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Role of Space Technology for enabling inter-generational equity of natural capital and disaster resilience: Corollaries of Indian Space Program

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1. Introduction

Since the introduction of the sustainable development concept in 1980 by International Union for the Conservation of Nature and Natural Resources (IUCN, 1980), the idea has been widely discussed (Allen, 1980; Goodland and Ledec, 1987; World Bank, 1987). It is about meeting the needs of the present, without compromising the ability of future generations to meet their own needs (WCED, 1987), in addition to the economic dimension (Peezey, 1992). Sustainable development will enable securing food, water, energy and environment for future generations, through optimal utilization of natural capital and its equity across generations. Sustainability also implies managing natural hazards and diseases, towards better survivability for evolving disaster resilient and healthy societies.

The sustainable development goals (SDGs) set by the UN specifically address the utilization of natural resources in productive and non-degrading manner, utilization of renewable energy, combating the impacts of climate change and developing safe & disaster resilient habitations towards ending poverty, providing food; water; health & shelter security, achieving economic growth, development and sharing prosperity (World Bank, 2016). Out of the 17 sustainable development goals, 11 of them have direct reference to natural resources, environment, climate change induced impacts, disaster resilience and health, implying the importance of these factors in achieving sustainable development and amenable to the use of space systems.

The sustainability of many natural resources is measured using suitable indicators (World Bank, 2016). These indicators include long term trends of arable land (as percentage of land area or per capita), agricultural land (% of land area), forest area (% of land area), surface water (fresh), dynamic ground water, energy utilization (from hydrocarbons, renewable sources & nuclear), atmospheric pollution (CO2, NOX, PM2.5), climate change induced impact (sea surface temperature increase, sea level rise, glacier retreat, polar ice fragmentation), etc.

Some of the indicators of development present a picture that is contrary to the notion of sustainability. For example, based on the database of development indicators presented by World Bank, the per capita arable land has decreased by 47% during the last 5.5 decades. With considerable share of fossil fuels for energy production (nearly 80%), GHGs have increased by 95% during the last four decades. Periodic monitoring of the state of natural capital and indicators of climate change are necessary to make sure that the development is sustainable. Natural disasters and extreme weather events cause extensive damage every year and the global economic loss estimated by EM-DAT amounts to $2600 Billion during 1994-2013 (CRED, 2015). Space Technology provides necessary data to estimate the status of natural resources & environment, to model climate change and study its impact and to reduce the risk from natural disasters. It helps decision makers to introduce policy interventions for managing development, in a sustainable way, provides input for disaster risk reduction and enables access of health care for population in remote and far-flung regions.

2. Role of Space Technology in Sustainable Development

Spaceborne systems are capable of recording the reflected or emitted energy from earth's surface and atmosphere, in EM wavelengths spread across Visible to Microwave regions, with half hourly observational frequency from Geostationary platforms to as fast as 24-hour revisit capability from Sun-synchronous orbits and with spatial resolution ranging from about 30 cm to 50 km.

Geospatial technology comprising of spatially referenced data from Earth Observation and from other sources, Geographic Information System for managing such data, and location-based services from Global/Regional Navigational Satellite Systems (G/R-NSS) are widely used today for addressing various aspects of sustainable development. The recorded energy from Spaceborne systems, integrated with ground based information helps to derive spectral characteristics of the targets to quantify their areal or linear extent, chemical composition, indices linked to their spectral absorptions and also to estimate bio/geo-physical or chemical parameters of Earth Systems. Such measurements directly or as input to models which derive, specific products related

to land, ocean or atmosphere and climate change, help policy makers to take informed decisions to ensure security of food, water, energy or environment, and to mitigate disaster risk and climate change induced impacts.

Concurrent use of high spatial & temporal resolution Remote Sensing, positional information from G/R-NSS and ground based inputs help planning expansion and intensification of cultivation, water stress / land degradation monitoring, soil nutrient and agricultural pest management, planning and monitoring of irrigation infrastructure, provision for agro-meteorological & potential fishing zone advisories, monitoring of surface waterbodies and its aquaculture potential, groundwater prospecting & recharge infrastructure development etc. towards enabling food and water security. Spaceborne inputs are used for deriving assured solar energy potential, hydropower potential, wind and wave energy potential, towards achieving energy security. Satellite data derived weather parameters are used as input in forewarning of vector-borne diseases or satellite communication services are used for enabling tele-medicine facility.

