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EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT IN AFRICA: THROUGH THE ADOPTION OF COST-EFFECTIVE SMALL SATELLITE PROGRAMS TO ATTAIN DATA DEMOCRACY AND ACHIEVE SUSTAINABLE DEVELOPMENT GOALS IN AFRICA

Kimani J. M. [a]* and Okeng'o G. O.[b]

*Astronomy and Astrophysics Thematic Research Group, Department of Physics, University of Nairobi, P.O. Box 30197-00100 GPO, Nairobi-Kenya. [a]*Corresponding Author – juliuskimaniju@gmail.com, [b]Co-author - gokengo@uonbi.ac.ke*

Abstract

Earth observation has been explicitly emphasized as one of the key tools needed in the pursuit of the attainment of sustainable development in Africa. Compared to its global peers, Africa is light years behind in matters of space science and space technology. However, in recent times, African governments have embraced a paradigm shift and realized that the adoption of space-based technologies can enable inclusive economic growth and empower social development to their people. This paper seeks to examine how cost-effective, modern and advanced small satellites can play a pivotal role in earth observation and contribute to the achievement of sustainable development goals in Africa. It focuses on the economic benefits of data derived from small satellites deployed in earth observation missions to developing countries in Africa in monitoring food security, water resources, and wind patterns for clean energy generation using wind turbines, human settlements, land use, climate change, blue economy, air quality, and the environment. It then highlights a case study of South Africa, a country that has remarkably adopted small satellite technology to advance its development agenda. Lastly, it provides a policy framework that is needed to ensure small satellite programs for earth observation missions become successful in Africa.

Keywords: Earth Observation, Small Satellites, Data, and Sustainable Development Goals.

1.0 Introduction

Earth observation programs have become essential tools in decision making processes in the pursuit of achieving sustainable development. Briefly speaking, earth observation basically entails the collection of data of our planet's resources without making any physical contact through the use of earth-orbiting satellites as well as in-situ aerial vehicles such as drones. International and continental bodies, governments, national agencies, non-government organizations, policymakers and among others have become recipients of earth observation applications in making bounding decisions on issues affecting humanity as a whole. Earth observation satellites can be used in monitoring and mapping agricultural activities, soil cover, forest cover index, green cover index, cities and urban settlements, climate change, land management, illegal logging, illegal mining, illegal exploitation of natural resources, marine and maritime resources, disease outbreaks, natural disasters such as floods, civilian conflicts and among others. Earth observation brings modernity into the statistical systems of governments and other relevant stakeholders and this ensures efficient monitoring of activities geared towards addressing the sustainable development goals. Earth observation is a vital data collection technique in enabling countries to upgrade their national statistical systems and integrates their geospatial data systems to ensure the data collected can effectively track the progress made in implementing the 17 sustainable development goals in a timely and comprehensive manner. Earth observation satellites are mostly located within the low-earth orbit, that's between 150 to 400 kilometers from above the earth's surface. These satellites are enabled with sensors such as high-definition cameras for optical imaging or spectrometers that capitalize on an electromagnetic spectrum which shows various spectral bands or wavelengths. The data collected by earth observation satellites positively transform societies as a whole by addressing the perennial challenges that humanity faces. The Committee on Earth Observation Satellites (CEOS) indicates that its member agencies have more than 300 earth observation satellite missions which are carrying out more than 1000 instrument payloads geared towards addressing sustainable development. The current and ninth Secretary-General to the United Nations, Mr. António Guterres has singled out earth observation as an essential mechanism in achieving the sustainable development goals for a healthier planet for all humanity. Regrettably, earth observation programs have not adequately taken root in the African continent thereby negating member states to become consumers than producers of earth observation data in the global space industry. Africa has for a long time been a consumer rather than a producer of data from earth observation satellites. The high cost in satellite design, manufacture, and deployment into orbit has barred many developing countries in Africa to venture into space technology. This has led to satellite industries develop miniaturized satellites with greater innovations, modern instruments and applications than larger satellites at relatively lower costs. Such developments present an opportunity for developing countries to utilize space technology to tackle and mitigate challenges facing their people. In recent times, the space industry has witnessed the rise of modern, advanced and relatively low-cost small satellites. Taking into account the budget constraints in most African countries, such low-cost small satellites can enable African governments to design and develop their own space-based programs such as earth observation.

1.1 Africa's Natural Resources: A Continental Concern

Rational and prudent management of natural resources is a significant undertaking towards the achievement and attainment of sustainable development. In the last few decades, natural resources in developing countries from across the African continent have experienced severe stress and strain as the human population continues to surge at an unprecedented rate. Arable lands for agricultural activities continue to diminish as demand for land for alternative economic activities such as real estate continue to go up, severe deforestation has depleted Africa's forest cover which has in-turn led to desertification of what was once productive land, water resource has become a stress factor, illegal fishing activities and over-exploitation of Africa's marine and maritime resources threatens oceanic or seas ecosystems; all of which have contributed to the rise of food insecurity in Africa. The breath-taking wildlife habitats in Africa face the threat of adverse extinction due to biodiversity loss and thereby posing a threat to the tourism sector which has been attributed as one of the biggest sources of foreign exchange revenue to many countries in Africa. In this regard, there have been calls for Africa to adopt sustainable development in the management, exploitation, and utilization of its natural resources.

1.1.1 A Need for Sustainable Development in Africa

Sustainable development has been described as the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It encompasses the economic, social and environmental progress and in the same breadth recognizes the concerted efforts by respective governments to develop their own countries. In order to safeguard the needs and demands for future generations, African countries must adopt a proactive approach in the development of their economies by investing in projects and programs that address and echo the calls for sustainable development. Space science and technology programs such as earth observation have been described as an anecdote in improving the quality of life and standard of living of societies in Africa by providing evidence-based and data-driven management of natural resources and human resources. With the aim of achieving maximum outputs, earth observation can caution governments to prudently utilize scarce resources available by monitoring and recording activities on the ground.

