Co-creation HUB

COMPARATIVE ANALYSIS OF USE CASES OF REMOTE SENSING FOR DEVELOPMENT

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EXECUTIVE SUMMARY

Remote Sensing (RS) technology has emerged as a crucial component in various sectors, offering critical applications for sustainable development. This comparative study explores the multifaceted utility of RS across 6 distinct areas namely: precision agriculture, environmental conservation, disaster management, urban planning, public health, and climate change mitigation and modelling. In precision agriculture, RS facilitates crop yield estimation, water resource management, and assessment of crop suitability based on geo-climatic parameters. Environmental conservation benefits from RS by monitoring ecological functions, identifying species habitats, and tracking environmental changes. Disaster management leverages RS for flood forecasting, landslide mapping, and forest fire detection, aiding in emergency response and mitigation efforts.

Urban planning benefits from RS by monitoring urban growth, estimating population densities, and the quality of life situation of residents, and assessing infrastructure needs. Public health initiatives utilise RS for disease mapping, vector habitat surveillance, and healthcare facility planning, aiding in disease control and healthcare accessibility. Furthermore, RS technology contributes significantly to climate change mitigation and modelling by assessing renewable energy potential, monitoring climatic variables, and predicting sea-level rise. Despite its vast potential, effective RS implementation requires attention to data quality, resolution, and integration with other analytical techniques.

This analysis underscores the indispensable role of RS in informing decision-making processes across various sectors for sustainable development. By providing valuable insights into land use, environmental changes, and infrastructure development, RS empowers stakeholders to adopt informed strategies towards a more sustainable future.

LIST OF ACRONYMS

AI
Artificial Intelligence

AIRS
Atmospheric Infrared Sounder

ASTER
Advanced Spaceborne Thermal Emission and Reflection Radiometer

CERES
Clouds and the Earth's Radiant Energy System

DEM
Digital Elevation Model

DREAM
Dust Regional Atmospheric Model

ERBE
Earth Radiation Budget Experiment

GIMMS
Global Inventory Modelling and Mapping Studies

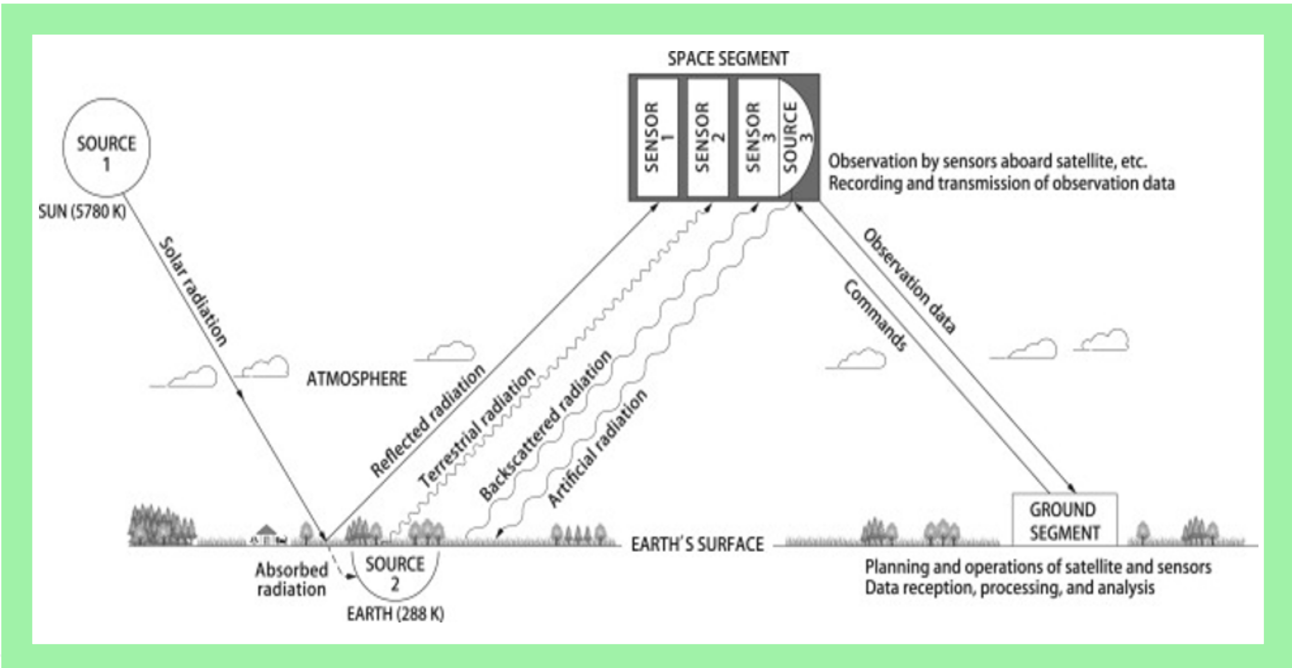
GIS
Geographic information system

GNDVI
Green Normalised Difference Vegetation Index

RS
Remote Sensing

INTRODUCTION

According to Acharya and Lee (2019) remote sensing (RS) refers to the branch of geospatial technology applicable for the capture of earth surface data through electromagnetic energy and other processes, and extraction of information for the GIS system, with other constitutive branches of geotechnology being geographic information system (GIS) and global positioning system (GPS). GPS is usable for capturing locations on earth surface by measuring distances from the satellites while GIS entails the wholesome process of capturing, storing, manipulating, processing and publishing of geospatial data (Acharya and Lee, 2019). Data from GeoBuiz Geospatial Industry Outlook & Readiness 2019, indicates that the geospatial industry was expected to hit a combined value of 439.2 Billion USD in 2020 backed by continuous integration of key emerging technologies such as unmanned aerial vehicles (UAVs), Internet of Things (IoT), Artificial Intelligence (AI), Virtual Reality (VR) and digital twins in the capture, processing and analysis of RS data. Satellite remote sensing systems comprise five key elements including sources of radiation (the Sun, the Earth, and artificial sources of radiation), interaction with the atmosphere, interaction with the earth's surface, space segment (sensors), and the ground segment (Kaku, 2019). Other critical components of the RS system include the human components including technical operators, and ground-level factors such as ground topography, density among others.



