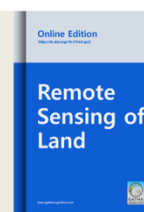




Remote Sensing of Land

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Review Article



Remote Sensing Satellites for Land Applications: A Review

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Abstract

Satellite remote sensing offers a unique opportunity in deriving various components of land information by integrating with ground based observation. Currently several remote sensing satellites are providing multispectral, hyperspectral and microwave data to cater the need of various land applications. Several old age remote sensing satellites have been updated with new generation satellites offering high spatial, spectral and temporal resolution. Microwave remote sensing data is now available with high spatial resolution and providing land information in cloudy weather condition that strengthening availability of remote sensing data in all days. Spatial resolution has significantly improved over the decades and temporal resolution has improved from months to daily. Indian Remote Sensing programs are providing state of the art satellite data in optical and microwave wavelength regions to meet large land applications in the country. Today several remote sensing data is available as open data sources. Upcoming satellite remote sensing data will help in precise characterization and quantification of land resources to support in sustainable land development planning to meet future challenges.

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1 INTRODUCTION

Remote sensing infers the surface parameters using measurements of emitted or reflected electromagnetic radiation from the Earth surface. Remote sensing satellites offer unique opportunity in collecting land information with wide details. Land applications broadly comprises of natural and man-made features such as soil, terrain, geology, geomorphology, land use / land cover, vegetation cover, water surface and urban sprawl, etc. of the earth surface (Bhagat, 2012). Remote sensing satellites offer variety of data comprising spatial, temporal and spectral resolutions facilitate scholars and planners for characterization, mapping and temporal monitoring at various scales ranging from reconnaissance to detail scale to meet the user requirement. They provide synoptic view and visit the land surface on regular time period enabling us to better understand about land surface and allow scientists for its precise characterization in systematic manner. They provide both the synoptic view of earth surface from

space in cost effective, in less time and economic manner (Landgrebe, 1999). Remotely sensed data in last 10-15 years have revolutionized the land applications in large extent by integrating multi-spectral or hyperspectral, high spatiotemporal resolution features (Jin et al., 2018).

The first remote sensing satellite was launched on July 23, 1972 named as Earth Resource Technology Satellites (ERTS) and later named as Landsat-1 was widely used for deriving land information. Thereafter, seven satellites in Landsat series were successfully launched over the period of time and made the important source of multi-temporal optical remote sensing data for land surface analysis. Landsat missions provided earth observation data as largest depositories to end-users for change detection analysis of natural and anthropogenic objects at local, regional and global scales. India launched its first remote sensing satellites as IRS [Indian Remote Sensing Satellite] 1A in March, 1982 and

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continued as IRS series and new generation satellite series of Resourcesat for varied land applications in the country. Wide range of spatiotemporal, radiometric and spectral resolution data has made it one of the best sources of data for land applications (Atoche *et al.*, 2011).

Currently several satellites such as Sentinel-2, Landsat 8, RapidEye, World View-2 and 3, SPOT-6 and 7, GeoEye-1, etc. are immensely contributing in generating reliable and precise land information at large scale for their operational use by various user agencies. In India, remote sensing data is widely being used for various operational projects, such as crop inventory and crop yield estimation, forest types and cover mapping, mapping and monitoring of water resources, soil resource mapping, waste land mapping, land degradation mapping, coastal mapping, geological and geomorphological mapping, monitoring watershed development planning, urban planning, disaster management support, environmental applications, etc. High spatiotemporal satellite data is supportive for initiatives in agronomy, forestry, land use, crop insurance, urban planning and real time disaster management, etc. Thus, this data is useful to establish sustainability goals and selection of strategies for sustainable land management and monitoring the degraded lands (Bhagat, 2012).

In coming years, remote sensing satellites will support wide variety of geospatial land applications for sustainable development of the region. Several remote sensing satellites are planned to be launched in the world and in India to cater wide variety of need for environmental monitoring and effective utilization of land resources to cope up with increasing food demands and keeping the environment in sustainable manner. The present paper provides a brief review of current and future remote sensing satellites.

