Opportunities for Increasing Societal Value of Remote Sensing Data in South Africa's Strategic Development Priorities: A Review

Paidamwoyo Mhangara[1] and John O. Odindi[2]

[1]South African National Space Agency, Earth Observation, Pretoria, South Africa
[2]School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa

Abstract

Despite the enormous capital required to fund remote sensing initiatives, governments worldwide are increasingly adopting earth observation technologies to optimise operational efficiency and societal benefit. However, the value of information derived from earth observation will increase substantially if augmented by socio-economic data within contextualised focus areas of direct societal relevance. Within the framework of the key strategic development priorities designed by the South African government, the objective of this paper was to review existing and emerging remote sensing applications and their relevance to South Africa's development priorities. Whereas there is potential for adoption of remote sensing techniques in other prioritised areas, this paper identifies health, crime analysis, rural planning and agriculture, natural resource management and physical planning as areas with considerable potential. However, to realise the set strategic priorities and outcomes, decision support systems that incorporate information derived from remote sensing should be maximised. To achieve this, it will be necessary to link patterns and processes from expert knowledge to emerging and existing societal challenges identified and to develop requisite policies of governance. The paper concludes that remote sensing technology has considerable potential to support sustainable socio-economic strategic priorities set by the South African government.

1. Introduction

In 2010, the South African government adopted twelve key outcomes that jointly address the strategic priorities of government, these include basic education, health, safety, skills, infrastructure, rural communities, human settlements, local government, environment and public service (http://www.thepresidency.gov.za). In a general context, techniques using earth observation datasets have emerged to be of great potential to contribute to some of the above mentioned outcomes like health, safety, infrastructure, rural communities, human settlements, environment and local governance. Based on a review of existing literature, the objective of this paper is to demonstrate how remote sensing can contribute to the attainment of some of the key outcomes of South Africa's strategic development priorities.

2. A Review of Remote Sensing Applications with Potential to Meet South Africa's Development Priorities

2.1 Outcome 2: A Long and Healthy Life for All South Africans: Health

Health is ranked as one of the fundamental outcomes of the South African government. The government aims to strengthen the health system and increase the life expectancy of all its citizens. The government for instance specifically highlights that one of its outputs under the health outcome is to halt the transmission of malaria countrywide and decrease malaria infections. Generally, remote sensing has wide applications in public health and epidemiology. According to Rinaldi *et al*. (2006) major applications of remote sensing and GIS in public health include assessment of spatio-temporal trends, disease vulnerability mapping, stratification of risk factors and intervention in resource distribution. Rinaldi *et al*. (2006) indicate that remote sensing and GIS tools provide a valuable means for processing, evaluating and visualising spatial data related to mapping diseases and epidemiological surveillance. Using techniques based on spatial statistics, interpolation and modelling Rinaldi *et al*. (2006) note that remote sensing and GIS can be used to support spatial assessment of health-related environmental factors.

A basic requirement for the application of remote sensing in epidemiology is the correlation between the parasite's life cycle or host and environmental characteristics that can be sensed remotely (Epstein & Chikwenhere, 1994). Remotely sensed datasets provide a valuable epidemiology mapping tool that can be used to generate spatially homogeneous environmental variables at different spectral, spatial and temporal resolutions (Cracknell, 1991). Use of remotely sensed data is particularly relevant to developing countries often characterised by limited knowledge of epidemiological spatial distribution and inadequate resources (Hay, 1997). One of the pioneering works on the use of remote sensing in epidemiology was the use of colour infrared aerial photographs to map different types of vegetation and residential areas for mosquito control in the Saginaw and Bay counties of Michigan (Wagner *et al*., 1979). In this study, mosquito flight range and vegetation types in relation to settlements were used to prioritise control areas.

Remotely sensed datasets are particularly important in determining critical environmental variables for disease mapping and prediction (Liang *et al.,* 2002). These variables include among others rainfall, temperature, vegetation cover, landscape wetness and land use. According to Curran *et al*. (2000) geographic distribution of a vector-borne disease is related to the habitat of the vector. Remotely sensed land cover data, vector habitats and human population density provide critical data on spatial distribution of diseases. Remotely sensed meteorological data in combination with field surveys have been used to identify the spread and patterns of malaria (Liang *et al.*, 2002). Hay *et al.* (2000) for instance used colour infrared aerial photography to spot the habitats of *Aedes sollecitans* (Eastern Saltmarsh mosquito) while Brown & Sethi (2002) used digital aerial photographs for mosquito surveillance. Malone (2005) notes that climate-based forecast systems that use the concept of growing degree days have been developed for mapping veterinary diseases such as *fasciolosis* (Liver rot) and human diseases such as *schistosomiasis* (Snail fever). According to Rinaldi *et al*. (2006), spatial prediction models are particularly useful in planning and decision-support for disease intervention. The Malaria Early Warning System (MEWS) for Africa is a classic example of a system that uses meteorological remotely sensed data to provide real-time predictions of malaria epidemics (Thomson & Conner, 2001). Increasingly, there is a focus to establish links between climate or land use change and the spatial distribution of vector-borne diseases.