Components of a Satellite Remote Sensing (RS) System
Source: Kaku, 2019

RS is a critical tool for monitoring earth systems at various spatial and temporal scales as such is critical for interventions in environmental, ecological and socioeconomic challenges. RS technology provides access to both archival as well as live data on earth systems (Jensen, 1996; Jensen and Cowen, 1999). Some of the most critical applications of RS technology include ground cover and forest management, vegetation indexing, urban planning, as well as water resource management and natural disaster management. The advancement in other frontiers of science and technology including GIS, and machine learning (ML) combined with RS have proven to be critical sources for monitoring and assessing sustainable development efforts across the globe. For instance, the increasing number of critical RS interfaces and platforms including graphic processing units and open data sources such as USGS Earth Explorer, Copernicus Data Hub, Bhuvan, Open Topography, and cloud platforms (e.g., Google Earth Engine) as well as increasing collaborations among the RS community on various social media platforms e.g. LinkedIn, Quora, Github etc. have contributed massively to the increased adoption of the technology across various fields (Avtar et al., 2020). There is also a relative increase in the number of RS analytic tools and software which have enhanced capturing and analysis of RS data. Some of the RS analytics tools available include SAGA, QGIS, SNAP, SeaDAS and LAS. This paper shall attempt a comparative analysis of use cases of RS technology in various areas of earth science for sustainable development across the world. A comprehensive review by Avtar et al. (2020) on the application of RS technology in sustainable development categorised the use cases into 3 main areas i.e. natural resource management and development, environmental assessment and hazard monitoring, and socioeconomic development. Avtar et al's (2020) study further subdivided the use cases into at least 9 areas of application including population, environmental assessment, biodiversity, quality of life, ground water, transportation, landslide mitigation and management, mineral resources and flood hazard forecasting and assessment.

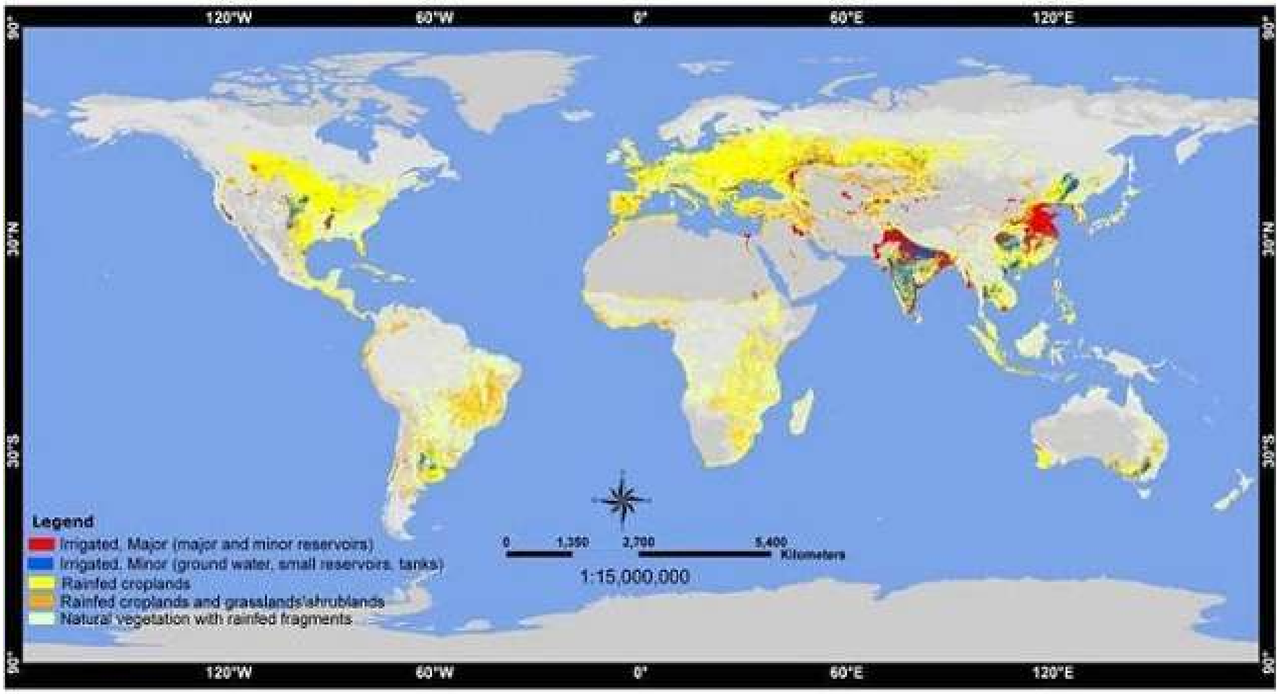
One of the most utilised satellites for RS remains the Landsat Series currently having 9 satellites with Landsat 9 having been launched in 2021, and Landsat 8 in 2013 with the ability to make 438 circles around the earth while utilising infrared light to capture 400 scenes per day and completing a full earth scan in 16 days. Some of the key applications of Landsat include mapping and monitoring of agriculture, forest and vegetation cover, hydrology, land use/cover change, and disaster management (Acharya and Lee, 2019). Other major high spatial resolution satellites currently in use for RS globally include Sentinel, SPOT, RapidEye, ALOS, Worldview, GeoEye, KompSat, SkySat, TripleSat, and Pléiades among others. Similarly, emerging areas of advancement in RS technology include the addition of fine spectrums to form hyperspectral sensing thus the possibilities for diagnosing and refining information on natural resources. Other areas include microwave remote sensing which escapes challenges initially posed on optical sensing by weather conditions, smoke, haze, and cloud cover. Additionally, interferometry allows Digital Elevation Model (DEM) generation thus can be utilised to study complex occurrences such as glaciers, volcanic eruption among others. New age satellites such as Suomi-NPP Visible Infrared Imaging Radiometer Suite (VIIRS) also presents nocturnal capabilities thus are able to function at night and can be utilised to monitor nighttime phenomena such as shiplights, human settlement lights, flaring of waste natural gas among others.