2 REMOTE SENSING SATELLITES

2.1 Optical Remote Sensing

Multi-spectral optical remote sensing sensors are providing earth observation with spatial resolution ranging from coarse (500-1000m) to fine (1-2m) resolution. High resolution data with 5-15 spectral bands (visible and infrared wavelength regions) has improved in generating information manifold and enhanced the capability for wide applications for land assessment and monitoring meeting requirement from regional to field scale. Panchromatic sensor provides very high resolution data (<1m) that helps in providing large details of land surfaces in single visible spectral band and being widely used for extracting information at very detail scale and implementing plans at local level. In recent years, it has been used in generating information at cadastral level (1:4000 scale) and for urban planning at large. Panchromatic stereo data is being used to generate high resolution digital elevation model (DEM). Brief details with salient features of Indian and other

remote sensing satellite with multispectral and panchromatic sensors are given in Table 1.

India launched state of art multispectral high resolution remote sensing satellite, Resourcesat-2A in 2016 and Cartosat-2E with very high resolution panchromatic sensor in 2019. The multispectral sensors offers spatial resolution ranges from 5.8 to 56m whereas panchromatic sensor provides data of <1m resolution. WorldView-3 satellite gives 31cm PAN, 1.24m MS and 3.7m SWIR resolution data every day. SPOT-7 provided 1.5m PAN and 6m multispectral data on daily revisit. Sentinel 2A and 2B provide 10 multispectral bands with spatial resolution of 10-20m and 5 days revisit for land applications. Availability of different spatial resolution RS data are facilitating inventory of land resources from large scale to small scale to cater need of various users (Table 2). High spatial resolution RS data is used for mapping at detailed scale for preparing land resource plan at field level whereas coarse resolution data is useful for land resource inventories as exploratory survey at state and country level. Landsat series, ASTER, Sentinel-2 and 2A, MODIS and AVHRR satellites provide 20 to 1000m spatial resolution data in multispectral bands as “open source” which is freely available for wide land applications to various users. ESA also provide open access high temporal multispectral RS data of Sentinel-1 and 2 which are more popular to users (Drusch *et al.*, 2012). Gaofen-1 and 2 (GF-1 and 2) are Chinese satellites provide PAN data at 2m and MS at 8-16m resolutions. Ziyuan-3 (ZY-3) with 2.1m resolution PAN and 5.8m resolution MS sensors is being used for land resource survey in China (Lin *et al.*, 2013). MS RS is useful to discriminate the different natural and man-made features on the surface of the Earth (Smith, 2001; Ustin, 2004; Govender *et al.*, 2006). US Digital Globe satellite systems are the world-leading providers of high resolution multispectral satellite data of 30cm spatial resolution from WorldView-3. Member agencies of the Committee on Earth Observation Satellites (CEOS) are planning more than 300 different remote sensing satellites for monitoring and observations of land, atmosphere and ocean in the coming years (CEOS, 2018).

2.2 Microwave Remote Sensing

Microwave Remote Sensing satellites provide better observation capabilities as they are not influenced by the weather condition. Microwaves (MWs) can penetrate through clouds and operate day-night in all-weather condition to provide valuable information of land surface. Space-borne microwave remote sensing includes active and passive sensors to record land observation to provide vital information on soil moisture, vegetation cover, crop inventory, crop yield, biomass, flood inundation, water logged surface geomorphology, topography and geology, etc. Microwaves can penetrate into upper layer of soils and measure the below surface soil contents (Bhagat, 2014).