2.0 Types of Earth Observation Satellites

2.1 Geostationary or Geosynchronous Satellites

These are satellites positioned at an altitude of about 36,000kms above the earth's surface and rotate in the same direction and same period as earth, thereby having a perfect view of earth at a fixed position. Such satellites are deployed mostly for weather monitoring and as well as communication and navigation applications.

2.1.1 Near-polar Orbiting Satellites

These are satellites that orbit the earth from pole to pole and are mostly positioned at the low-earth orbit at an altitude of about 400kms above the earth's surface and rotate around the earth at a period of about 90 minutes. Such satellites are deployed for close monitoring and detailed observation of earth especially in optical remote sensing since they provide high-spatial-resolution imagery for scientific analysis.

2.2 Satellites and Sensors

2.2.1 Electromagnetic Radiation

The Sun emits solar energy or radiation into space. Earth's surface (land, water, vegetation) reflects this solar energy or radiation back to space. The earth also emits its own energy or radiation in the form of infrared and microwave bands in the electromagnetic spectrum. The sensors and instruments installed in satellites are designed to capture this radiation from earth and create imagery or non-imagery data for scientific analysis and subsequent policy and decision making.

2.2.2 Spectral Signatures

Different objects, surfaces and air absorb and reflect different variations of bands of wavelengths in the electromagnetic spectrum. This is commonly referred to as a spectral signature. Water, vegetation, ground, and air absorb and reflect radiation differently in various bands of wavelengths and such can be detected and studied by sensors and instruments embedded in satellites.

2.2.3 Spectral Resolution

This is the ability of spectrometers embedded on a satellite to detect and resolve different bands of wavelength into their defined separate channels or intervals. Narrower wavelength bands or channels provide finer spectral resolutions. This thereby enables scientists to define objects or matter by their nature of absorption of specific bands of wavelengths.

2.2.4 Spatial Resolution

This is the ability of a sensor to define an image of a ground by one pixel in the digital image processing. A greater number of pixels provides high-resolution images. Such optical images can be used to analyze and record the changes on the earth's surface and provide information to decision and policymakers.

2.2.5 Radiometric resolution

Measured in bits, this is the ability of a sensor to be able to sensitively distinguish the radiated energy or brightness levels from the earth's surface. A sensor with a powerful radiometric resolution should be able to capture a high degree of intensities of objects or matter on the earth's surface and thereby provide finer and detailed digital images for scientific analysis.

2.2.6 Passive Sensors

These are satellite sensors that measure the emitting or near reflectance of radiation or natural energy from the earth-atmosphere systems. Most passive sensor satellites sense and capture the near-infrared radiation which is just beyond the visible spectrum.

The sensors include sounders, spectrometers, imaging radiometers, hyperspectral radiometers and among others.

2.2.7 Active Sensors

These are satellite sensors that operate under the microwave band of the electromagnetic spectrum by sending beams of radiation that penetrate into the earth-atmosphere systems and measure the scattered radiation of the ground surface.

These sensors include radars, scatterometer, lidars, lasers, ranging instruments and among others.

2.3 Small Satellites

Traditionally, satellites have been designed to be large in size and mass at relatively high-costs. This has proven to be capital-intensive to many developing countries in Africa, besides the brain drain in satellite design and manufacture in the African continent. Consequently, this has led to many countries in Africa to be consumers rather than producers of space technology. However, due to the complexity in operations and high-costs associated with large satellites, the space industry has begun to produce high-powered miniaturized satellites at relatively low-costs, thereby enabling governments, national agencies, and organizations in developing countries to invest in space science programs such as ***Earth Observation***. Throughout the decades, satellites have been getting smaller and smaller.

2.3.1 Categories of Small Satellites

Small satellites can range in size and mass, from Femtosatellites to Minisatellites, which weigh from <0.1kg to <500kg respectively.

Below is a classification outlining groups of small satellites and they include:

Type	**Mass**
Minisatellites	100-500kgs
Microsatellites	10-100kgs
Nanosatellites	1-10kgs
Picosatellites	0.1-10kgs
Femtosatellites	<100g

Figure 1.1: Types and masses of small satellites.

2.3.2 Small Satellite Industry: Boosting Africa's Space Renaissance

According to a research by Markets and Markets (2016), the small satellite market is expected to be bullish with a growth from USD 1.21 billion in 2019 to USD 3.49 billion in 2024 at a compound annual growth rate of 23.7%. The fast-changing technology has been attributed as a catalyst for the surge of demand for small satellite technology. The applications of small satellite technology include communications, mapping and navigation, scientific research, earth observation, and remote sensing and among others. However, according to Markets and Markets, earth observation and remote sensing segment is projected to be the fastest-growing segment with a prediction that more than 40% of small satellites to be launched by the end of 2022 will be for earth observation operations.

