MAP UPDATING USING HIGH RESOLUTION SATELITE IMAGERY A CASE OF THE KINGDOM OF SWAZILAND

W. Ottichilo, E. Khamala *

Regional Centre for Mapping of Resources for Development (RCMRD), P.O Box 18118, Nairobi, Kenya, rcmrd@rcmrd .org

KEY WORDS: Map updating, Remote Sensing, GIS, GPS

ABSTRACT:

Most national maps in Africa are old, outdated, and largely exist in analogue form. Due to the high cost of aerial photography, these maps have not been updated for many years and as such are not useful for planning and navigation purposes. Therefore, there is an urgent need to produce new maps or update existing ones. The Regional Centre for Mapping of Resources for Development (RCMRD) has a wide experience in rapid and cost-effective updating of maps using high resolution satellite data. The method entails undertaking preliminary interpretation of georeferenced satellite imagery based on predefined classification and aided by secondary ancillary data; identification of sample points that prompt GPS facilitated 'ground truthing'; conducting the final image interpretation; development of database driven thematic map layers; mosaicing of all the thematic layers to form country-level thematic maps; and integration of these datasets with administrative boundaries. In this paper, the updating of the national map of the Kingdom of Swaziland using the 20 by 20 meter resolution SPOT satellite imagery is given as a case study. The successful completion of the project not only demonstrates the capabilities and potential of satellite remote sensing in modern day mapping but also illustrates the flexibility and dynamism of GIS generated map databases in the provision of value-added products for quality planning and decision-making.

1. INTRODUCTION

The recent availability of high resolution satellite imagery has led to increased interest in the use of satellite data for large scale mapping applications and detailed land use assessments (Amuyunzu and Bijl, 1999). This growing interest not only emanates from the fact that satellites provide a synoptic coverage, have a high repetitive cycle, and carry multispectral band sensors that provide information beyond the ordinary ability of the human eye, but also because they offer a cost-effective source of data that enables timely detection of changes to the landuse and landcover, the monitoring and mapping of urban development, assessment of deforestation extents, evaluation of post fire vegetation recovery, the revision of topographic maps among numerous other environmental assessments.

Conventional mapping techniques in Africa are still pegged on the use of black and white aerial photographs and extensive fieldwork exercises. This method is both slow and cumbersome and is also very costly to the extent that continuous national mapping remains far beyond the realms of affordability for the countries. No wonder, most national maps in Africa are very old and out dated and thus unsuitable for planning and navigation purposes. For instance, Kenya uses topographic maps produced from the aerial photographs of 1969.

As competition for diverse uses for limited natural resources increase, it is becoming more important that we carefully examine and plan for sustainable use of these resources (Civco and Hurd, 1991). It is almost axiomatic that accurate, reliable, and up-to-date information is essential for wise and efficient decision-making. This is particularly true in the management of natural resources which fall within spatially and temporally complex dynamic systems. Data of high precision as well as state of the art analytical techniques are needed to derive maximum information about earth resource features and phenomena.

Given the diversity and heterogeneity of the natural and human-altered landscape, it is obvious that the time-honoured and laborious method of ground inventory is inappropriate for mapping land use and land cover over large areas. A more synoptic vantage point, such as provided by remote sensing is required for effective detection, identification, classification, delineation, and analysis of landscape features. Satellites equipped with high resolution sensors thus provide a platform for wide area land use and land cover mapping.

There is therefore an urgent need for countries in Africa to embrace rapid and cost-effective mapping techniques in order that they constantly update their maps for sound and sustainable national planning and development. This paper articulates through a case study, the methodology of using high resolution satellite data to undertake nationwide mapping exercises at relatively lower costs and within shorter time-frames. The paper reports on how the Regional Centre for Mapping of Resources for Development successfully used high resolution SPOT satellite imagery (acquired through a grant by the Military Survey, Ministry of Defence, United Kingdom) to update the national map of the Kingdom of Swaziland at 1:250000 scale on behalf of the Surveyor General's department, Ministry of Natural Resources and Energy, Swaziland.

* Corresponding author.

2. AREA OF STUDY

The Kingdom of Swaziland is one of the smallest countries on the African mainland. Located between longitudes 30^{o} and 32^{o} East and Latitudes 25^{o} and 28^{o} South, the country occupies about 6700 square miles.