Table 1. Remote sensing satellites with panchromatic and multispectral sensors

Satellite	Country (Year)	Sensors	Spatial resolution (m)	Revisit time (days)	Remarks
Resourcesat-2	India (2011)	4 MS - LISS IV	5.8	5	-
		4 MS - LISS III	23.5	5	
		3 MS - AWiFS	56	5	
Resourcesat-2A	India (2017)	4 MS - LISS IV	5.8	5	-
		4 MS - LISS III	23.5	5	
		3 MS - AWiFS	56	5	
Resourcesat-3* series	India (2020-2021)	5 MS	10/20	5	
Cartosat-1	India (2005)	PAN	2.5	5	Stereo
Cartosat-2A	India (2008)	PAN	<1	4	-
Cartosat-2B	India (2010)	PAN	<1	4	
Cartosat-2 series (2C,2D,2E &2F)	India (2017 and 2018)	PAN	<1	4	
Cartosat-3A*	India (2020-21)	1 PAN	0.25	Daily	Continuous
		4 MS	0.50		
		MIR	5		
		VNIR & SWIR	30		
GISAT / GeoHR	India (2020-21)	6 VNIR	50	Daily 30 minutes	
IKONOS	USA (2000)	PAN	0.8	3-5	Stereo
		MS (4)	4	3-5	
Landsat-8	USA (2013)	OLI (8)	30	16	
		TIRS (2)	100		
		PAN	15		
SPOT-7	France (2014)	PAN	2.5	1-5	Stereo
		MS (3)	10/20		
Rapid Eye	Germany (2008)	MS (5)	6.5	1-5.5	
WorldView-3	USA (2014)	PAN	0.3	1-4.5	-
		MS (8)	1.2		
		MS SWIR (8)	3.7		
Planet Labs	USA (2014)	PAN	3	-	-
		MS (3)	5		
GeoEye-1	USA (2008)	PAN	0.46	3	
		MS (4)	1.84		
Sentinel 2A & 2B	EU (2015)	MS-VNIR (4)	10	5	-
		MS-VNIR (6)	20	5	
		MS-SWIR (3)	60	5	
Terra - ASTER	US (1999)	MS (14)	15/30	4-16	
		MS-IR (2)	90	4-16	
Terra - MODIS	US (1999)	MS-HIS (36)	250, 500 & 1000	Twice daily	-
Landsat-9*	US (2023)	OLI (8)	30	16	-
		TIRS (2)	100		
		PAN	15		
HyspIRI*	US (2020)	8 (IR)	60	5	

*Remote sensing satellites to be launched.

Table 2. Land resource mapping scale and remote sensing data

Mapping scale	Thematic mapping scale	Standard scale	Spatial resolution of remote sensing data (meter)	Remote sensing data	User's applications
Intensive (Very detailed)	1:10,000 to 1:5,000 or more	1:5000	Very fine resolution (< 5)	Cartosat-1 and 2; IKONOS; Worldview	Village level, farm level
Detailed	1:10,000 to 1:25,000	1:25000	Fine resolution (5- 10)	Resourcesat LISS IV 1&2; Quickbird; Worldview	Sub-district, block level
Semi-detailed	1:25,000 to 1:100,000	1:50000	Medium resolution (10-50)	Resourcesat - LISS II and III; LANDSAT; Aster; Spot	District level
Reconnaissance	1:100,000 to 1:500,000	1:250,000	Coarse resolution 50-100	Resourcesat- AWiFS;	State level
Exploratory	1:1000,000	-	Very coarse (>100)	MODIS; AVHRR	Country level

SMMR on Nimbus-7, SSM/I on DMSP, TRMM-TMI), AMSR-E on Aqua, SMOS mission by ESA, NASA-HYDROS mission and SMAP mission are major passive microwave radiometers (Wang and Qu, 2009). European SM and Ocean Salinity (SMOS) mission is first satellite (2009) with L-band (1.4 GHz) dual-polarized multi angular observations gives data for every three days at global scale with 50m resolution (Zhao *et al.*, 2014). The low frequency microwaves penetrate more into the canopy therefore low frequencies (<15 GHz) are more suitable for SM retrievals (Zhao *et al.*, 2014) and high frequencies (37 GHz) for vegetation studies (Wigneron, *et al.*, 2003; Wen *et al.*, 2006).

Active microwave sensor like SAR transmits MWs around 1 GHz-10 GHz to illuminate the land surface and measures the backscattered radiation from the object on the land surface to generate images at high spatial resolutions (10-100m). Active microwave remote sensing includes data in wavelength region of X-band (2.4-3.75cm), C-band (3.75-7.5cm), S-band (7.5-15cm), L-band (15-30cm), and P-band (30-100cm) and provides data in high spatial resolution (Solberg, 2012). X-band is useful for military purposes, terrain mapping and surveillance. Penetration capability of C-band is limited and restricted to the top layers whereas L-band penetrates into soil, vegetation (Jin *et al.*, 2018). P-band (30-100 cm) not used much and being used for research and experimental applications. Passive microwave sensors such as radiometer measures emitted microwave energy from 19 to 200GHz. Emissivity are directly related to brightness temperatures (Tb) and used to estimate soil moisture but at coarse spatial resolution (Bhagat, 2014).