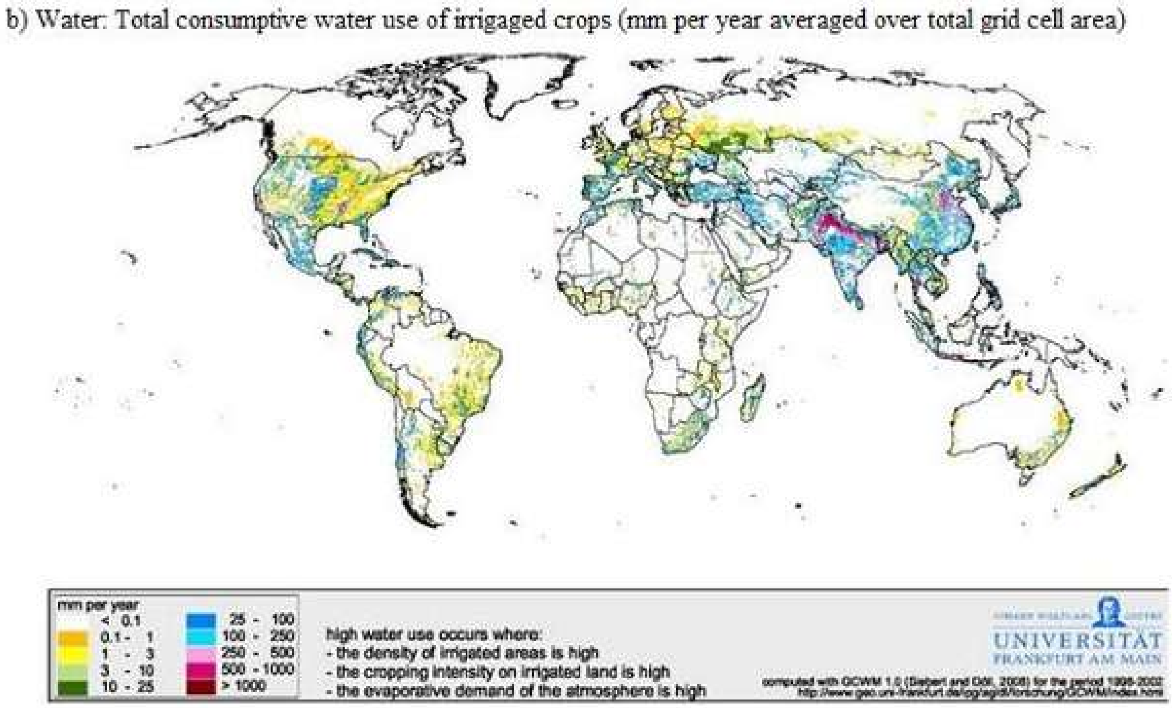
The Global Navigation Satellite System (GNSS) which is utilised for provision of precise locations is also critical for among other things aircraft navigation and control of drones and other autonomous vehicles, as well as for the study of the atmosphere, landslides, earth structures, and for precision agriculture. The application of combined data generated from RS and GIS are key for development planning including in key areas such as urban planning; managing water, traffic or sewers, and predicting disaster to reduce risk and develop resilience, resource management; mapping resources, and environmental conservation; modelling pollution among others. Considering the vastness of applicability of RS technology globally, this analysis shall analyse the use case of RS based on 6 key areas of applications thereby detailing the extent of use. The main areas to be considered for analysis include precision agriculture, environmental conservation, disaster management, urban planning, public health and climate change mitigation and modelling.

Precision Agriculture

RS technology is majorly applicable in agriculture in mapping and estimating crop yields, analysis of crop-suitability based on geo-climatic parametres, groundwater resources, drainage patterns, variable rate application, and management of fertilisers, pesticides, and insecticides (Avtar et al., 2019). For instance a report titled "A Holistic View of Global Croplands and Their Water Use for Ensuring Global Food Security in the 21st Century through Advanced Remote Sensing and Non-remote Sensing Approaches" by Thenkabail et al. (2010) applied remote sensing techniques or otherwise and found that there existed at least 1.47-1.53 billion hectares of global cropland with 80% of human water use being channelled towards irrigation. Similarly about 6,685 to 7,500 km3 yr–1 with rainfed croplands (green water) consuming 4,586 km3 yr–1 and the rest by irrigated agriculture (blue water). The analysis also discovered that of the 2,099 km3 yr–1 of water utilised by irrigated lands about 1,180 km3 yr–1 was drawn from reservoirs and the rest from rain as such translating to a 40 to 62% efficiency (Thenkabail et al., 2010).

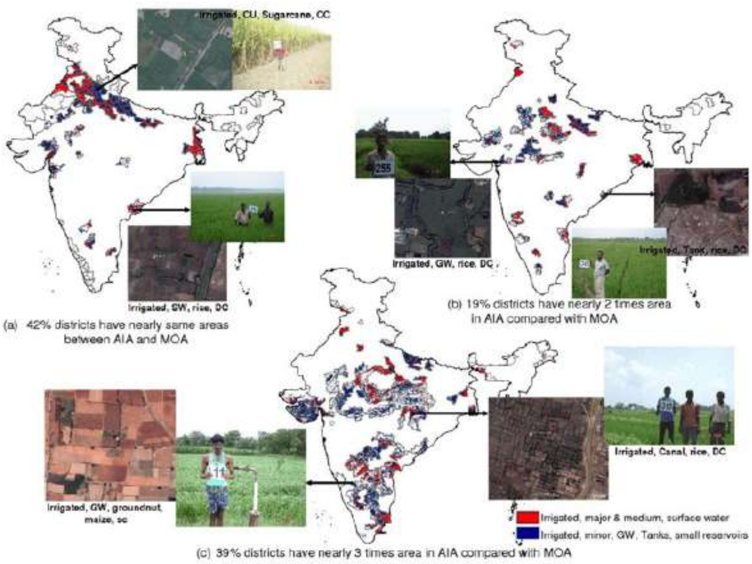
a) Croplands: Global Cropland Map





Global Cropland Map
Source: Thenkabail et al., 2010

Such analyses underscore the applicability of RS technology in agriculture. A further comparative analysis of remote sensing-based data, with MODIS satellite data integrated with census-based data of irrigated lands in India showed a near perfect match, with the RS-based data being more detailed as to account for among others areas with irrigation from groundwater, small reservoirs and tanks.



Remote Sensing vs Census Data for Irrigated Lands in India
Source: Ministry of Agriculture of India, 2009

It is key to note that cropland maps and agriculture-based RS mapping require finer resolution satellites to avoid uncertainties related to coarser resolutions as well as to enhance the precision and accuracy of the cropland areas on the maps. Similarly, the nuanced details required for crop classification further informs decision-making on among other areas water use by crops, water productivity, biomass, yield and carbon

Precision Agriculture

sequestration. In addition, the impending climate change reality coupled with other key uses of cropland mapping information including for the study of global water use trends, food production trends, land use change patterns, investment targeting, and policy simulation and future scenario modelling demands precise and accurate information for proper decision making (Thenkabail et al., 2010). Aside from finer spatial resolution, there is also a critical need to employ RS technologies with higher temporal frequency in order to ensure certainty and reliability of the cropland estimates. For instance, an analysis by Liu et al. for China in 2000 approximated the country's cropland area at 141 Mha against the FAOSTAT's figure of 160 Mha and Portmann et al and Siebert and Doll's at 168 Mha (Thenkabail et al. 2010). Thus highlighting potential discrepancies that need to be addressed.