2.2 Outcome 3: All People in South Africa are and Feel Safe: Crime Analysis

Personal safety is a key concern in South Africa. With a 21.88 and 78.12 safety and crime index respectively recorded in 2012, the country has one of the highest crime levels in the world(http://www.numbeo.com/quality-of-life/rankings_by_country.jsp). The government aims to reduce the levels of crime and create a safe environment for all citizens.

In over a century, pins on paper maps have been used by intelligence and police officers to indicate crime locations (Ratcliffe, 2004). However, recent developments in geo-information technology have increased adoption of remotely sensed raster data in combination with vector based GIS in mapping crime (Weisburd, 2001). Typically, these geo-information technology developments make use of a range of spatial analysis techniques to determine crime distribution. According to Jensen & Cowen (1999) these techniques offer a means of linking criminal activities with respective physical environments. According to Chen *et al*. (2005), crime mapping applications that may involve remotely sensed datasets include crime event assessment, visibility analysis, situational awareness and movement control. Remotely sensed images involving landscape parameters can be used to derive vegetation indices and other urban attributes like land use and settlement density for identification of crime indicators and modelling crime risk. According to Ratcliffe (2004), other exploratory techniques like karnel density and cluster analysis techniques are valuable in determining crime hotspots (Ratcliffe, 2004). Such an analysis may be valuable to policy formulation on community safety (Messina & May, 2003). Chen, *et al.* (2005) illustrates how remote sensing and statistical tools can be used to identify “place” features associated with crime. Using 2007 burglary crime data in Houston, Texas, Gong (2010) demonstrates how remotely sensed and social data sets can be integrated to show spatial crime distribution.

2.3 Outcome 5: An Efficient, Competitive and Responsive Economic Infrastructure: Physical Planning

The South African government has prioritized maintenance and improvement of an efficient, competitive and responsive economic infrastructural network. Some of the outputs set to achieve this outcome are reliable generation, distribution and transmission of electricity, maintenance and strategic expansion of road and rail networks and maintenance of bulk water infrastructure. The value of satellite imagery in mainstream service delivery and planning in public institutions can for instance be demonstrated by the existing SPOT Building Count (SBC) project that was initiated by Eskom and CSIR, Satellite Applications Centre (now South African National Space Agency-SANSA) to support the planning process for the Integrated National Electrification Programme

(INEP) (De la Rey, 2008). The SBC uses the SPOT 5 mosaic as a base layer to identify, extract and generate an inventory of all dwelling units in South Africa. The benefits of the geo-referenced dwelling frame could also be directly relevant to other public institutions in South Africa such as Statistics South Africa for population estimation and demarcation (Breytenbach, 2010). Furthermore, the SBC dwelling framework has potential applications of use by South African Post Office, Department of Home Affairs and the security and intelligence units. These examples indicate the potential of satellite imagery in planning and decision making in government for improved public service delivery.

2.4 Outcome 7: Vibrant, Equitable and Sustainable Rural Communities and Food Security for All: Rural Planning and Agriculture

In the last decade, there has been a significant focus on operational remote sensing services that have direct socio-economic impact. Outcome 7 of the South African government seeks to improve the livelihoods of rural communities and ensuring food security. Sustainable agrarian reform and provision of rural services have been identified as some of the means to achieve this goal. The Famine Early Warning Systems Network (FEWS NET) in particular has great potential to achieve this priority. This system provides frequent early warning and agro-climatic vulnerability information based on satellite data and ground based information to over 20 countries. FEWS NET gives decision makers timely information to enable contingency and disaster response planning (Funk *et al.,* 2006). FEWS NET supports and informs disaster relief decisions that affect masses of people and with huge financial implications (see http://www.fews.net/ml/en.aspx).