SAR satellites acquires images in dual mode: 1) like-polarization and 2) cross-polarization (HH and HV; or VV and VH). The quad polarization mode gives four linear polarizations: HH, VV, HV, and VH as amplitude and phase (Onojeghuo *et al.*, 2018). In contrast to optical satellite images, synthetic aperture radars (SARs) can penetrate into the crop / vegetation canopies and soil

surface and be used to generate sub-canopy and sub-surface information. Several researchers have showed the application of SAR data for analysis of crop canopy and soil properties at regional level (Kim *et al.*, 2012; Wiseman *et al.*, 2014). Today, several microwave remote sensing satellites namely IRS-RISAT, ENVISAT, Sentinel-1A and 1B, ALOS, ALOS-2, RADARSAT-2, TERRASAR-X, etc. are providing precise and valuable information for major land applications such as soil moisture estimation, kharif crop inventory and monitoring, multi-crop discrimination and mapping, crop bio-physical characterization, forest vegetation biomass estimation, snow cover area and glacial characterization, sea and coastal land characterization and monitoring (Bhagat, 2017; Singh *et al.*, 2011; Srivastava *et al.*, 2008). Passive space-borne sensors like AMSR-E, ASCAT, SMOS, SMAP and ESA-CCI are currently being used largely for providing global soil moisture products at very coarse spatial resolution to user community for various land applications (Ray *et al.*, 2017; Peng and Loew, 2017). Global Precipitation Measurement Mission (GPM, launched in 2014) is follow-on of TRMM satellite in another satellite with passive radiometer sensor. Currently available major SAR satellites are described in Table 3.

2.3 Hyperspectral Remote Sensing

'Hyperspectral Remote sensing satellites acquire very narrow, contiguous spectral bands throughout the visible, near-infrared, mid-infrared, and thermal infrared portions of the electromagnetic spectrum' (ELwesemy, *et al.*, 2016; Filchev, 2014). The hyperspectral sensing is based on beam splitting and the bands as a line sensor (Toth and Józków, 2016). Hyperspectral sensors collect spatial data using more than 50 narrow spectral bands based on continuous reflectance from each pixel in the image facilitate in-depth study of land surface elements. Intensive image pre-processing including corrections for atmospheric, radiometric and spatial distortions, data normalizations and quantitative analysis require for effective use of this data for quantitative estimates of

Table 3. Microwave remote sensing satellites

Satellite	Country (Year)	Sensors	Spatial resolution (m)	Revisit time (days)
RISAT-1	India (2012)	C-band SAR	1-50	
RISAT-1A/1B*	India (2019-20)	C-band SAR	1-50	
ALOS-2	Japan (2014)	L-Band SAR	3	24
EnviSat	EU (2002)	C-band SAR	28/50/950	35
Sentinel-1A&1B	EU (2014/2016)	C-band SAR	5/25	12
RADARSAT-2	Canada (2007)	C-band SAR	3/100	24
RADARSAT-3*	Canada (2019)	C-band SAR	3/100	24
Terra-SAR-2	Germany (2007)	X-band SAR	1/16	11
TenDEM-X	Germany (2010)	X-band SAR	1/3	11
HJ-1C	China (2006)	C-band SAR	5/20	4
KOMPSAT-5	South Korea (2013)	C-band SAR	1/20	28
NISAR*	India (2021)	L-Band SAR S-Band SAR	3-10	12
LIDAR				
ICESat-2 (Lidar)	US (2003)	2 HSI	70	-
ICESat-1 (Lidar)	US (2018)	1 HIS	10	-

*Remote sensing satellites to be launched.

biophysical and chemical properties of land surface features (Goodenough *et al.*, 2006). Hyperspectral images have found many applications in vegetation, agriculture, soil, geology, water resource and environmental monitoring (Smith, 2001). It provides ample opportunity to study biophysical and biochemical parameters of crop and vegetation (Clark and Roberts, 2012). Several studies have used hyperspectral vegetation indices for analysis of characteristics of vegetation and crops (Pan *et al.*, 2015), soil type and their mineralogical and chemical compositions (Ninomiya *et al.*, 2005; Mahoney *et al.*, 2002; Gosh *et al.*, 2012). The Hyperion data is useful for assessments of salt-affected soils for sustainable land management at regional level (Kumar *et al.*, 2014). Hyperion-1 remote sensing satellites provided large number of hyperspectral data and have been worldwide used for various land applications. Realizing its great potential in quantification of land surface features, several new hyperspectral RS satellites are planned by various agencies in coming years. A brief detail of existing and planned space-borne hyperspectral satellite is given in the Table 4. Relatively voluminous data, higher costs for data storage and pre-processing, requires skilled human resource, etc. are major constraints for applications of this technology (Filchev, 2014). Coarse spatial resolution (30m) is major drawback of majority hyperspectral sensors (Hyperion, PRISMA, HISUI, EnMAP and HypIRI) overcome by high resolution (10 and 8m) sensors like SHALOM and HypXIM for detection and analysis of complex biophysical environmental aspects (Transon *et al.*, 2018). High resolution panchromatic sensors of SHALOM, PRISMA and HypXIM could be helpful to improve the applicability of hyperspectral data (Transon *et al.*, 2018). SHALOM provides high quality data on direct demand of end user (Feingersh, 2015).