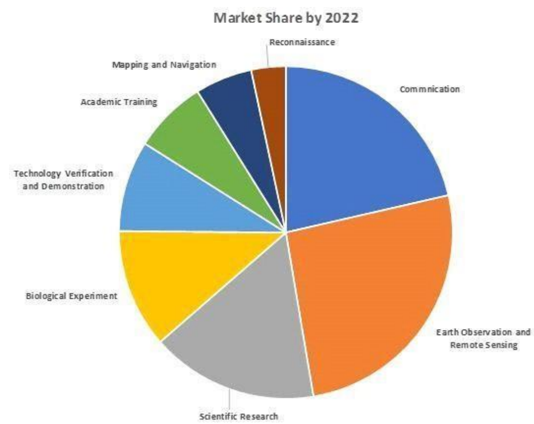

Figure 1.2: Segments of the applications of small satellites. Image Credit: Markets and Markets, 2016

At relatively low-costs, small satellite industries can quickly design and develop small satellites and deploy them more efficiently and get the data that is required by their clients. A majority of small satellites are deployed to their desired orbits by astronauts aboard the International Space Station with the help of a robotic arm. Small satellites generally weigh under 1000kgs and they can perform, if not better, the operations of the relatively expensive conventional satellites. This has led to a high demand for small satellites by government organizations, non-government organizations, research institutions and as well as institutions of higher learning in the pursuit of developing space science programs.

2.3.3 Why should Africa invest in Small Satellites for Earth Observation?

Large-scale satellites focus on a variety of complex space missions that demand high-level expertise in engineering in determining design, manufacture, mission control, and launch. To the contrary, miniaturized satellites are designed and tailor-made with high-powered innovation to serve a specific mission for a particular time. One key specific mission for small satellites in remote sensing is by focusing on imagery collection. More often than not, most of these miniaturized satellites are equipped with a camera or a sensor which acts as the payload for the satellite. These cameras or sensors can capture clear images of a particular region of interest on earth so as to monitor current developments such as mining, forest cover, green cover, natural disasters, food production, and human settlement, among others. Such can be designed and built by university students in collaboration with satellite experts, as it was the case for Kenya in 2018 where it launched its first locally made satellite to space from the International Space Station. This enables the development of sustained human expertise in satellite technology, thereby enabling the local industry to benefit from space technology and ensure a thriving tech-savvy society in Africa. Due to the surge in demand for miniaturized satellites, a number of start-ups, including some from the Silicon Valley, specifically focused on the design and production of mini-satellites, have been founded. One case example is a start-up called Planet, which has successfully built mini-satellites for national geospatial agencies in the United States and other countries as well.

2.3.4 Role of Small Satellites in Attaining Data Democracy in Africa

The African Space Policy defines data democracy as the provision of wider and easier access to geospatial data, software tools for manipulating data and capacity building, education and training. Data is only useful if it's accessible. Small satellites can play a pivotal role in promoting data democracy by ensuring timely and equitable access to data to make decisions about urban planning, land use, environment, agriculture, and climate change and among others. Undertaking data analytics on the data collected by small satellites enables a holistic approach to how better services can be provided to the people.

2.3.5 Small Satellites in Championing United Nation's Space for All Initiative

Over the decades, access to space has only been limited to wealthy nations with profound, established and well-funded space agencies. Developing countries, and in this case, countries from the African continent have played a passive role in space science and space technology. This is mostly attributed to the high costs associated with the design, manufacture and deployment of satellites and as well as subsequent operations which require high technical know-how. With the entry of small satellites, which are cost-effective, easier to make and operate similar functions of the traditional costly and bulky satellites, African governments have found the opportunity to venture into space science and space technology as emerging space nations and enabled the much need benefits that space has to offer to the human society.

3.0 Earth Observation Process Flow

Earth observation process flow is a technical operation that initiates from data collection by satellites that have been deployed into their desired orbit and trajectory to deriving useful information for decision or policymakers.

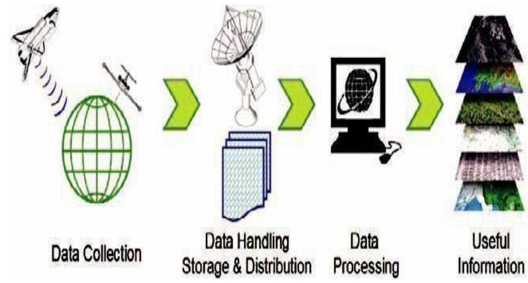

Figure 1.3: Earth Observation Process Flow. Image Credit: Annelie Schoenmaker, 2008

4.0 Small Satellites for Earth Observation: A Tool in Achieving Sustainable Development in Africa

4.1 Sustainable Development Goal 1, 2, 3 and 6: No Poverty, Zero Hunger, Clean Water, and Sanitation

According to the Food Security and Nutrition report by the Food and Agriculture Organization (FAO) of the United Nations, the Sub-Saharan African region witnessed a rise of prevalence of undernourishment from 20.8% to 22.7% between 2015 and 2016. The number of undernourished people in Sub-Saharan Africa region also increased from 200 to 224 million, accounting for 25% of the 830 million people undernourished in the world in 2016. Extreme hunger has for a long time become synonymous with the African continent. Adverse and perennial climatic conditions such as El Niño phenomenon and drought, degradation of the environment such as desertification, deforestation, soil erosion, water shortages; prolonged conflict between communities, outdated crop and livestock farming production techniques, coupled with the lack of vital data have adversely affected the agricultural economy in the African continent making her people food insecure. Preventable disease outbreaks such as malaria have become more and more prevalent. Small satellite technology can mitigate the aforementioned namely through:

4.1.1 Enabling Precision Farming

Data collected through small satellites can assist in reviving the agricultural sector in Africa. Equipped with modern cameras, small satellites can on a daily basis capture high-quality images of farming fields, down to a spatial resolution of 2.5 meters above the earth's surface. The on-board computers, spectrographs, and machine learning systems embedded on the small satellites can also carry out an assessment on the health and conditions of the vegetation on the earth's surface using techniques such as crop cover index and spectral signatures. The aforementioned enables precision farming. This farming technique is enabled by the use of small satellites to allow farmers to pinpoint the specific areas in the field that need improvements in nutrient content, soil cover, water volume, and others.