The Advanced Fire Information System (AFIS) is another illustration of how earth observation can impact directly on livelihoods. AFIS (see; http://afis.co.za) is a satellite-based fire information system that provides information about the prediction, detection and assessment of fires (Frost & Volsoo, 2006). The significance of the fire monitoring is evident given the detrimental impacts of fire in rural communities such as loss of human life, crops, animals, grazing resources and property. The SHARE (Soil Moisture for Hydrometeorologic Applications) - https://www.ipf.tuwien.ac.at/radar/share/ provided a semi-operational soil moisture monitoring service based on the unified utilization of Advanced Synthetic Aperture Radar (ASAR) and METOP scatterometer aboard the now defunct ENVISAT satellite. Reliable soil moisture information was provided on a weekly basis or less to support hydrological and agricultural applications. The SPOT 5 dataset distributed yearly by SANSA has also been used widely for mapping and monitoring agricultural units. The Agriculture Research Council (ARC) for instance extracts agricultural fields from SPOT 5 imagery that are used for annual crop yield estimation and agricultural planning. The Global Monitoring for Environment and Security (GMES) (see; http://www.gmes.info/) initiative in Europe provides a further example of how earth observation technology can be used to directly benefit rural societies. GMES is aimed at providing a number of operational services that support environmental and security issues.

2.5 Outcome 8: Sustainable Human Settlements and an Improved Quality of Household Life: Improved Quality of Life

Since 1994, there has been significant growth in informal settlement in South Africa. The government has therefore prioritized human settlements as key outcome through upgrading 400 000 residential units in informal settlements and facilitate provision of 600 000 low cost housing to workers earning between R3 500 and R12 800. The improvement of basic services is also central to this outcome. Within South Africa, satellite imagery is increasingly gaining popularity as demonstrated by a number of value added products derived from satellite imagery in support of spatial planning and decision making. Typical examples include the North West Informal Settlement Atlas developed by SANSA and SATPLAN to support the North West Informal Settlement and Upgrading Program (see; http:// www.nwpg.gov.za/Human Settlements/Upgrading Programme.asp). The atlas provides comprehensive temporal and spatial information regarding informal settlements in the North West province. A combination of SPOT 5, Worldview, IKONOS, Geoeye and high resolution multispectral aerial photography were used to develop an informal settlements database and to analyze the evolution of informal settlements in the province. The database on informal settlements has also been used as benchmark to evaluate government's progress in delivering low-cost housing. The Human Settlements Atlas series developed by the Council for Scientific and Industrial Research (CSIR) is another example of the potential of satellite imagery in supporting South Africa's government programs (see; Goss *et al*., 2011).

Parameters such as vegetation cover indices and roof types which are derived from satellite imagery can be used as socio-economic indices of urban residential areas. In imagery analysis, it could be assumed that residential areas of high vegetation density with tiled roofs are affluent suburbs while neighbourhoods with very low vegetation and zinc/iron roofs are high density low income areas. The degree of imperviousness, proportion of vegetation cover and bare soil could also be used to categorize land use/cover and to inform priorities for development. The integration of remotely sensed data with social-economic data has the potential to provide a greater understanding and context of the observed pattern and trend. The value of remote sensing can be extended by providing measurements which show the anthropogenic impacts of socio-economic and demographic processes on the environment. Measurement of building height and volume using digital surface models and satellite stereoscopic image pairs can be used to develop indices to measure economic development. In this case, areas with a high density of tall buildings may be an indicator of high economic value as they commonly reveal commercial business centres while residential and industrial urban development which can be quantified and monitored continuously using remote sensing can be used to estimate energy and urban spatial demands (Rindfuss & Stern, 1998).

2.6 Outcome 10: Environmental Assets and Natural Resources Well Protected and Continually Enhanced: Natural Resource Management

Temporal and multi-temporal remote sensing has been proven to be an indispensable tool for qualitative and quantitative measurements of physical and social phenomenon. Satellite remote sensing has considerable potential to contribute to the attainment of outcome 10 that seeks to ensure protection and sustainable use of natural and environmental assets. Some of the key outputs of the environmental and natural resource outcomes are enhanced quality and quantity of water resources, sustainable environmental management, protected biodiversity and reduction of greenhouse gas emissions, climate change impacts and improved air/atmospheric quality. Water is a critical requirement for any social and ecological system. South Africa is regarded as a semi-arid country with limited water resources. Consequently, relevant remote sensing applications offer great knowledge base for sustainable use and management of the scarce water resource. Earth observation technologies can be used for mapping water features like dams, lakes, rivers and wetlands. In addition to mapping water bodies, satellite remote sensing is an effective means to assess water quality parameters such as chlorophyll content, sediment concentration, turbidity, chemical contamination and temperature variability (Raghu & Swamy, 2009). The South African government predicts that the demand for water is to rise by at least 52% in the next 30 years, while wetlands, a critical hydrological component are increasingly under threat. The government has prioritised conservation of water resources and mitigation of wetlands destruction by increasing the rehabilitation of wetlands from 95 to 150 as a means of preserving groundwater reserves. Furthermore, the government intends to reduce the proportion of land affected by various forms of degradation from 70% to 55%. Attainment of these goals is feasible through accurate temporal and multi-temporal measurements of landscapes provided by emerging and existing earth observation techniques.