Environmental Conservation

Remote sensing is often used to monitor and observe environmental changes across wide areas (Duro et al., 2007; Xie et al., 2008). Key areas of application of RS technology in environmental conservation include the exploration of various ecological functions and anthropogenic drivers of landscape changes (Gould, 2000; Kerr and Ostrovsky, 2003; McDermid et al., 2009) including identification of biophysical traits of species habitats, distributions, locations and species variations. Acharya and Lee (2019) underscore the increasing adoption of integrated sensor capabilities for measuring varying environmental parametres including water level, air temperature, air moisture, wind speed, and soil moisture among others. RS is also applicable for monitoring of land cover; Landsat Thematic Mapper (TM), Compact Airborne Spectrographic Imager and other narrow-bandwidth visible and near-infrared spectroradiometer sensors are utilised to capture images of ground cover. RS earth observation data often yield key indices including productivity, richness, spatial and temporal distribution, disturbance, composition, topography, heterogeneity, biomass and structure of the earth among others. RS technology is also applicable for indirect environmental parametres setting and mapping of species patterns and diversity including species primary productivity, climate variables and habitat structure (Abdalla, 2012), such parameters are critical for the analysis of species diversity at a given location and time (Turner et al., 2003). RS is also key for monitoring the overexploitation of key natural resources including water, forest, grassland among others for sustainability. For instance, satellite images are critical for water ecosystem monitoring including mapping of sea surface temperature and assessment of seagrass thermal dynamics among others (Maximenko et al., 2019). Other areas of RS for water resource monitoring include extraction of under sea debris plastic pollutants as well as monitoring of chlorophyll-a, a component that controls eutrophication process (Han and Jordan, 2005). Earth observation data can also be used to determine forest cover, a critical indicator of earth surface cover for environmental conservation, mitigation of degradation and restoration efforts.

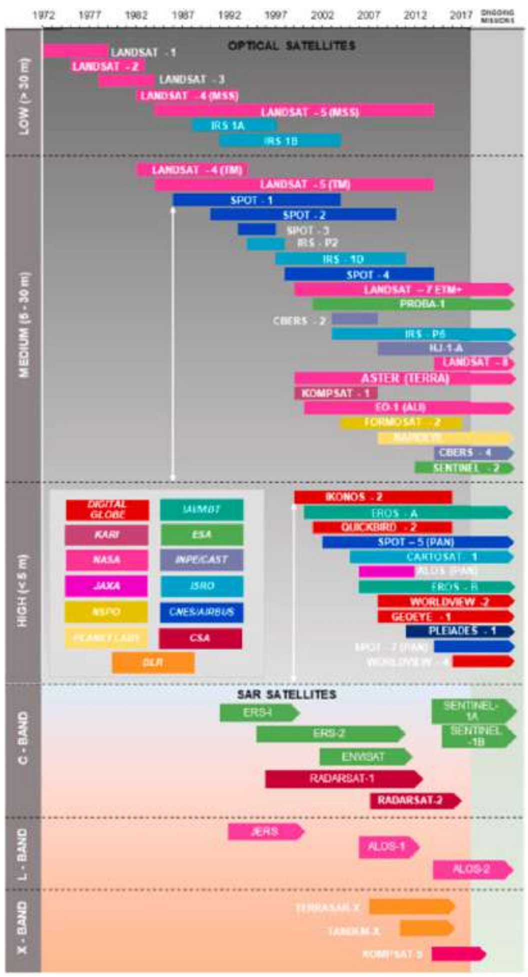
Acharya and Lee (2019) observe the increasing utility of unmanned aerial vehicles (UAVs) for environmental monitoring as opposed to satellites, which, regardless of their usability over wide areas, portends temporal and accessibility challenges. A comparative study by Ali et al. (2020) on the application of UAV-based multispectral sensors corroborates Acharya et al.'s assertion. The study was conducted in Kuwait's Al Abdali protected area and found that satellite images had significant limitations as regards accurately monitoring drylands as a result of the special characteristics of dryland plants. As a result, high multispectral UAVs were found to be more efficient (ALi et al., 2020). Unmanned aerial vehicles (UAVs) were also found to be especially useful in precision agriculture as they counter challenges with satellites including low resolution and prohibitive costs, as well as the constraints of ground based mapping such as inaccessibility to muddy and dense regions. UAVs often hover at around 500 to 1000 metres thus able to acquire high spatial and temporal resolution at lower costs. Advancement in UAV technology also includes among other features enhanced georeferencing and mosaicking of image and improved analytics and extraction of information capabilities (Badsod et al., 2017).

Disaster Management

Remote sensing technology has been employed for large scale environmental assessment activities such as monitoring of global warming for preparedness. The Advanced Very High Resolution Radiometer has been used to measure the sea surface temperature (SST) for the past 40 years recording an average increase of 0.28 degree celsius between 1984-2006 (Yang et al., 2013a). Such information is crucial for the estimation of sea-level rise and earth's albedo. Similarly, flood hazard forecasting is another key component of RS technology. RS data are critical in predicting floods, landslides, subsidence,