Space technology helps to evaluate the quality of environment and ecosystem in terms atmospheric aerosol and chemistry, GHGs, biodiversity, deforestation, water quality and waste management. Space borne observations of atmospheric parameters such as temperature, humidity, cloud fraction, solar insolation as well as rainfall measurements provide input for weather research forecast models and for now-casting. Climate change induced impacts such as increase in sea surface temperature, glacier retreat, permanent snow cover reduction, polar ice dynamics, sea level rise and extreme weather events are also measurable or can be modelled for predicting future scenario. Out of the nearly 50 Essential Climate Variables (ECVs) (Bojinski *et al.*, 2014), nearly half are amenable to earth observation systems.

In the pre-disaster phase of the disaster management cycle, input from earth observation systems are used in hazard/risk assessment and development of early warning systems for flood, earthquakes, landslides and cyclone. Models using space inputs such as temperature, humidity, rainfall and land cover are used for Flood Forecast Modelling (Weather Research & Forecast coupled with Hydrological Model) and Cyclone Track Prediction (Hurricane Weather Research & Forecast / Lagrangian Advection Model) or Land Surface Temperature based Forest Fire Alerts. Thermal Infrared & Visible domain images and wind vectors are used in cyclogenesis and track prediction. During the disasters, the earth observation data provides images for rescue and relief operations, and tracks progression of the natural hazards like flood, cyclone etc. Satellite based emergency communication facilities are extremely helpful in coordinating search, rescue and relief operations. High-resolution remote sensing data is useful in assessing the damage caused by natural hazard to infrastructure, habitations, utilities, agriculture and forests. In short space based inputs are widely and effectively used in disaster management to enable the societies to become resilient to the disasters.

3. Indian Space Programme and its Contribution for Sustainable development

The prime goal of Indian Space programme is national development. The earth observation, communication and navigation programmes support the developmental activities by providing necessary data, products and services (Kasturirangan *et al.*, 1996). Currently, India has deployed15 operational Communication satellites and 17 Earth Observation satellites for Atmosphere, Land and Water, both from Geostationary and Sun-synchronous orbits, in optical and microwave domains. The 7-satellite navigational constellation; NavIC is established, for which the first generation receivers are being tested. The current EO systems are capable of providing data with 0.62m spatial resolution; 14bits spectral resolution and 2.5-day temporal resolution. The data and products from India EO satellites are disseminated through online Data Distribution System, Bhuvan Geospatial Gateway, MOSDAC meteorological product gateway, SCORPIO cyclone early warning system and also to the National Meteorological Department.

The EO application projects, data products, services and dissemination mechanism are designed and developed to address the management of natural resources (monitoring, enhancement of output from their utilization and as input for decision making for food, water and energy security), utilization of renewable resources, monitoring of environment (quality of air; water; soil; forest, biodiversity etc.), weather and agrometeorological support, climate change impact assessment and decision support for disaster management.

3.1. Assessing the Status of Natural Resources

The Natural Resources Census (NR-Census) programme initiated by Indian Space Research Organisation (ISRO) carries out national level, periodic assessment of various parameters such as Land use / Land Cover, Forest, Soil, Geomorphology, Lineaments, Land Degradation, Wasteland, Wetland and Snow & Glacier, at intervals of 1 to 10 years. The intervals are aligned with national planning process and the rate of change of parameters. The land use and land cover information is generated at multiple scales (1:250K; annually and 1:50K; 5-yearly), The 1:50K land use / land cover layer is generated using 3 seasons' IRS Resourcesat-2 LISS-

III data (Figure 1) with 54 classes at lowest level; Level#III (NRSC, 2012). It is used in the decision making for agricultural productivity enhancement, utilization of cultivable wastelands and fallow lands, watershed development, afforestation planning, coastal zone management and climate change research.

3.2. Input for Enabling Food Security

India extensively uses Earth Observation based input for Agriculture related applications such as area estimation, production forecasting, pest and diseases detection and incidence forecasting, cropping system analysis, agricultural area expansion, crop intensification, horticulture area assessment and area identification for expansion etc. Potential fishing zone advisory and inland aqua-culture development are also being done for achieving food security.