Land locked between its neighbours - South Africa and Mozambique, the Kingdom of Swaziland is divided into four regional administrative units namely; Hhohho, Lubomba, Manzini and Shiselweni.

The country is covered by fourteen SPOT satellite image scenes (see Figure 1), four.Landsat TM satellite image scenes and thirty five 1:50000 topographic maps (see Figure 2).

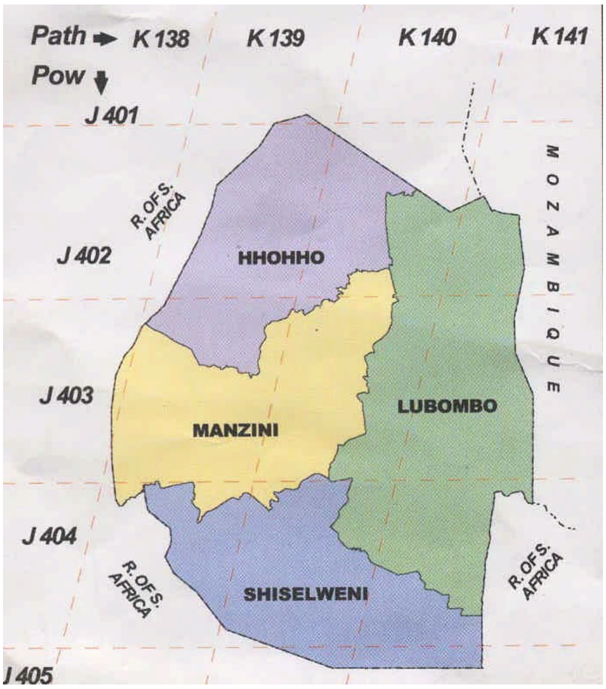

Figure 1. SPOT scenes coverage of Swaziland

3. METHODOLOGY

Map updating of the Kingdom of Swaziland was done using high resolution satellite remote sensing data and Geographic Information Systems (GIS). This was implemented in six stages. These stages were: (i) data collection and pre-processing, (ii) preliminary image interpretation, (iii) field verification, (iv) final image interpretation, (v) quality control (vi) digitization of the final interpretation.

3.1 Data Collection and Pre-processing

After undertaking a comparative evaluation of various satellite imagery products, SPOT XS data was identified as most suitable for the project. Cloud-free or near cloud-free three band digitally enhanced and georeferenced SPOT XS satellite imageries of 1995 covering the entire Swaziland were acquired from the Satellite Application Centre (SAC) of South Africa. The three spectral bands were; band 1 (0.51 – 0.59 um), band 2 (0.61 – 0.68 um), and band 3 (0.79 – 0.89). Other ancillary data acquired included Landsat TM satellite images, topographic maps, existing land use/ land cover maps, and literature reviews on the Kingdom of Swaziland.

Pre-processing especially of the satellite images involved geometric correction to the local UTM grid using the PCI image processing software. Where necessary, some of the ancillary spatial data were either digitized or scanned and georeferenced in UTM projection so as to provide better 'vertical' comparison with the SPOT data.

Figure 2. 1:50000 topographic maps coverage of Swaziland

3.2 Preliminary Image Interpretation

In classifying and interpreting land use and land cover from remote sensed data, the quality of the interpretation is improved by the integration of ancillary data. Manual interpretation of all the SPOT images covering the entire Swaziland was therefore conducted based on the implicit and explicit use of collateral information which included maps, photographs, reports and personal experience of the interpreters and was done using a pre-defined classification system. Colour, tone, pattern, texture, association, shape, size, shadows, and site clearly enabled photomorphic delineation of line and polygon features to produce the preliminary maps.

3.3 Field Observations

Sample points across the entire country were selected during the preliminary interpretation. Whereas emphasis for designating sample sites was based on feature ambiguity, representative sampling of all classes within the classification system was also done to enable authentication of feature identity as specified in the interpretation and to some extent assist verify the appropriateness of the classification system. To ensure actual access to each sample site, proximity to the road network was given high weighting in the sampling criteria.

Fieldwork forms were prepared and coordinates of the sample points acquired directly from the digital satellite images for entry into the GPS. The actual fieldwork exercise entailed compass and GPS aided navigation based on the coordinates of the sample points as entered into the GPS. Once on site, the area was sampled based on the fieldwork form. Information collected included actual site GPS position readings, area name, land use / land cover, topographic data, and socio-economic data. Also sampled were other land use / land cover types omitted in the classification system. Site photographs were also taken as additional records of the field observation.