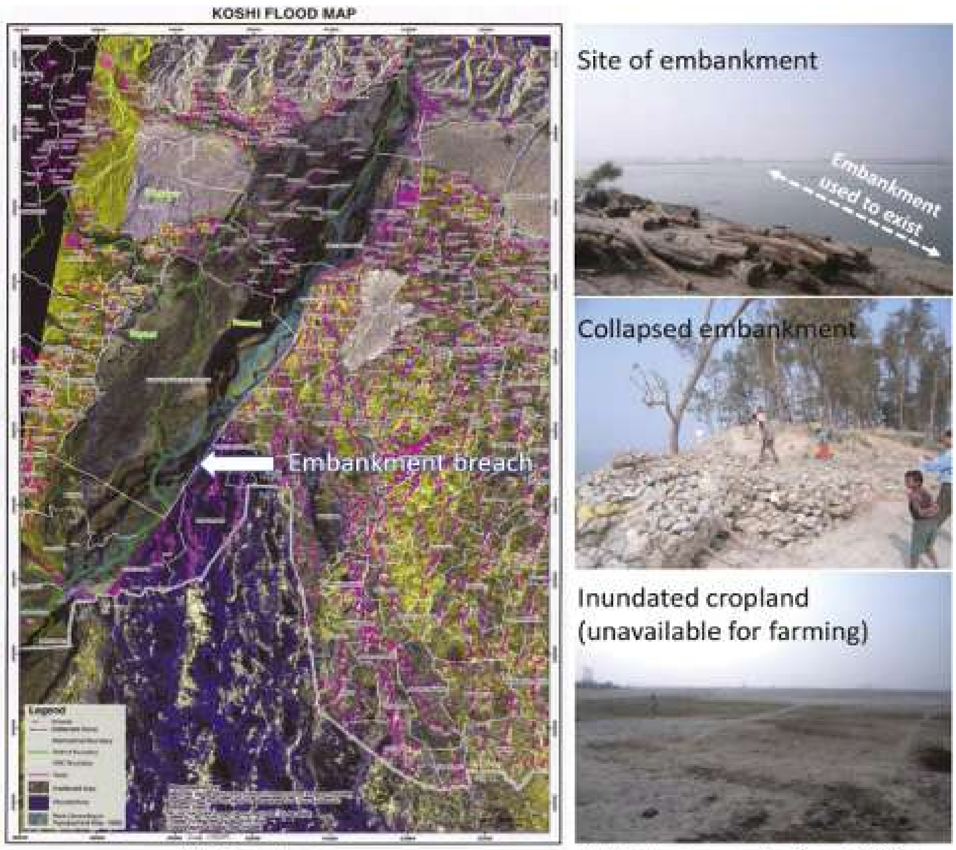
and ground instability for intervention planning (Carrasco et al., 2003). RS digital models are also applicable for the development of key predictive tools including catchment geometry, hill-slope angles, measurements of rainfall intensity and duration and measurement of soil moisture for quantification and modelling of flood hazards (Yan et al., 2013). Satellite recordings of seasonal land cover changes e.g. water interception, potential, soil strength assessment, permeability and erosion potential and climatic behaviour data such as severity and extent of flood hazards are retrieved through thermal and microwave active and passive sensing techniques. RS data is also critical for disaster risk management as it can be applied by emergency response teams to among others assess the extent of flood damages.

Another key use of RS data involves the generation of landslide inventory maps which documents the probability of landslide occurrence in a region, "to investigate the distribution, types, pattern, recurrence and statistics of slope failures, to determine landslide susceptibility, hazard, vulnerability and risk, and to study the evolution of landscapes dominated by mass-wasting processes" (Guzzetti et al., 2012). Some of the existing landslide maps have been developed through among others Landsat ™, ETM+, OLI; Sentinel, Planet data, LiDAR elevation data and Google Earth Platform (Avtar et al., 2020). Satellite data is also often used to predict and detect forest fires and assess extent of damage caused. Moderate Resolution Imaging Spectroradiometer (MODIS) data is especially preferred for detection of forest fires as a result of its relatively higher resolution while other sensors including SPOT, Landsat TM, ETM+ and OLI, AVHRR, ERS2, RADARSAT among others aid in mapping burned areas, detect forest fire changes, for risk and damage assessment (2020). Navarro et al. (2017) urges the use of Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Normalized Burn Ratio (NBR) and Normalized Difference Vegetation Index (NDVIreXn) for post-forest fire analysis and mapping as they entail red edge spectral bands.



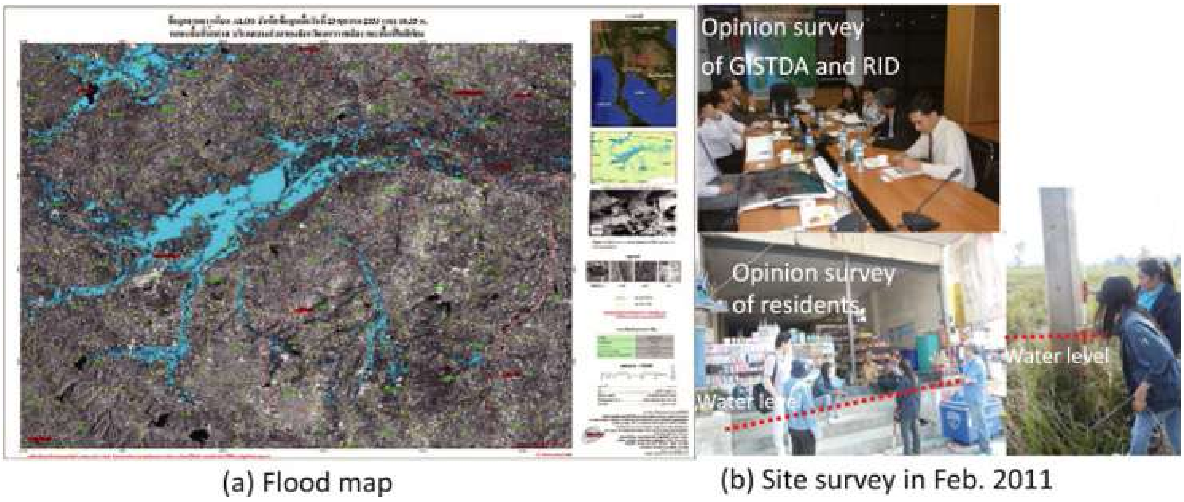
Remote sensing satellites used in landslide mapping
Source: Avtar et al., 2019

Kazuya Kaku (2019) giving a synopsis of the The Sentinel Asia (SA) Project implemented by The Japan Aerospace Exploration Agency (JAXA) underscores critical use cases of RS technology for disaster management across the Continental Asia. Some of the case studies highlighted included the application of RS to study the Large scale flood in Nepal in August 2008, in which case JAXA utilised the panchromatic Remote-Sensing Instrument for Stereo Mapping (PRISM) and Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) for emergency observation of the situation on August 22 and 24 as well as a site survey in December 2008. Data captured from these observations were handed over to the Nepalese Government. According to JAXA, the RS data integrated with census data enabled the authorities to make an analysis on the number of flood victims, number of houses affected and manage relief support for the victims (Kaku, 2019). Other applications of the SA Project RS technologies for disaster management include observations by JAXA for the 50-year long-term deluge in Thailand as well as hazard mapping with the local communities in the Philippines, as well as landslide early warning, volcano and land subsidence monitoring across Asia, wildfire early detection (Indonesia), glacial lake flood early warning (Bhutan) and response to the Great East Japan Earthquake in 2011.