ISRO initiated a national programme called FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based observations), to address the uncertainties in production, distribution and marketing through informed decision making related to pricing and import-export policies. From the mid-season to pre-harvest stage of crop growth, satellite data is used for estimating the crop area and crop yield. FASAL programme has been institutionalized with the establishment of Mahalanobis National Crop Forecasting Centre (MNCFC) by the Ministry of Agriculture. Currently in-season, multiple, pre-harvest crop production forecasts are given for 8 crops covering 53.2% of total cropped area; 78.3% of food grain production in the country (Ray, 2016), in addition to production forecast for pulses in the Rabi season. Space inputs are also used for better horticulture development for 7 major horticultural crops, in about 185 districts; spread over 12 States, in India. The activities include area assessment, production forecasting, and decision support for horticulture development & management; such as area expansion and intensification, post-harvest infrastructure planning etc.

The potential fishing zone (PFZ) advisory is another programme that has been developed by ISRO and internalized by the concerned agency under Ministry of Earth Sciences for operational execution (http://www.incois.gov.in/MarineFisheries/PfzWebGis), currently benefiting nearly 0.3 million fishermen. The potential zones of fish aggregation are derived from space-derived inputs on Sea Surface Temperature (SST) and Chlorophyll. Prior information on the potential zones (latitude/longitude and the bathymetry) is disseminated in the form of maps and text to the fishermen community through multiple means (web, sms, digital displays etc.) which helps to reduce the time and fuel spent for the fishing activity.

Methodology is developed for assessing the suitability, potential and management measures of village water bodies for inland aquaculture development, as a source of protein rich food for population and also as an employment opportunity.

3.3. Enabling Water Security

Sustainable use of water from all sources, efficient irrigation systems and reservoir storage restoration etc. are important factors with respect to water security. ISRO has operationalised the use of earth observation input for irrigation infrastructure monitoring, assessment of irrigation potential created and utilized, periodic automated surface water spread extraction & waterbody information system, reservoir capacity estimation, development of hydrological information products, snowmelt runoff modelling, ground water prospects mapping and water resources assessment. A web-enabled, national information system of water resources; known as India-WRIS, has also been developed, with more than 100 spatial layers starting from vintage periods (~100 years) for decision making for water resources management (http://www.india-wris.nrsc.gov.in/wris.html).

The percentage of the districts in the country with more than 70% as ground water development stage (ratio of draft to available resource) as semi-critical to critical stage, has increased from 8 to 29 during 1995 to 2011 (Suhag, 2016). ISRO has implemented a national programme for identifying the prospective zones of ground water and locations of recharge structures. The methodology involved mapping the rock types, morphology and discontinuities using remote sensing and ancillary data, which influence the occurrence and movement of ground water, and then integrating these to derive composite units indicative of ground water prospects, in terms of expected yield and suggested depths of water. Locations of suitable recharge structures have also been identified so that, the ground water resources could be utilized in a sustainable way (Figure 2). A ground water information system for the country has been developed using this database and is available online on ISRO’s Bhuvan geoportal.

3.4. Towards Achieving Energy security

It is necessary to explore and exploit the renewable resources to reduce the dependency on fossil fuels for energy. Evaluating the potential of solar, hydro, wave, geothermal and wind energy sources for their increased utilization in the national energy mix is the primary step towards this where space based inputs are used. In 2016 renewable energy sources contributed 39 GW of installed capacity (IEA, 2016) (13% of the total), mainly

by wind (65%), solar (13%) and biomass (12%). The renewable installed capacity showed an increase of 23% during 2014 to 2015 where the installed capacity from solar energy showed nearly 85% increase during this period. This analysis shows that, though the fossil fuels contribute a major share of energy needs, there is focus towards enhanced utilization of renewable energy.