3.4 Final Image Interpretation

Fieldwork findings were incorporated to refine both the preliminary classification system and the preliminary image interpretation. In some cases, this stage involved re-labelling and redrawing of certain feature boundaries to give the actual representation as revealed by the field observation exercise. Accuracy assessment between the laboratory and field classification and interpretation were also undertaken.

3.5 Quality Control

Quality control involved cross-checking the feature boundaries to ensure accurate and consistent interpretation. Also important was the confirmation of feature codes/labels, polygon closures, and where applicable, line feature continuity among many other topological issues. Once approved the final interpretation would proceed for digitization.

3.6 Digitization of Final Interpretation

Digitization of the final interpretation was done on a scene by scene and theme by theme basis using Arc/Info and ArcView GIS software. Land use / land cover polygons, hydrological features and the road network were thus digitized as independent thematic layers. Each thematic layer was then edited to eliminate digitization errors and thereafter coded and georeferenced. Prints of the preliminary digitization were then made at the same scale as the original images so as to allow direct 1:1 overlay evaluation of the quality and accuracy of the digitization and coding. Whenever errors were identified, the necessary correction was made. Additional feature information was then input and appended to the GIS database.

Following approval of the quality of the digitized themes, adjacent digital themes were edge-matched and joined together to produce single nationwide thematic mosaics of the entire Kingdom of Swaziland. Using ArcView, all the different national map layers were overlaid to produce a single multi-thematic map of Swaziland at the scale of 1:250000 (Figure 3).

4. RESULTS

The results of this project were as follows:

i) A cost-effective and rapidly updated national map of the Kingdom of Swaziland was produced using SPOT satellite imagery at the scale of 1:250000. The map carried eight land use / land cover classes, hydrological features, the transportation infrastructure, towns, and the administrative boundaries.
ii) A rich GIS database containing both spatial and aspatial information was developed. From the flexibility of scale and thematic overlays, scalable thematic maps of the Kingdom of Swaziland can be generated at fairly short notice from the massive database.
iii) Despite various limitations, the appropriateness of this mapping methodology was tested, refined and is thus suitable for nationwide mapping of African countries especially considering the socio-economic inadequacies perpetually inherent in this countries.
iv) The satellite image interpretation accuracy was about 80% indicating that the methodology is robust and reliable if well executed.

5. DISCUSSION

The results of this project indicate that high resolution data can be reliably and rapidly used to update maps at both national and regional levels. However, it should be noted that use of remote sensing data has certain limitations. These include:

i) Geometric inaccuracies and errors: satellite mapping carries high possibilities of inheriting and cumulatively propagating inaccuracies and errors through both the source data and methodology. It is therefore important that potential users are aware of these limitations and thus use the maps as a general information source and not for site specific studies. As with any earth resource issue, regulatory and policy decisions demanding the most accurate and precise information will require more detailed data, especially those from ground observations.

It should also be recognized that the spatial properties of the final land use / land cover data are a combination of the geometries of the individual source data layers i.e (a) different paths and rows of SPOT data; (b) the use of geocoded and in-house geometrically-corrected data; and (c) the integration of ancillary data whose geometry has been altered somewhat in the raster-to-vector conversion. However the geometric fidelity of each dataset, combination of datasets, and products derived through image processing operations in this case were carefully scrutinized at each stage of the mapping project to maintain the highest level of co-registration possible.

ii) Effect of cloud cover: The use of satellite mapping is sometimes limited by various atmospheric noises of which cloud cover especially in the coastal regions is the most significant. In such cases there tend to be an excessive reliance on collateral data majority of which are usually old. Field observation in this case is most suitable but is usually confined to the more accessible areas. On the other hand aerial photography, though expensive, may also be used.

Despite the limitations, high resolution satellite data can be used effectively and rapidly to update old maps. The resulting maps provide useful and general information that is necessary for planning and decision-making at national and regional levels.

6. CONCLUSION

The results of this project are encouraging and confirm the utility of SPOT satellite data (and indeed other high resolution satellite data like Landsat TM, Ikonos, Eros, etc) in updating statewide land use / land cover maps and monitoring change.