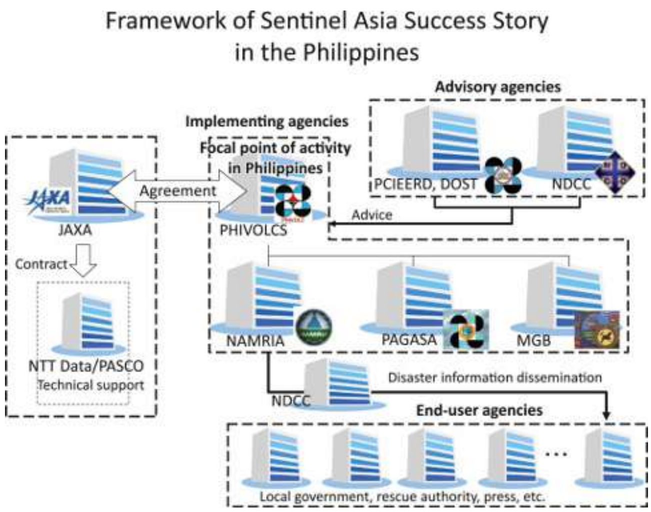


(a) Flood map (b) Site survey in Dec. 2008

RS map for Large Scale Floods in Nepal, 2008
Source: JAXA, SA



RS map for the 50-year deluge in Philippines, 2011
Source: JAXA, SA Project



Framework of Sentinel Asia Success Story in the Philippines (hazard mapping)
Source: JAXA, SA

Bello and Aina (2014) observes that despite RS's increasing adoption in disaster management as a result of its short temporal orbiting and large coverage among other reasons, its full adoption is impaired by among other reasons a resounding economic divide between the developed and developing countries, limited access to high resolution imagery data as well as technological constraints. Bello and Aina (2014) also noted the impending revolution in RS for disaster management including increasing adoption of alternative RS data sources such as Google Earth, crowdsourcing platforms and the Global Land Cover, and call for enhancement of collaborative and interdisciplinary efforts in utilisation of RS for disaster management.

Urban Planning

Data obtained from satellite and ground sensors and other integrated geospatial technologies are used for monitoring various aspects of cities and towns. For instance, high resolution satellite and aerial imagery can be used to generate urban mapping metrics. With fundamental applications in various areas including urban transportation networks, buildings and impervious areas, land use data and biophysical attributes of urban areas (Acharya et al., 2016, Huang et al., 2007, Lalljee and Facknath, 2008), as well as to monitor urban growth. Integrated census and RS data have also been used to estimate population and residential densities thus aiding government planning for the socioeconomic needs and analysis of quality of life aspects of the residents including standards of living, the quality and availability of water, housing, environmental quality (greenness), healthcare, safety, energy consumption and the climatic or atmospheric temperature (Faber and Lo, 1997, Avtar et al., 2020).

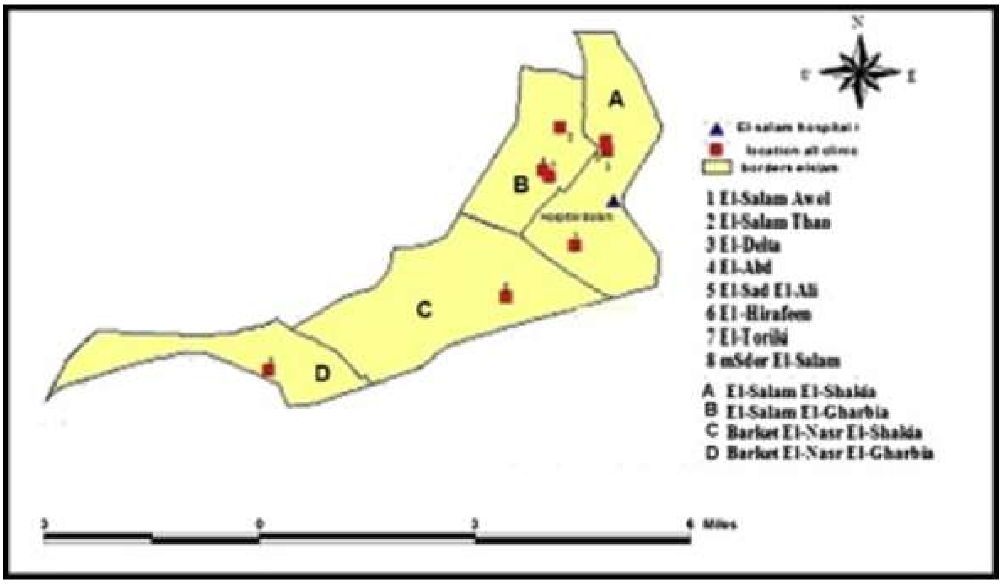
Thermal RS data can also be used to monitor extent of sustainability in urban areas as they map heat islands (Banafoni et al., 2017). In a comparative study of urban forms across the world, Jingnan Huang et al. (2007) applied remote sensing and spatial metrics to analyse the nature of urban form for 77 metropolitan areas in Asia, US, Europe, Latin America and Australia. Urban forms in developing countries were found to be more compact and dense compared to their counterparts. A “good” or “sustainable” urban form is essential for economic vitality, social equity and environmental conservation with lingering debates over the suitability of compact or sprawl urban forms (Breheny, 1992, De Roo and Miller, 2000). A similar comparative study of urban forms across 25-mid sized cities across the world using RS data determined the existence of four types of cities; low-growth cities with modest rates of infilling, high-growth cities with rapid and fragmented development, expansive growth cities with extensive dispersion at low population densities, and frantic growth cities with extraordinary land conversion rates at high population densities (Scheider and Woodcrock, 2008). Nighttime light data gathered from satellite images can also be used to estimate the rate of consumption of electricity, hence income levels of respective communities as well as their population densities (Shi et al., 2014, Sutton et al., 1997).