Optical sensors with potential application in the water sector include among others Landsat, SEAWIFS, SPOT, EOS, MODIS, MOS, MERIS OrbView, IKONOS, and Sumbandilasat. Ritchie & Cooper (2001) demonstrate the role of remote sensing in water clean-up efforts. A number of studies have explored the potential of remote sensing in determining water quality and quantity. Mattikalli & Richards (1996) used Landsat MSS, SPOT and Landast TM images to determine the effect of historical and future land-use changes on suspended sediment and nitrogen loading in the eastern parts of England while Yang (1999) used SPOT imagery to assess a range of water quality variables like temperature, chlorophyll, turbidity and suspended solids in Te-Chi Reservoir, Taiwan. Liu *et al*. (2003), provides a review of the potential of remote sensing in mapping and quantifying quality parameters of waters due to human-induced waste while Schmugge *et al.* (2002) used surface temperature data from remotely sensed thermal infrared data, surface moisture from passive microwave and lidar data to determine hydrological state of Little Washita Watershed facility in southwest Oklahoma, USA. Other studies include monitoring eutrophication caused by algal and phytoplankton (USEPA, 2000), mapping thermal discharges in water bodies from electrical power plants (Gibbons *et al.,* 1989), wetland change detection and ground water assessment (Prasad *et al.,* 2008).

Remote sensing is a valuable means of measuring human induced processes such as deforestation and land degradation. Landscape metrics can be used to extend the analysis of land use/cover classified outputs by providing detailed information on landscape fragmentation processes. According to Innes and Koch (1998), remotely sensed landscape data offer multiple views that include horizontal, vertical, multi-spectral and multi-temporal perspectives. These views offer valuable information on a landscape's structural characteristics and inter and intra-annual transformation (Odindi & Mhangara, 2012). Griffith & Lee (2000) used a combination of summer and winter Landsat TM spectral characteristics to improve the delineation between highland and lowland vegetation types to mitigate degradation in Great Britain while Nagendra *et al.* (2004) notes improved forest delineation when using Digital Elevation Model (DEM) data for tree species diversity and prediction of areas of bird species endemism.

Griffith and Lee (2000) note that techniques applied on remotely sensed datasets are invaluable for predicting the effect of human induced disturbance on species richness and diversity. The assessment of the key human induced drivers of land cover change can easily be inferred by using landscape matrices like largest patch, number of patches, patch density, mean patch size, landscape shape, interspersion and juxtaposition (McGarigal *et al.,* 2002). Such indices are important for correlating the underlying processes driving land use/cover patterns to associated anthropogenic, hydrological or geomorphologic processes.

Temporal assessment of landscape integrity can be done effectively using key indicators such as land cover composition and pattern, degree of biophysical constraints, ground water, greenness pattern, erosion potential and riparian extent and distribution (Jensen, 2007). Jensen (2007) identifies three societal values from remotely sensed data on landscape metrics; these are biodiversity, watershed integrity and landscape resilience. Since these indicators directly affect ecological health which in turn affect the quality of human life, further adoption of relevant satellite remote sensing techniques insight these indicators.

The potential societal value of earth observation data and information is apparent in sustainable resources use and landscape planning processes. However, this potential can further be enhanced by integrating information derived from satellite imagery with other geospatial socio-economic data. Decisions based on multiple sources of data may enhance the ability to identify, formulate, implement and assess processes. Recent successes in integrating remote sensing software and stochastic models have paved way for use of remotely sensed data for environmental forecasting. Within South Africa's context, these developments offer an opportunity to extend remote sensing application from currently popular land use/cover mapping to predictive scenario simulation.

The significance of ecosystem goods and services to human sustenance is uncontested (Daily, 1997). Quantifying ecosystem goods and services has potential to positively impact on rural and urban livelihoods. These include rangelands, water, soil and forest resources (Odindi & Kakembo, 2011). Remote sensing has found wide applications in the ecological assessment of rangelands, riparian zones, soil erosion and other areas of environmental significance. Anthropogenic impacts such as urbanization, agricultural intensification, exploitation of natural resources, air and water pollution threatens the function and productivity of ecosystems and reduces their ability to produce goods and services for socio-ecological sustainability. Whereas it is acknowledged that humankind has transformed the natural environment for societal benefaction, most of these transformations have accelerated environmental degradation (Hooper *et al*., 2005). South Africa as signatory to a number of environmental conventions such as the Kyoto protocol has an obligation to reduce greenhouse gas emission, protect forests and mitigate environmental degradation. The government thus strives to maintain a net deforestation of less than 5% by 2020 and to protect indigenous forest resources. To meet these obligations, remote sensing can play a significant role in providing repetitive and quantitative measurement of forests and related environmental changes. Due to societal over-reliance on ecosystem goods and services, decisions based on remote sensing are not limited to meeting signatory obligations but can further be used as a basis for sustainable poverty alleviation and improvement to quality of life.

