developed system had the facility to monitor record and display vehicle information such as vehicle's number, vehicle's plate number, driver's name, driver's cell phone number, alarm, GPS location and date, SIM number of device, and descriptions of vehicle status (exact location, stop/move, and speed). Hopefully, with the existing VTS, the company can manage the fleet of trucks resources and consequently will benefit in many aspects such as reliable data flow, enhanced fleet control, better decision making, increasing productivity and lesser complains.

3.8 Civil Works Layer

Finally, the civil work layer was prepared by using satellite data (IKONOS) for the residential area, and the administrative buildings. Similarly, the layer was drawn following the same procedure mentioned before in filed base maps production. The residential and administrative areas were traced with space image and database was entered for each as shown in Fig. 11.

4. CONCLUSIONS

Adoption of spatial information techniques such as Geographical Information System (GIS), Global Positioning System (GPS), and Remote Sensing (RS) are expected to play an increasingly important role in Sudan's Sugarcane industry becoming more competitive in local and international markets. Despite the real and potential benefits of using these techniques, still their adoption has not been fully implemented. This study attempted to explore the initiative program for Kenana Sugarcane Company for adopting these techniques with special emphasis on capacity building and base map establishment. Training and human resources development in these techniques is curtail for efficient use and insuring the sustainability of the system. Various map layers such as field layout, irrigation network, soil type, roads network, and civil work were prepared from remote sensing data along with the existing maps using Arc GIS, RTK GPS and ERDAS hardware and Software. Establishment of GPS control reference points will help in using the GPS in many applications including vehicle tracking system (VTS). The production of digital maps for all layers and features facilitate the management operations and make the data exchangeable between the different concerned authorities. Updating the produced maps, data base and learning about the new applications of these tools will lead to achieve its promised objectives in the future.

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