Public Health

Geospatial data aid in the mapping of endemic and pandemic diseases. For instance, designation of cholera outbreaks; source and hotspot areas (Acharya and Lee, 2019). RS images are also applicable for the mapping and surveillance of vector habitats for elimination of diseases (Malone et al., 2019). Similarly, the potential geographic distribution of diseases can also be investigated through RS modelling techniques which yields discovery of geospatial characters of diseases including the link between diseases, poverty levels, climatic and environmental conditions, and access to critical resources including water among others (Malone and Bergquist, 2012). For instance Hall et al.(2008) utilised infant mortality rates to model poverty. Ramzi and El-Bedawi et al. (2019) conducted a remote sensing analysis of the distribution of primary health care centres (PHCC) in El-Salam medical region of Egypt. The RS images and GIS data obtained from this study uncovered the presence of 8 PHCCs in the area of study with 4 of these being conveniently distributed while 4 being out of reach from the target population. Ramzi and El-Bedawi's (2019) study approach proceeded as follows;

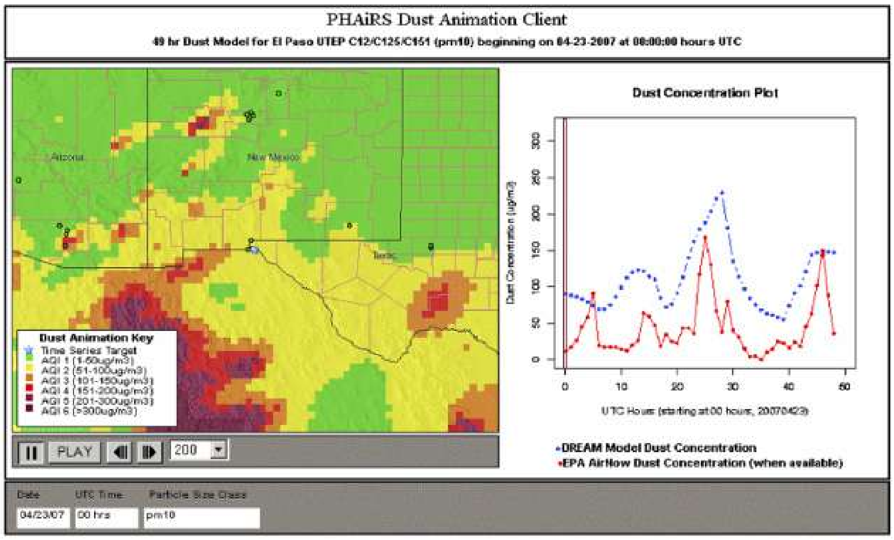
> *"...the method (relied) on advanced techniques in remote sensing science, computer science and population prediction and was based on different models such as exponential models and census data. The following steps were proposed: Data collection (satellite images, maps, administration borders) covering the study area; Acquisition of GCPs, CPs and location of PHC using Handheld GPS from field; Pre-processing of satellite images; Registration satellite image; Accuracy assessment of rectified satellite image registration based on RMS; Image subset; Database design of PHC centres included types of clinics, labs, staff, medical facilities and others; Distribution and locations of government PHCCs. Producing vectors layers; Projecting population to 2015; Calculating supply of PHC centres; Applying international and Egypt guidelines of PHC centres; Calculating demand of PHC centres and served/unserved citizens and area; And evaluate the results."*

Above is an excerpt from the RS methodology applied by Ramzi and El-Bedawi et al. (2019). The applicability of the output from the RS analysis of the spread of PHCCs in the study area by the Ministry of Health of Egypt in projecting future healthcare needs and accessibility to by the public demonstrates the usability of RS for public health. For instance, based on the Egyptian government's regulation that a single PHCC should serve 20000 inhabitants with a predicted population for the area being 519723 in 2015 the PHCC deficit was 18. Regardless, the PHCCs available were found to cover the physical area of study due to population density.



Remote Sensing Mapping of Public Health Care Centres in El-salam medical region, Egypt
Source: Ramzi and El-Bedawi, 2019

Remote sensing of the environmental and atmospheric conditions can also be used for public health and safety planning for instance reducing exposure to desert dust storms, hitchhiking, moulds, heavy metals etc. Sprigg et al. (2020) utilised data from NASA's Terra satellite to generate a Dust Regional Atmospheric Model (DREAM) and using an operational weather forecast model simulated and predicted the onset of dust storms and the 3D size concentration characteristics of the resulting airborne-dust clouds in El Peso, USA.



Remote Sensing from EL Peso, USA obtained from DREAM
Source: Sprigg et al.

A bibliometric analysis conducted on Scopus of scientific research and publications on the application of remote sensing in human health between 2007 and 2016 found that among the most remote sensed diseases included malaria, dengue fever and schistosomiasis (Viana et al., 2017). The correlation of environmental factors with diseases was also an important application of remote sensing for public health. The study also found an increase of 172% in research publications in the application of remote sensing in public health as compared to a 46% overall publications and 72% medical sciences related publications in the years between 2014 and 2015 thus showcasing a rapid adoption of remote sensing for public health utility.

Climate Change Mitigation & Modelling

RS technologies offer unique opportunities for climate change modelling and carbon monitoring. For instance, RS and geospatial data can be used for among others the exploration of the potential of solar and wind energy sites (Anwarzai and Nagasaka, 2017). Key mapping of the earth's strategic clean energy resources including onshore and offshore wind potential also aid in sustainable development planning (Bosch et al., 2017). Some other key microclimatic data that can be captured by RS technologies include the earth's water cycle; evaporation from oceans, water vapour in the atmosphere, clouds, precipitation, soil moisture, sea ice, land ice and snow cover on land and ocean, as well as radiating energy fluxes, aerosols, vegetation cover, phytoplankton (base of aquatic food webs) and water temperature (Avtar et al., 2020). Some of the most common sources of RS data for climate change monitoring include TERRA and AQUA satellites.