Instantaneous solar insolation is computed using spectrally integrated radiative transfer scheme and three-layer cloudy-sky model using satellite derived inputs such as cloud-top albedo, temperature, atmospheric water vapour, aerosol and ozone (Vyas et al., 2016), as input for solar energy harvesting. The estimates show that India receives assured annual global insolation up to 2500 KWhm–2, with majority of Indian landmass receiving annual solar energy above 1750 kWh/m2. Spaceborne scatterometer data-based wind energy potential and altimeter-data based wave energy potential have also been estimated, over the Indian seas. These inputs could be utilized for enhanced renewable energy utilization. Mobile Application has been developed for estimating location based solar energy potential, and model based wind energy potential, over India. 48-hour forecast of solar energy, is generated at every 15 minutes, which can be used as input for planning the energy grid operations.

3.5. Contributing for Environment and Health Security

Sustainable development also demands preserving the environment and ecosystem with respect to quality of air; water and soil, biodiversity, forest / mangrove cover, coastline status, wetlands etc. Space borne data helps to discriminate the forest cover based on the crown density into multiple classes such as very dense (>70% crown cover density), moderately dense (70-40%) and open forest (40-10% crown density). The programme initiated by ISRO for assessing the forest cover using space technology has been internalized by the Forest Survey of India, the agency responsible for assessing the status of Forests in the country. Now, national level, biennial forest cover assessment is done for periodic evaluation of the forest cover. Further, ISRO has operationalized an automated methodology for detection of forest cover loss, using temporal integration of image pixels representing forested areas.

ISRO uses space data for mapping turbidity of water, salinity of soils, soil moisture, biodiversity, wetland spread and dynamics, coastal erosion status, coral reef morphology etc., which provide input towards decision making for ensuring environmental security. Air quality assessment using INSAT-3D/3DR data, based on aerosol optical depth, is also carried out, for monitoring purpose.

Access to quality medical consultation is enabled to people living in in-accessible and remote region using the tele-medicine concept. It connects the hospitals in the remote / rural regions and Mobile Units using Indian satellites to major specialty hospitals in cities and towns through customised medical software & hardware, and diagnostic instruments, connected to VSATs. Presently, around 130 Telemedicine nodes are operational across the country. Using output from weather forecast models and information on locations of waterbodies, land cover etc., forewarning on outbreak of vector borne diseases is also generated, for appropriate prior management measures.

3.6. Providing Information on Weather / Atmospheric parameters towards sustainable development

Information on atmospheric parameters has relevance in providing inputs for agro-meteorological models and services towards enhancing the food production. Measured atmospheric parameters form input to weather forecast models, for appropriate decision making on crop planning and also for disaster management with respect to extreme weather events. The measurement of weather parameters and keeping its records over long period of time is critical to understand the climate pattern and changes. ISRO’s Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) derives products from Atmospheric and Weather satellites’ data. Nearly 30 products are generated every 15 minutes using the INSAT-3D & 3DR data. These products include short range forecast of temperature, relative humidity, cloud, wind and rain, now-casting of heavy rain and heatwave condition, sowing suitability for rice transplantation etc. The data from the atmospheric observation satellites also flow to the national meteorological organization for weather related advisories.

3.7. Monitoring of Climate Change induced impacts

The impact of climate change gets reflected in the form of extreme weather events (storms, cloudbursts, flood etc.), increase in sea surface temperature, recession of glaciers and decrease in permanent snow cover, fragmentation and reduction of polar ice, sea-level rise etc. ISRO formulated the National Information System for Climate and Environment Studies (NICES) with the mandate to build an information base for climate change impact assessment and mitigation (http://www.nrsc.gov.in/nices) by generating spatial & temporal blended Essential Climate Variable (ECV) products using space and in situ observations. About 52 climate/environment related variables across terrestrial, ocean, atmosphere and cryosphere domains have been generated and are available from the NICES geoportal. These include 13 ECVs also.

3.8. Disaster Management Support

ISRO's Decision Support Centre for Disaster Management addresses major natural disasters like flood, landslide, earthquake, forest fire, cyclone and agricultural drought, through early warning; hazard evaluation; (cyclone) track and landfall prediction; near-real time alerts; status updates and damage assessment, for enabling to move towards disaster resilience. It operates 24X7 providing timely input to the stake holders of disaster management in the country.

The flood situation in the flood prone regions of the country is monitored during the flood season through Optical and Microwave remote sensing data. Spatial flood early warning has been implemented in Godawari, Mahanadi, Brahmaputra and Barak valleys (covering 33 districts of Assam), using inputs such as forecast rainfall, flood inundation simulation using digital elevation from laser terrain mapping or spaceborne stereo data, modelled runoff and real time discharge data. The flood early warning system (FLEWS) in Assam has given an average year to year alert success score of 75% with alert lead time of 24 to 36 hours, since initiation.