2.4 LiDAR

LiDAR [Light Detection and Ranging] is active remote imaging system and uses a very narrow band of electromagnetic spectrums. Satellite laser systems are primarily used to measure height of the target and land surface, ice sheet elevations, sea ice thickness, measurement of cloud and aerosol content of the atmosphere or high biomass vegetation assessment (Rosette *et al.*, 2010). GLAS-LiDAR sensor was on the ICES Satellite (January, 2003) and its data is available for all, freely (Haji *et al.*, 2017). CALIPSO is another space-borne LiDAR of ESA's Aeolus Mission with the Atmospheric Doppler LiDAR (ALADIN) aboard in April 2006.

2.5 Sensing from UAV Platforms

Recent progress of mini unmanned airborne vehicles (UAVs) emerged as most promising high resolution remote sensing imagery for land applications. The technology is already miniaturized electronics for sophisticated personal use and these sensors are facilitating in the development of small UAVs. UAVs are typically used for data collection in the forms of video and images (Patterson and Brescia, 2010). The imaging payloads are approximately 300g for 1kg micro UAVs and about 5kg for 25-30 kg UAVs (Nebiker *et al.*, 2008). The sensors are available in visible, multispectral, thermal infrared and microwave regions (Bhardwaj *et al.*, 2015). These widely used remote sensing UAV sensors are inexpensive versions of lightweight optical cameras. UAV cameras with thermal range (8µm to 12µm) are useful to collect land surface data with ability of discrimination in temperature variations.

Table 4. Hyperspectral remote sensing satellites

Satellite	Country (Year)	Spectral bands	Spatial resolution (m)	Revisit time (days)	Data access
HySI on IMS-1	India (2018)	64	550	-	Constrained access
GISAT / GeoHR*	India (2020-21)	60 VNIR	320		
		150 SWIR	192		
		6 LWIR	1500		
Hyperion (EO-1)	US (2000)	220	30	16-30	Open access
HJ-1A/B	China (2008)	128	100	4	Constrained access
HyspIRI*	US (2020)	214	60	5-16	For Italy only
EnMAP-1	Germany (2017)	244	30	4	
EnMAP-1*	Germany (2020)	244	30	4	
PRISMA*	Italy (2019)	249	30	7-14	
ALOS-3*	Japan (2019)	57 (SWIR)	30	35	
		128 (SWIR)			
HISUI*	Japan (2019)	185	30	2-60	-
PROBA-1/2/V	Belgium (2001, 2009 and 2013)	15 (VIS)	100-300	1-2	
		4 (NIR)			
HypXIM	France (2011)	210	8	3-5	-
TianGong-1	China	128	10 (VNIR) 20 (SWIR)		
SHALOM	Italy-Israel (2017)	275	10	4	

*Remote sensing satellites to be launched.

Several manufacturers have started fabricating and testing hyperspectral sensors for UAVs to collect the data in visible and NIR (0.3 μ m to 1.0 μ m) bands. They are small enough to install on small size UAVs. Brigham Young University (David Young at BYU), Utah, developed a lightweight micro-SAR sensor in collaboration with the University of Colorado (USA) to provide data at high spatiotemporal resolutions for real time applications (Jin *et al.*, 2018). LiDAR sensors like 1) Ultra-lightweight Velodyne VLP-16 and 2) Powerful Riegl VUX-1 (Starek and Jung, 2015) and hyperspectral sensors like Rikola hyperspectral camera (Marcucci *et al.*, 2014) have been introduced recently and more sensors systems are going to develop in coming years (Toth and Józków, 2016). UAVs are establishing as very promising tool for crop biophysical and nutrients mapping for crop management, crop disease and insect damage assessment and monitoring, mineral identification and mapping, disaster monitoring and forest fire monitoring due to its low operational cost, high temporal and spatial resolutions, user friendly operation, on-demand access to data, etc. (Matese *et al.*, 2015; Yang *et al.*, 2017). Reported constraints of technology are: 1) less capability and the strict airspace regulations for UAVs, and 2) lack of suitable methods and techniques for fast data processing and limited models for estimations and predictions of complex environmental parameters (Matese *et al.*, 2015; Yang *et al.*, 2017). This technique is more suitable for research application conducted for small region (Matese *et al.*, 2015) and still unexplored for research applications in different bio-physical environmental conditions (Bhardwaj *et al.*, 2015).