The widespread application of remote sensing in environmental assessment and monitoring is largely motivated by the socio-economic value of the ecosystem goods and services derived from the environment. Remote sensing and GIS models are increasingly used to quantify ecosystem goods and service produced per unit area (Grêt-Regamey *et al*., 2008). To increase the socio-economic value of earth observation technology, the applications of remote sensing should encompass the economic assessment of ecosystem goods and services. Satellite remote sensing provides a credible, timely and verifiable means for estimating forest carbon content (Weaver *et al*., 2008). Unlike traditional quantification methods like ground surveys and aerial photography, Brown (2002) notes that remote sensing is an effective means to map vast and inaccessible forested terrains and is cost effective. In the recent past, carbon trading has emerged as one of the key measures for mitigating climate change. Third world communities' participation in the carbon trading schemes has the potential to significantly improve livelihoods and environmental quality. The carbon market is likely to increase in the near future due to political, social, economic and environmental pressure. Weaver *et al.* (2008) quote a prediction by the New York Times that states "*Carbon will be the world's biggest commodity market, and it could become the world's biggest market overall.*" Approximately 50 billion metric tonnes of carbon dioxide is emitted per year and signatories of the Kyoto Protocol are obliged to reduce this figure. Consequently, remote sensing techniques provide new opportunities for credible carbon quantification.

2.7 Decision Support and Information Dissemination to Maximise Remote Sensing Products

Decision support systems that incorporate information derived from satellite imagery should be maximised for the benefit of society. To achieve this, environmental managers and policy makers should incorporate critical environmental variables in decision making. In recent years, a number of ecological and economic models have been developed to determine relationships between land use, biodiversity, ecosystem services under global changes of climate, markets and policies (Thomas *et al*., 2004; Koellner *et al*., 2010).

Within a South African context, the full value of information derived from earth observation satellites can only be achieved if the derived information is disseminated to society effectively and in time. Consequently, the use of multilingual, interactive and user friendly online catalogues will impact positively on society. This approach will help overcome language as a barrier to science and will enable users to quickly access earth observation products. The turn of the decade has seen a proliferation of mobile, portable internet and communication devices. Real time communication with the public on predictions of environmental conditions and disasters using portable media like cell phones will significantly increase the relevance of earth observation to society. To increase public participation in the earth observation domain, participatory GIS can be used to involve the public in acquiring additional geospatial attributes. The provision of web mapping tools and online catalogues is one way of providing an interactive platform for selected user groups. To realize the full societal benefits of earth observation technologies to society, it is necessary that governments and funding institutions invest in adequate and reliable Information Technology infrastructure for both earth observation specialists and general users. These should be augmented by requisite training, conferences, workshops, outreach and stakeholder engagement. The Spatial Data Infrastructure (SDI) initiatives should be harnessed to ensure dissemination of earth observation products of high standards to the public.

3. Conclusion

This review demonstrates that remote sensing has considerable potential to contribute to the attainment of the key development priorities of the South African government. Specifically, remote sensing can play a significant role in the measurement of progress towards the attainment of government outcomes with geospatial linkages. Satellite imagery has been proven valuable in assessing the progress being made in protecting the environment through change detection analysis and biomass estimations. The eradication of informal settlements has been prioritized by the South African government and examples explored in this paper demonstrate how progress towards the attainment of this goal can be assessed through monitoring the growth of informal settlements against that of low cost housing. It is evident from this review that most of the government outcomes have an inherent spatial component which can be analysed effectively using geospatial technology. Remote sensing can therefore play a critical role in providing accurate measurements of the biophysical parameters and the spatial attributes linked to the government outcomes. Whereas this paper has focussed on the potential contributions of remote sensing in the attainment of strategic priorities of the South African government, the examples highlighted in this review are applicable to most countries around the globe. The strategic priorities of the South African government are aligned with the United Nations Millennium Development Goals which are widely adopted by many countries. The value of remote sensing in socio-economic development is therefore evident and governments should continue to prioritize investment in remote sensing to support planning and decision making in all environmentally related priority areas.

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