4.1.2 Assessing Comparative Advantage in Agricultural Production

Small satellites can also gather valuable data to ascertain the comparative advantage of a country's agricultural productivity. This is by pinpointing where and when a certain variety of food crops is grown in certain areas of the country and for how long. Such data can help identify regions producing a surplus of agricultural commodities and the areas experiencing a deficit and this can go a long way in tackling the issue of demand and supply of food commodities in the agricultural sector.

4.1.3 Issuing Early Detection and Warnings

Imagery data from small satellites can also assist planners wade off and give early warnings on the pending potential disasters such as insect or pest invasion which, if not addressed, can wipe out crops, hence reducing the agricultural bounty for the people. Many indigenous communities in Africa depend on livestock for their livelihood and as a source of income. Data gathered from small satellites can inform policymakers to assist such communities manage their livestock more effectively. Through earth observation, policymakers can map-out areas prone to livestock disease outbreaks and advise communities to avoid such disease-borne areas. Small satellites can also map-out vegetation cover on specific areas. This allows policymakers to effectively manage grazing fields for livestock holders, especially nomadic communities, thereby reducing the conflicts between communities associated with competition for grazing resources for their livestock.

4.1.4 Monitoring Desertification

According to the Food and Agriculture Organization (FAO), the African continent is projected to lose about two-thirds of its arable land resource to desertification. Satellite images have over the decades recorded the rapid spread of semi-arid and arid areas in the African continent. The United Nations pinpoints desertification as a threat to the achievement of sustainable development. Africa hosts large groups of nomadic and pastoralists communities whom they depend on the availability of water and pasture to feed their livestock which act as a major source of income for communities. Desertification has to a greater extent led to sparks of wars between nomadic communities as they fight for control of water and pasture. Earth observation through small satellites can be utilized to combat the adverse effects of desertification in Africa through the gathering and provision of satellite images so as to enable policymakers, scientists and governments to measure, analyze, predict and mitigate desertification. Such methodologies include:

4.1.4.1 Monitoring and Understanding Soil Moisture Content

Understanding the soil moisture content is essential in studying desertification in Africa. The most available technological tools and sensors used by earth observation satellites are through the use of thermal infrared. Through this, scientists can identify where soil moisture content is high and these areas are mostly colder than the surrounding environment. This is a great deal in addressing water stress in Africa which has significantly contributed to the continent being rendered food and pasture insecure.

4.1.4.2 Measuring and Monitoring Vegetation Index Cover

Plants reflect light from the Sun and this can be used to measure the health of the chlorophyll content of the vegetation. This is measured using the electromagnetic radiation spectrum in the red and near-infrared reflected wavelength. High chlorophyll content in plants absorbs and reflects more radiation (light) as contrary to low chlorophyll content plants. Through these indices, for example, the Normalized Difference Vegetation Index (NDVI), scientists can produce vegetation cover maps of different regions of the earth to give deep insight on growth or decline of vegetation cover.

4.1.4.3 Assessing and Monitoring Land Degradation

Land degradation poses a great threat to food security in Africa. This affects the land productivity over time and as a result, adversely affects the crop yields. Land degradation is mainly caused by land overuse, loss of soil fertility, low soil moisture content and lack of proper land management practices that ensure that land is improved over a period of time. By use of satellite images, scientists can monitor the biomass productivity of a region, whether an increase or decrease and ascertain potential causes of land degradation. These causes can include, for instance, the overuse of agricultural lands. Scientists can also map-out the current land degradation driven activities in a certain region. Such can also inform policymakers on natural factors such as drought or man-made factors (land overuse) that causes land degradation and as a result help to predict and mitigate. This can inform scientists on the way forward to sustainable land use.

4.1.4.4 Assessing and Monitoring Land-use Changes

Land-use changes and trends are easily captured by earth observation satellites. Land-use changes cause a direct impact on the vegetation cover index which has an effect on food production and supply of fuelwood. Changes in land use also affect the water cycle process. Bush or forest fires, either caused by natural or man-made factors generate high levels of CO_2 into our atmosphere hence contributing to climate change. Region experiencing rapid bush or forest fires can easily be spotted by earth observation satellites which can serve to detect and survey areas prone to wildfires.

4.1.4.5 Halting Deforestation and Analyzing Forest Cover Index

Over the decades, Sub-Saharan Africa has continued to experience increased levels of deforestation of its majestic tropical and equatorial rain forests. This has been catalyzed by increasing demand for raw materials extracted from timber which has led to uncontrolled, unregulated and illegal logging of trees at an unprecedented rate. In the process, rare and indigenous tree species have been diminished. CO_2 that was once trapped in forests has leaked away into the atmosphere and hence contributing to global warming and climate change. Reduced rainfall has been recorded and attributed to loss of forest cover which has in-turn led to dry rivers, streams, and tributaries known to feed lakes and seas; thereby degrading and contributing to biodiversity loss. Small satellites can be utilized to halt deforestation activities in the continent. They can take images of a certain region of Africa over a certain period of time and continuously monitor any changes in the forest cover. A decrease in forest cover index will alert policy and decision-makers on the ground to caution forest entities tasked with protecting the forests and also initiate laws geared towards mitigating illegal logging and increased deforestation.

4.1.5 Monitoring Sporadic Floods

Severe floods have continued to wreak havoc in many parts of Kenya and the entire Africa leading to the destruction of crops in the farms and loss of livestock. Floods are a threat to food security. Small satellites have the capability to forecast and monitor floods and storms and have the ability of mapping areas prone to perennial floods. This provides a great deal of preparedness to mitigate the destruction of farm produce and loss of livestock.