Cyclogenesis (one to five days in advance), real time cyclone tracking and land fall prediction using Lagrangian Advection Track Prediction Model have been implemented as web based service; called Satellite based Cyclone Observations and Real-time Prediction over the Indian Ocean (SCORPIO), for timely evacuation in case of tropical cyclones. This had helped timely evacuation and saving precious lives during cyclone PHAILIN (2013), cyclone HUDHUD (2014) and cyclone VARDAH (2016, figure 3).

Using thermal data from spaceborne sensors, forest fire alerts are generated six times daily and are disseminated to the Forest Department officials for ground validation and management measures. Landslide susceptibility assessment, automated landslide inventory from remote sensing data and early warning for rainfall induced landslides are also implemented in ISRO's Bhuvan Geoportal.

Agricultural drought assessment is done based on satellite data derived indices such as Wetness, Vegetation, Soil Moisture and Shortwave Angle Slope (indicating surface moisture dynamics) and rainfall deviation from normal values for drought mitigation measures so that the agricultural production is not adversely affected. All these programmes and projects provide valuable input in disaster management towards evolving resilience and sustainable development.

4. Global Earth Observation Initiatives for Sustainable Development

Globally, the space faring nations have successfully demonstrated effective utilization of space based inputs for sustainable development in many aspects and have made collaborative efforts to achieve this. Global products on land cover, atmospheric chemistry, soil moisture, ocean salinity, etc. are generated by multiple space agencies under different programmes and are available for use in research or application programmes.

The intergovernmental organization called Group on Earth Observations (GEO) was set up in 2005 which envisions a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations. GEO facilitates the development of solutions to societal challenges by mobilizing resources including observations, science, modelling and applications, to enable end-to-end systems, in partnership with Global organizations like WMO, FAO etc. GEO's mission consists of establishing a Global Earth Observation System of Systems (GEOSS) as set of coordinated Earth observation, information and processing systems by facilitating the sharing of Space and ground data and processing tools for sustainable development, climate change impact reduction and disaster resilience (Source: Geo Strategic Plan 2016-2025-Implementing GEOSS).

5. Depending Outer Space for sustainability on Earth

Enhanced capabilities in accessing outer space, technological advances and innovative thinking enabled scientists and entrepreneurs to explore the possibility to utilize space as an alternate source for resource and to develop business out of it. If this becomes a reality in a cost-effective manner, it will be one of the major achievements of humanity towards sustainable development. In terms of resources, mining near-earth asteroids that are rich sources of Nickel, Iron, Semiconductor elements, Platinum Group metals etc. is one of the possibilities being explored. Similarly, extracting and bringing Helium-3 from Moon is another idea which is relevant to energy security, for fusion based power generation, without producing radioactive waste. Extracting lunar water to generate liquid oxygen and hydrogen as space craft fuel is also an innovative idea that is being pursued by entrepreneurs. This can provide service to customers for launching inter-planetary and asteroid hunting missions from Lunar launch base.

Space based solar power generation is an idea which is being explored, and if successful, it will be a long-term solution for the ever-increasing energy requirements on Earth. The other dimension is about colonization of outer space, as a novel approach for sustainability of life on earth, such that, chance for survivability of the

human species will be more, in the worst case scenario of mass extinction on Earth. Space entrepreneurs dream of making humans a multi-planetary species.

6. Conclusion

Space and space based observations offer wide range of input to support sustainable development. Space based observations on status of natural resources, and environment for informed decision making towards ensuring food, water, energy, environment and health security is the prime benefit of space input for sustainable development. Global space agencies as well as ISRO have implemented operational plans to capitalize on this aspect. Monitoring of weather and atmospheric parameters, climate change induced impacts and disaster management support are further aspects where space technology is being used for sustainable development. These help the present generation in judiciously utilizing the natural capital and making it available for future generations, while being resilient to natural disasters and diseases. Finally, outer space itself offers solutions which might become commercially viable, positively in about 5 decades or beyond, to address energy security and survivability threat on Earth.

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