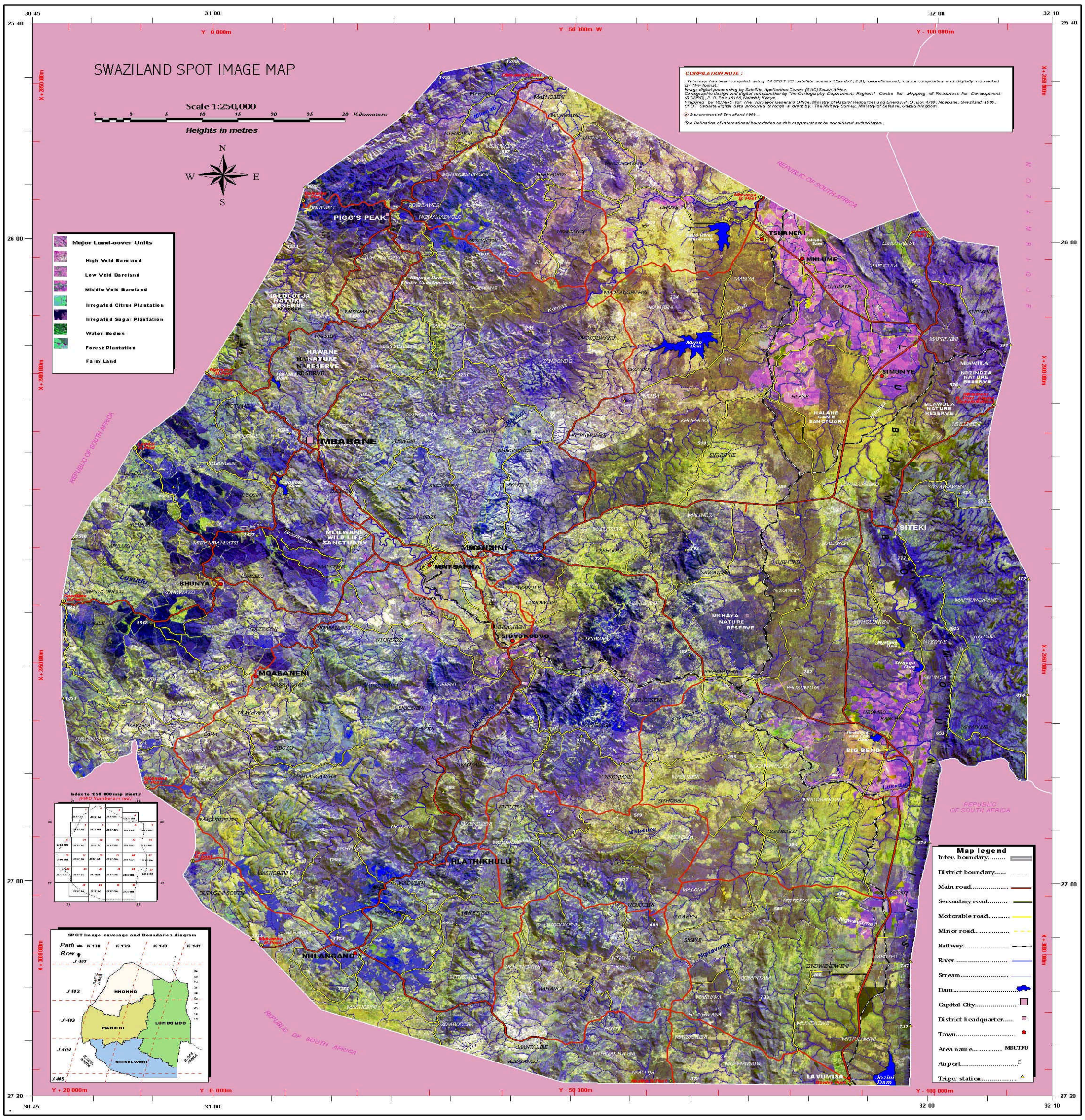

Figure 3. Updated national road network map overlaid on mosaiced SPOT satellite images of the Kingdom of Swaziland

ACKNOWLEDGEMENTS

The authors greatly acknowledge the cooperation of the Military Survey, Ministry of Defence, United Kingdom for their grant that enabled the procurement of the SPOT satellite data and the Satellite Application Centre (SAC) of South Africa for the elaborate digital enhancement of the SPOT satellite images. Special thanks are also extended to all the staff of the Cartography and Remote Sensing Departments of the Regional Centre for Mapping of Resources for Development for their tireless dedication to the project to ensure its timely and successful completion.

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