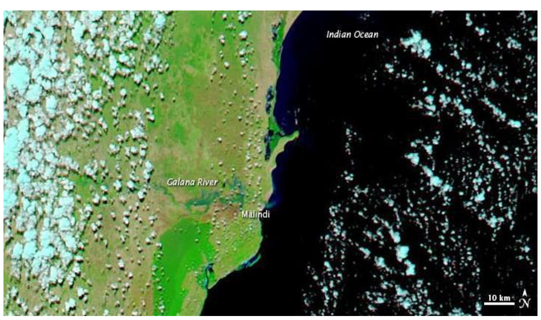

Figure 1.4: A false-color image of flooding in southeastern Kenya in early May 2012 after River Galana broke its banks and changed its course. Image Credit: NASA

The above false-color image is a combination of visible and infrared light drawn from the electromagnetic spectrum to distinguish between land and water. Blue and navy colors represent the water; the bright green represents the vegetation cover while the ground is earth-toned. Galana River appears blue as it feeds into the Indian Ocean.

4.1.6 Monitoring Water Cycles and Precipitation

Water is a scarce resource and a threat to food security. Kenya is a water stress country, and this has led to people shun investing in rain-fed and irrigated cropping systems and instead venture into other sectors of the economy. Small satellites can help monitor the water cycles in our by analyzing the evapotranspiration in our ecosystems. Evapotranspiration is of utmost important because it accounts for about 20% of the water vapor which in turn forms clouds and precipitation. By monitoring evapotranspiration, one can predict rainfall and advise when the best time to plant crops is.

4.1.7 Monitoring and Identifying Algae Blooms

High chlorophyll content from algae blooms can be monitored and identified by the use of small satellites by assisting scientists' pin-point on where to take water samples for further testing and analysis in order to determine the level of toxins present. Cyanobacteria or algae blooms have become a major problem in Africa. They are extremely harmful as they produce considerable large amounts of toxins that are hazardous to marine species and human life. They contaminate drinking water for humans, wildlife species and marine life. They also deplete oxygen levels in waters thereby suffocating life underwater leading to deaths of marine life such as fish leading to potential economic losses to the blue economy.

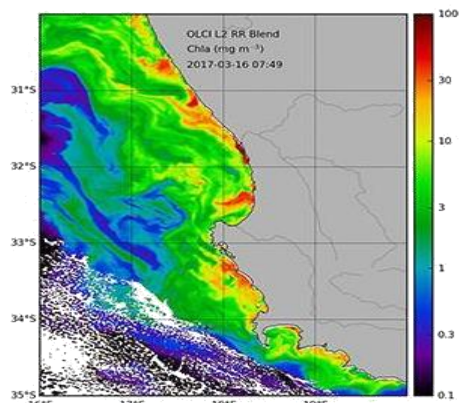

Figure 1.5: A false-color image captured by sensors onboard Sentinel satellite showing an algae bloom at the St. Helena Bay region in South Africa. Image Credit: EUMETSAT

4.1.8 Monitoring and Mapping-out Disease Outbreaks

Disease outbreaks are a rampant phenomenon in the African continent. Malaria, for example, is one of the top killer diseases which have contributed to increased child mortality in Africa. High humidity, wetlands, surface water, floods, and land cover have been known to contribute to the breeding of various mosquito species identified to cause malaria outbreaks. Small satellites can easily detect water bodies, pinpoint and measure the breeding zones of mosquitoes. Small satellites can also provide key imagery of landscapes and land cover and provide information on the breeding habitats. Temperature variations are known to affect the lifecycle of mosquitoes and with that small satellites can be used to measure land surface temperature in known breeding habitats of mosquitoes and predict on nature of the lifecycle and a potential occurrence of a malaria outbreak in the future.

4.1.9 Prospecting for Underground Water Resources from Space

By monitoring the earth's gravity, state-of-the-art remote-sensing technologies on small satellites can map-out water reservoirs hidden underground, mostly in the form of aquifers which a great water resource for large-scale farming. In September 2013, the WATEX system, a groundwater detecting technology developed by Radar Technologies International (RTI) detected underground water reserves in Turkana County, Northwestern in Kenya. The underground water reserve is estimated to host about 250 billion cubic meters of water. Such volume from this single source is projected to supply the entire country of Kenya with water for the next 70 years.

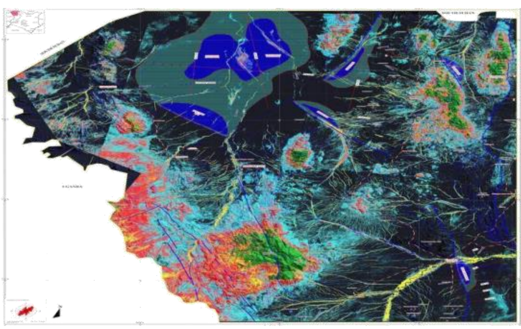

Figure 1.6: A hydrogeologic map of the Turkana region in Northwestern Kenya created by WATEX underground water detection system. Image Credit: Radar Technologies International

Turkana Country is one of the poorest and driest parts of Kenya. It also happens to be one of the parts of Africa ravaged by food insecurity. Hunger is a perennial problem in this part of the world. Its community has for centuries depended on livestock and fishing from the nearby Lake Turkana as sources for livelihood. With this discovery, and upon its drilling, communities are expected to benefit from a constant supply of water for their household consumption, livestock and agricultural activities for the foreseeable future. This will improve the nutrition levels of the Turkana people, decrease the levels of hunger and poverty, and in turn mitigate the vicious cycle of tribal conflicts over water resources that have spanned for decades.