3 FUTURE PLANNED REMOTE SENSING SATELLITES

In recent time, advances in microprocessors and electronics have resulted in a significant increase in remote sensing satellite capability in terms of high spatial, spectral and temporal resolutions. These satellites will be providing immense data as input for various operational and research projects in the field of cartography, defense, geology, agriculture, natural resources and more. India's space agency ISRO has planned its third generation remote sensing satellite of Resourcesat-3 and 3A and Cartosat-3 series with high spatial and temporal resolution for wider land applications in coming years (planned to be launched 2019 or later). It will have a panchromatic resolution of 0.25 meters and multispectral of 1m. Resourcesat-3 and 3A are planned with 10m resolution with large coverage. India is developing Hyperspectral Imaging Satellite (HySIS) to acquire data in 55 spectral bands from 630km above ground by 2020. India in collaboration with NASA-JPL (USA) developing microwave remote sensing satellite namely NISAR that is scheduled to be launch by 2020. It will provide data in L- and S-bands with high spatial resolution data that will bring new era investigating hydrological applications, kharif crop inventory and crop yield modeling, multi-crop inventory, monitoring soil moisture and estimating high biomass vegetation cover types, etc. in the coming years. Landsat-9 (rebuild of Landsat 8) of Landsat series is a planned to launch in December, 2020 by NASA, Earth observation satellite. Landsat-10 with improved spectral bands is planned in 2027-28. Microwave remote sensing satellites 1C and 1D planned to be launched by 2021 by ESA which will insure the

continuity of ERS and Envisat C-band data. Similarly, ESA is planning to launch its multispectral remote sensing satellites Sentinel-2C and 2D by 2021 to provide continuity of Sentinel series data. Canadian Earth Observation Company, UrtheCast's has proposed constellation of sixteen OptiSAR Satellites (8 tandem pairs with 2 orbital planes) and eight optical satellites by end of 2020. It will provide multispectral data (4 band) at 5m in addition to having a 1m resolution X-band and 5m resolution in L-band SAR.

High-definition video from space

Now the novel capability of earth observation is being offered as full-motion video. It is one of the most exciting opportunities being offered from RS satellites to observe land processes and utilize temporal insight in observing earth surface processes. Google's TerraBella provides high spatial (approximately 1m) and temporal (30 fps - frames per second) full-motion video imagery (Murthy *et al.*, 2014; McCabe *et al.*, 2017). UrtheCast will also providing HD video with spatial (1m). IRIS satellite is planned to provide 1m full-color video from space of ~60 seconds long. These data will be quite useful in understanding land surface processes of ecosystem functioning as well as monitoring of disaster and response in great details. These are providing video limited (60 and 90s captures) (McCabe *et al.*, 2017) but the technology can be expanded for full-coverage with real-time observation in low Earth orbit satellite configurations (Han *et al.*, 2015). They are also looking for a geostationary space surveillance system in future (Villien *et al.*, 2014; McCabe *et al.*, 2017). There are several satellites (Optical, hyperspectral and microwave) have been planned in coming years by various space agency. A brief list of these satellites with salient characteristics is given in Table 3 and 4.