"...TERRA has five onboard sensors designed to monitor the Earth's environment and changes in climate, as follows: (i) the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), (ii) Clouds and the Earth's Radiant Energy System (CERES), (iii) Multi-angle Imaging Spectroradiometer (MISR), (iv) MODIS, and (v) Measurements of Pollution in the Troposphere (MOPITT). AQUA has six onboard sensors for water studies: (i) the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), (ii) MODIS, (iii) Advanced Microwave Sounding Unit (AMSU-A), (iv) Atmospheric Infrared Sounder (AIRS), (v) Humidity Sounder for Brazil (HSB), and (vi) CERES." (Avtar et al., 2020)

Purkis and Klemas (2011) further expounds that for a satellite to be usable for monitoring of climate data it must fulfil key characteristics including ability to have frequent repeat cycles and global coverage (Latifovic et al., 2005). Some of the satellites forming part of the global climate observing system, in addition to those listed above include the analysis of the Earth's radiation budget through the Earth Radiation Budget Experiment (ERBE), Scanner for Radiation Budget (ScaRaB), International Satellite Cloud Climatology Project (ISCCP), vegetation research through the Global Inventory Modelling and Mapping Studies (GIMMS) and the NOAA-NASA Pathfinder Program (Latifovic et al., 2005).

Yang et al. (2013) highlights the emerging and unique applications of RS technology in climate system modelling including the modelling of the spatial patterns of sea-level rise and cooling effect of increased stratospheric aerosols. Backed by fine-resolution imagery and global-scale coverage, RS generated data is essential for climate change monitoring and prediction. However, it is critical to note the constraints posed by short duration observation series and uncertainties from RS generated images (Yang et al., 2013). An evaluation of the ecological vulnerability of the Northern and Southern foothills of the Yinshan Mountains of Inner Mongolia, China (NSFYM) demonstrates the effectiveness of RS generated data for climate change preparedness (Jiang et al., 2018). The ecological evaluation conducted by Jiang et al. (2018) revealed moderate to high vulnerability scales with distinct regional levels of vulnerability. For instance 29% of high vulnerability areas are located in the highlands with poor natural conditions and pronounced human activities. Similarly 31% of medium vulnerability were within the low-lands with intense agricultural activities. Areas with higher ecological vulnerability scales were thus found to have lower adaptability levels to climate change as such required more nuanced eco-environmental protection strategies in the face of increasing climate change scenarios.

Conclusion

Apart from the 6 key areas of application remote sensing technology can also be utilised for among others mineral exploration and monitoring, security and intelligence gathering, and development of transport networks. Overall, remote sensing (RS) is increasingly emerging as a versatile tool applicable across multiple sectors for sustainable development, from agriculture, environmental conservation, urban planning, climate monitoring and modelling to disaster management and public health among others. Its applications include crop monitoring, forest surveillance, and early warning systems for natural disasters. By providing valuable data on land use, environmental changes, and infrastructure development, remote sensing facilitates informed decision-making and sustainable development strategies. However, effective utilisation of RS will require consideration for RS data quality; resolution, and integration with other emerging analytical techniques.

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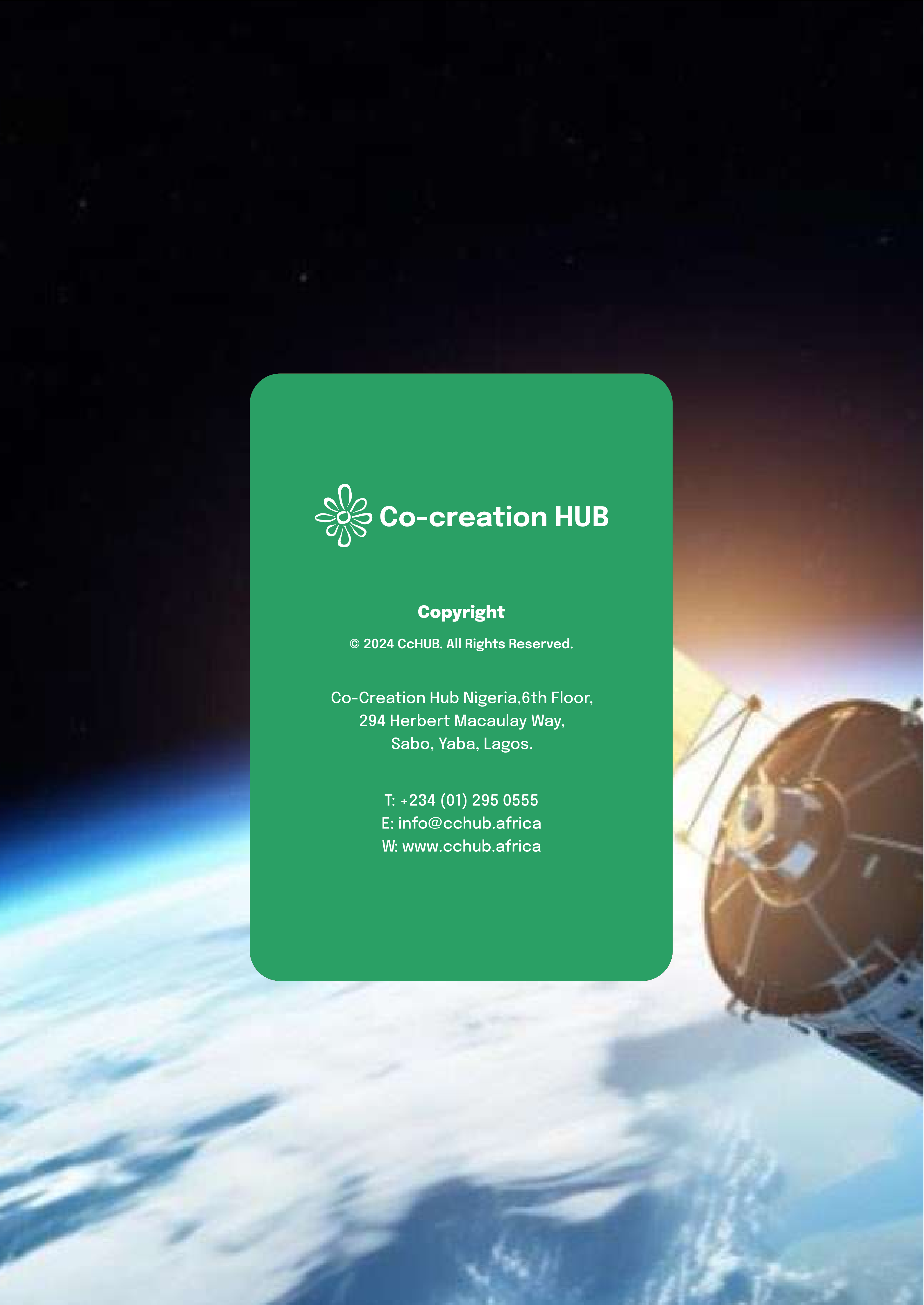

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