4.2 Sustainable Development Goal 7: Affordable and Clean Energy

Access to affordable energy and power is one of the major challenges experienced in the African continent in decades. According to a report by the International Energy Agency (2016), about 6 out of 10 people in Africa lack access to power. The African Development Bank further notes that the manufacturing sector in Africa is greatly affected by insufficient power supply where they experience an average of about 60 days of shutdown time per year due to frequent power outages, forcing them to rely on generators powered by liquid fuel which not only balloons the operating costs but also emits high levels of CO_2 into the atmosphere. A number of certain power production methods common in Africa such as the use of thermal generators have contributed to climate change by releasing high amounts of CO_2 into the atmosphere. This calls for the need to adopt clean and affordable energy production methods and precipitately shut down carbon-emitting power generation methods. Small satellites can enable this by:

4.2.1 **Monitoring** *Wind Power Generation*

Small satellites can enable energy policymakers in Africa to forecast the winds on the earth's surface so as to enable the operations of wind turbines to produce energy and thereby predict power input into the national grid. Small satellites can also be used to prospect and identify suitable locations that typically have strong winds for the investments in wind power production.

Figure 1.7: Wind power turbines in Turkana, Kenya. This is also the largest wind power farm in Africa capable of producing 310MW of power per year. Image Credit: Lake Turkana Wind Power Limited.

4.2.2 Prospecting for Geothermal Energy Sites.

Another form of renewable source of power is the geothermal energy. It is powered by seismic activities that produce heat from beneath the earth. This can include heated water and rock that produces hot springs which are used to power the rotation of turbines on the ground thereby producing electricity. Geothermal is one of the cleanest and most renewable sources of energy.

Figure 1.8: Natural occurring hot steams ejecting from underground at Olkaria Geothermal project in Naivasha, Kenya. Water beneath is heated by hot rocks due to seismic activities. Image Credit: Geothermal Development Company

Ground exploration of geothermal energy is an expensive and tedious process. However, data from small satellites can be used to map out areas of geothermal activities in Africa. A case in example is the GOCE satellite (Gravity field and steady-state Ocean Circulation Explorer) where scientists from European Space Agency (ESA) and the International Renewable Energy (IRE) prospected sites for potential geothermal energy sites in across the world. Capitalizing on 'Bouguer' and 'free air', which is one of the two of the global gravity anomalies, GOCE was able to specifically detect areas of potential geothermal exploration. 'Free air' gravity was used to produce information about the geological structures of certain parts of the earth while 'Bouguer' was used to produce information about the earth's topography by showing difference in the thickness of earth's crust in different regions of the globe. Both of these maps were used to identify potential areas of hidden geothermal reservoir.

4.3 Sustainable Development Goal 11: Sustainable Cities and Communities

According to the UN report titled Urbanization and Migration in Africa (2018), Africa's urban population has grown at an unprecedented rate from 27% in 1950 to 40% in 2015 and is further projected to reach 60% by 2050. This has mainly been driven by high rates of poverty due to underdevelopment in rural areas. People travel to urban towns and cities in search of better opportunities. However, this has brought rise to the negative effects of rapid urbanization in Africa. There has been a sharp increase in the proliferation of unplanned settlements such as slums. This has piled pressure on essential resources and necessities such as water and electricity supply. This has also led to high rates of crime and lack of proper sanitation that at times lead to disease outbreaks such cholera. Proper housing has also become a problem as people are overcrowded in limited square feet of land that at times result in perennial fire and disease outbreaks. Most commercial cities in Africa are faced with overcrowded urban settlements. Such settlements contribute to air and water pollution which can contribute to disease outbreaks and other health concerns. Through earth observation, policymakers can monitor the air quality in these urban settlements and guide in the formation of policies to regulate activities from these settlements that contribute to air pollution. Earth observation data from small satellites can also assist in urban planning in most cities in Africa. Such include:

4.3.1 Monitoring Air Quality

According to the World Health Organization, air pollution results in about 4.5 premature deaths annually. The United Nations has classified air pollution as 'Africa's Invisible, Silent Killer.' Ironically, Africa contributes to less than 5% of global greenhouse emissions. The United Nations further states that about 650,000 deaths in Africa are associated with air pollution. Major air pollutants include carbon dioxide, nitrogen dioxide, lead, sulfur dioxide, and others. Small satellites can provide data that can be used to monitor air quality in Africa and address the relevant stakeholders on how to mitigate air pollution by measuring the magnitude of air pollutants in the atmosphere and locating their origins.

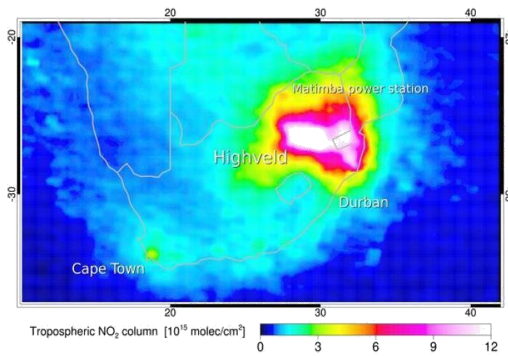

Figure 1.9: A false-color image showing the high concentration quantities of nitrogen dioxide in Northeastern South Africa. Image Credit: ESA

4.3.2 Mapping Urban Growth and Planning

African countries are embarking on ambitious economic development activities geared towards boosting the lives of their people. Small satellites can play a role by providing data that can inform policy experts on the progress of key sectors of the economy such as road networks, electricity connection, and construction of dams, housing projects, railway networks, airports, power plants and among others. The image below shows a variation in the electricity connection in Nairobi, Kenya. Such images are vital to economic policymakers in Kenya on how to implement power distribution in urban areas. Access to power empower many to venture into income-generating activities and can also power Nairobi to be a 24-hour economy.