4 CONCLUSIONS

Application of remote sensing satellites for mapping, characterization and monitoring land resources has been advanced from small scale to large scale to cater need of various user segments. It has been proven very useful for a range of applications of land use / land cover mapping, terrain mapping, vegetation cover, soil resource, land degradation, watershed planning, wetland mapping, flooding, water resources, urban planning, etc. A large number of small satellites constellations expected to be launched in near future with improved sensors to acquire earth observation satellite data in multispectral, high spatiotemporal resolution data with novel capabilities such as full-motion video. NASA and European Space Agency (ESA) are also looking for small satellite technology with a view to reducing the cost. Indian Space Agency is also planning to have constellation of small satellites (300-500kg) with high resolution cameras and innovative features in the near future for the ISRO's own remote-sensing users. There will be huge challenge to users for its effective utilization for land resource characterization and understanding various land processes to meet the challenge of near future. Future of remote sensing satellite for land application is exciting in executing

operational projects and field level and monitoring of land resources in very effective manner.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

ALADIN: Atmospheric Laser Doppler Instrument; **AMSR-E:** Advanced Microwave Scanning Radiometer-EOS; **ASTER:** Advanced Space-borne Thermal Emission and Reflection Radiometer; **AWiFS:** Advance Wide Field Sensor; **CALIPSO:** Cloud Aerosol Lidar and Infrared Pathfinder Observations; **CEOS:** Committee on Earth Observation Satellites; **DEM3D:** digital elevation model; **DMSP:** Defence Meteorological Satellite Program; **EnMAP:** Environmental Monitoring and Analysis Program; **ERTS:** Earth Resource Technology Satellites; **ESA:** European Space Agency; **GF:** Gaofen; **GLAS:** Geoscience Laser Altimeter System; **HD:** High Definition; **HIS:** Hyperspectral Imager; **MS:** Multispectral; **HyspIRI:** Hyperspectral Infrared Imager; **LISS:** Linear Imaging Self Scanner; **MS:** Multispectral; **MW:** Microwaves; **NASA-HYDROS:** NASA Hydrospheric States; **NASA-JPL:** NASA's Jet Propulsion Laboratory; **NIR:** Near Infra-Red; **NISAR:** NASA-ISRO Synthetic Aperture Radar; **OLI:** Operational Land Imager; **PAN:** Panchromatic; **PRISMA:** PRecursor IperSpettrale della Missione Applicativa; **SAR:** Synthetic Aperture Radar; **SHALOM:** Spaceborne Hyperspectral Applicative Land and Ocean Mission; **SMAP:** SM Active and Passive; **SMMR:** Scanning Multichannel Microwave Radiometer; **SMOS:** European SM and Ocean Salinity; **SMOS:** SM and ocean salinity; **SPOT:** Satellite Probatoire de l'Observation de la Terre; **SSM/I:** Special Sensor Microwave/Imager (SSM/I); **SWIR:** Short Wave Infra-Red; **TIRS:** Thermal Infrared Sensor; **TRMM-TMI:** Tropical Rainfall Measuring Mission Microwave Imager; **UAV:** Unmanned Airborne Vehicles; **VNIR:** Visible Near Infra-Red.

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REFERENCES

- Atoche, A. C., Lopez, J. E., Muñoz, P. P. and Aguilar, S. S., 2011. High-speed VLSI architecture based on massively parallel processor arrays for real-time remote sensing applications. *Applications of Digital Signal Processing*, 133-151. DOI: <https://doi.org/10.5772/26496>
- Bhagat, V. S., 2012. Use of remote sensing techniques for robust digital change detection of land: A review. *Recent Patents on Space Technology*, 2, 123-144. DOI: <https://doi.org/10.2174/1877611611202020123>
- Bhagat, V. S., 2014. Space-borne passive microwave remote sensing of soil moisture: A review. *Recent Progress in Space Technology*, 4, 119-150. DOI: <https://doi.org/10.2174/221068710402150513123146>
- Bhagat, V. S., 2017. Space-borne Active microwave remote sensing of soil moisture: A review. *Remote Sensing of*