Figure 1.10: A satellite image showing Kenya's capital Nairobi at night. Image Credit: NASA

4.4 Sustainable Development Goal 14: Life below Water

About 38 of the 54 African countries own vast coastal and maritime regions. In contrast, very few of these countries have made significant investment in the blue economy sector. This sector generally entails economic activities undertaken on the flora and fauna, rivers, lakes, seas and ocean. The African Union has described the blue economy as the "New Frontier of African Renaissance". Marine and maritime natural resources in Africa have been for a long time been underexplored and underexploited but in recent times, they have been highlighted to positively contribute to sustainable development. However, a number of threats such as uncontrolled and unregulated fishing activities have led to a rapid decline in fish production in most lakes, seas, and oceans in Africa. Small satellites equipped with sensors, lasers, and optical cameras can help to monitor both the natural and artificial activities on marine resources and enable proper utilization and management of marine resources namely through:

4.4.1 Monitoring Life Underwater for Food Security

Fisheries have been identified as key contributors to food security. Despite the vast resources in the fishery sector, the aqua economy in Africa contributes significantly little to the economies of Africa as compared to other sectors that make up the food economy. People continue to search for healthier alternative sources of protein such as fish products as they become health cautious. Small satellites can play a significant role in boosting fish production by detecting bioluminescence which is a natural occurring production and emission of light by marine living organisms upon disturbance by fish movements. This allows one to pinpoint where marine life is concentrated, thereby reducing the time fish farmers take in the oceans.

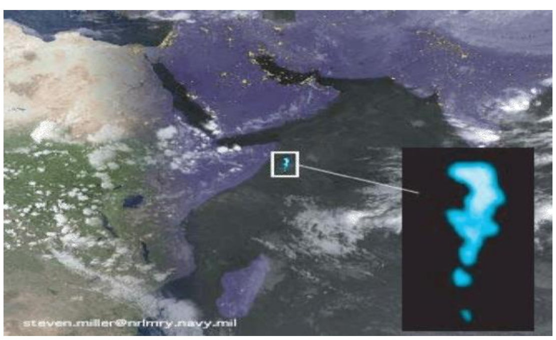

Figure 1.11: A composite image prepared by Steven Miller of the U.S Naval Research Lab showing the first detection of a bioluminescence activity off the coast of the Horn of Africa. Image Credit: Miller, et al. 2005.

4.4.2 Monitoring Water Temperature for Fishing Activities

Equipped with remote sensors and spectrometers, small satellites can also be used to measure the water temperature of oceanic resources and predict when and where is the best time to fish. Water temperature affects the activity of marine life, either to increase or decrease. Fish are cold-blooded species and therefore they do not have the biological capability to regulate their body temperatures and hence they're influenced by the temperature around them. This brings the distinction between cold-water fish and warm-water fish and thereby introduces the aspect of metabolism rate. Certain fish species found in our maritime resources have a high metabolism rate either when the water temperatures are warm or cold and tend to concentrate on the respective regions. Knowing the right level of water temperatures and the fish species thriving under the pre-determined water temperatures can increase the fish production from our oceans.

4.4.3 Monitoring the Effects of Climate-Change-Induced Sea-Level Rise (SLR)

Coral reef ecosystems are of great importance both to marine species and human life. They provide shelter and safe haven for marine species to flourish thereby boosting the current and future prospects for the fishing economy. They also help to shield coastlines from damaging waves and storms reducing further damage to the surrounding human settlements. However, the effects of climate change are resulting in a depletion of coral reefs which take centuries to grow. It takes about one century for one meter of coral reef to build. Oceans absorb high quantities of Carbon-dioxide (CO_2) from the atmosphere. As the levels of increased greenhouse gases continue to rise, oceans continue to absorb more and more CO_2 from the atmosphere resulting in ocean acidification which hinders the growth of coral reefs. Climate change also leads to warming of oceans which in turn causes a rise in the sea levels. Such an increase in sea levels accumulation of reefs located near the land. Climate change also leads to drastic changes in storm patterns which can result in the destruction of coral reefs.

Figure 1.12: An image of the port city of Mombasa in Kenya taken by ESA Astronaut Thomas Pesquet aboard the International Space Station. The image shows the effects of climate-induced sea level rises (SRL) on coral reefs. Image Credit: ESA Astronaut Thomas Pesquet.

4.5 Sustainable Development Goal 15: Life on Land

Forest cover is essential to conservation of environment and biodiversity. Africa's natural resources such as majestic forests are diminishing at a rapid rate due to man-made activities such as deforestation and also natural causes such as wildfires and in the process have led to the loss of thousands of hectares of forest cover. This contributes to increased CO_2 emissions into the atmosphere leading to climate change and unpredictable weather patterns. Our forest ecosystems are vital to the survival of humans and wildlife and in this regard, the said needs to be reversed to mitigate biodiversity loss, sustainable exploit natural resources and conserve the environment. Small satellites can achieve this by:

4.5.1 Monitoring Forest Fires

Rampant forest fires lead to a rapid loss of biodiversity in Africa and beyond. Forest fires are most rampant in the dry seasons and can be ignited by both natural occurrences and human activities. Forest fires not only emit high levels of CO_2 into the atmosphere but also release toxic air pollutants. Small satellites can provide imagery data that focuses on a particular region on Earth that has been affected by forest fires and alert responders on the ground to act in quick response to avert further damage of natural habitat. They can also be used to measure the toxic level of the breathable atmosphere and assist in the preparedness to mitigate disease outbreaks associated with smoke from wildfires.

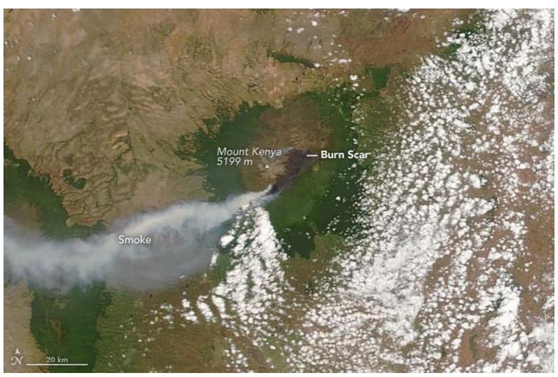

Figure 1.13: An image showing an occurrence of a forest fire in February 2019 around Mt. Kenya which is also the second-highest mountain in Africa and a UNESCO Heritage site. Image Credit: NASA Terra Satellite

4.5.2 Monitoring Wildlife Species

Africa is endowed with vast species of wildlife animals. However, due to human-wildlife conflict, and the invasion of wildlife reserves by the human population, this has led to the decline in wildlife population due to the loss of their habitat. Data from small satellites can help monitor activities in protected wildlife habitats and detect any forms of illegal activities or unapproved developments that can destroy wildlife habitat.

4.5.3 Monitoring Biodiversity Loss

Land degradation, desertification, and deforestation are a threat to various forms of life on the land. Data from small satellites can enable policymakers in Africa to monitor the current activities ongoing in the protected areas such as forests and wildlife reserves and parks. This enables access to damage of the natural habitat and provides information on how to mitigate and preserve natural ecosystems.

5.0 A Case Study: South Africa

South Africa is one country other African countries can emulate when it comes to exploiting space technology for national development. It has one of the oldest and advanced space programs in the African continent. Dating back to the 1950s, South Africa has engaged with international partners such as NASA to grow and advance its space program. In the late 1990's, South Africa's space program adopted the use of the small satellites for remote-sensing and earth observation. Ever since it has launched a number of small satellites into space, the latest being ZACube-2 dubbed the most advanced small satellite ever built in the African continent. Launched in December 2018, the small satellite will help to monitor ocean traffic, ocean economy and provide real-time data to ensure quick response to disasters. These developments have enabled South Africa to develop its own human expertise in satellite technology, thereby becoming a key producer in space technology in Africa.

6.0 Policy Framework

Policymakers from the developing countries in Africa need to draft space policies that will guide their countries to venture into space-based technologies driven by small satellites. A number of policy options exist for policymakers to choose from and they include:

6.1 Bilateralism or Multilateralism Programs

Policymakers from Africa can choose to venture into space technology either through bilateral agreements, that's between one country and another, or through multilateralism, that's between one country and various other countries; for example, a regional economic bloc.

6.2 National Space Agencies

Countries in Africa can also decide to venture into space science through small satellite programs as individual countries. Through relevant national agencies, such as a country's space agency, a weather agency or a geospatial agency; a country can deploy a small satellite into space to serve a specific mission for a specific target or goal. However, this demands the utmost political will from the government and the financial commitments that tag along with it.

6.3 Public-Private Partnerships

African governments can pursue small satellite programs through partnerships with the private sector involved in fields such as mapping and navigation, communication, scientific research, earth observation, and among others in order to share the risks and the benefits.

6.4 Universities and Technical Institutions

Policymakers in Africa can choose to develop small satellite programs through partnerships with universities and technical institutions. Besides this being affordable to developing nations, this also ensures relevant knowledge transfer to the students; hence building a reliable human expertise ready to tap into space sciences. For this to be successful, concerted efforts have to be made to ensure capacity building of students is done in a consistent manner.

7.0 Opportunities and Challenges: African Context

Data obtained from small satellites in earth observation missions brings closer the achievement of the sustainable development goals. In Africa, small satellites provide the best access to space science and space technology and can help to:

a) Synthesize and supplement traditional and historical data.
b) Improve data record and data access.
c) Provide detailed spatial and spectral information.
d) Improve consistency in the gathering and analysis of data.
e) Shift from costly and time-consuming traditional methods of ground data collections such as surveying.

However, a myriad of hurdles and challenges lie ahead as Africa adopts space science and space technology and they include:

a) Lack of necessary expertise to operate complex earth observation missions.
b) The presence of an inefficient internet bandwidth connection to gather, process, prepares and analyzes huge volumes of raw data.
c) Lack of established national statistical systems to supplement raw data from earth observation systems.
d) Lack of political will to venture into space science.

8.0 Conclusion

Modern-day humanity continues to be plagued by myriads of challenges such as food insecurity, lack of proper housing, polluted environments, disease outbreaks, depletion of key natural resources, water scarcity, and natural disasters and among others. Sustainable development has been cited by member states of the United Nations (UN) as part of the solution to these challenges. Concerted efforts have been initiated to ensure solutions are geared towards achieving sustainable development. It's clear that space science and technology through the adoption of small satellite programs can play a pivotal role in addressing the pressing challenges in the course for prosperous economic, political and social development in the African continent. Such can guide in sustainable use of our natural resources by spurring various sectors of the economy and creating thousands of jobs for the youth, thereby reducing the rates of poverty; hence addressing the Sustainable Development Goals. This can only be realized with good political will from relevant governments in Africa. Time has come for Africa to rise up to the occasion and invest in technology and achieve its goal of becoming a producer rather than a consumer of space-based applications.

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