- Land, 1(1), 53-86. DOI: <https://doi.org/10.21523/gcj1.17010104>
- Bhardwa, A., Sam, L., Akanksha, Martín-Torres, F. J. and Kumar, R., 2015. UAVs as remote sensing platform in glaciology: Present applications and future prospects. *Remote Sensing of Environment*, 175, 196-204. DOI: <https://doi.org/10.1016/j.rse.2015.12.029>
- CEOS, 2018. EO handbook: Satellite earth observations in support of the sustainable development goals. *European Space Agency*.
- Clark, M. L. and Roberts, D. A., 2012. Species-level differences in hyperspectral metrics among tropical rainforest trees as determined by a tree-based classifier. *Remote Sens.* 4, 1820-1855. DOI: <https://doi.org/10.3390/rs4061820>
- Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., Hoersch, B., Isola, C., Laberinti, P., Martimort, P., Meygret, A., Spoto, F., Sy, O., Marchese, F. and Bargellini, P., 2012. Sentinel-2: ESA's optical high-resolution mission for GMES operational services. *Remote Sens. Environ.*, 120, 25-36. DOI: <https://doi.org/10.1016/j.rse.2011.11.026>
- ELwesemy, A. E., Abdelghany, N. A., Abohadid, A. F. and Aboelghar, M. A., 2016. Assessment of the spectral characteristics of different physiological stages of some olive cvs and its relation with productivity. *International Journal of Advanced Remote Sensing and GIS*, 5(3), 1580-1591.
- Feingersh, T. and Dor, E. B., 2015. SHALOM - A commercial hyperspectral space mission. Ed. Shen En Qian, *Optical Payloads for Space Missions*, 247-263.
- Filchev, L., 2014. Satellite hyperspectral earth observation missions - A review. *Bulgarian Academy of Sciences. Space Research and Technology Institute, Aerospace Research in Bulgaria*. 26, 191-206.
- Ghosh, R., Padmanabhan, N., Patel, K. C. and Siyolkar, R., 2012. Soil fertility parameter retrieval and mapping using hyperion data. *Investigations on Hyperspectral Remote Sensing Applications* (Ed. Panigrahy, S. and Manjunath, K. R.), Space Applications Centre (ISRO), Ahmedabad, 29-31.
- Goodenough, D., Li, J., Asner, G., Schaepman, M., Ustin, S. and Dyk, A., 2006. Combining hyperspectral remote sensing and physical modeling for applications in land ecosystems. *IEEE International Symposium on Geoscience and Remote Sensing*, 10265347. DOI: <https://doi.org/10.1109/IGARSS.2006.518>
- Govender, Chetty, M. K. and Bulcock, H., 2006. A review of hyperspectral remote sensing and its application in vegetation and water resource studies. *Water SA*, 33(2), 145-151. DOI: <http://dx.doi.org/10.4314/wsa.v33i2.49049>
- Hajj, M. E., Baghdadi, N., Fayad, I., Vieilledent, G., Bailly, J.-S. and Minh, D. H. T., 2017. Interest of integrating spaceborne lidar data to improve the estimation of biomass in high biomass forested areas. *Remote Sens.*, 9, 213. DOI: <https://doi.org/10.3390/rs9030213>
- Han, F., Zhang, Z., Wang, Z., Zhang, S., Liang, Y., and Chen, Y., 2015. Real-time earth observation system based on micro-nano networks. *Proceedings of the International Astronautical Congress, IAC*, 12-16, October 2015, Jerusalem, Israel, 3271-3278.
- Jin, X., Kumare, L., Li, Z., Feng, H., Xu, X., Yang, G. and Wang, J., 2018. A review of data assimilation of remote sensing and crop models. *European Journal of Agronomy*, 92, 141-152. DOI: <https://doi.org/10.1016/j.eja.2017.11.002>
- Kim, Y., Jackson, T., Bindlish, R., Lee, H. and Hong, S., 2012. Radar vegetation index for estimating the vegetation water content of rice and soybean. *IEEE Geosci. Remote Sens. Lett.*, 9 (4), 564-568. DOI: <https://doi.org/10.1109/LGRS.2011.2174772>
- Kumar, S., Ghosh, G. and Saha, S. K., 2014. Hyperspectral remote sensing data derived spectral indices in characterizing salt-affected soils: a case study of Indo-Gangetic plains of India. *J. Environmental Earth Sciences*, 73, 3299-3308. DOI: <https://doi.org/10.1007/s12665-014-3613-y>
- Landgreb, 1999. Information extraction principles and methods for multispectral and hyperspectral image data. *Multispectral Information Extraction Principles*, 1-30.
- Lee, J. S., Grunes, M.R. and Pottier, E., 2001. Quantitative comparison of classification capability: Fully polarimetric versus dual and single-polarization SAR. *IEEE Trans. Geosci. Remote Sens.*, 39 (11), 2343-2351. DOI: <https://doi.org/10.1109/36.964970>
- Lin, L., Luo, H., Zhu, H., Li, Z., and Tang, X. M. T., 2013. User-oriented image quality assessment of ZY-3 product in agriculture area. Second International Conference on Agro-Geoinformatics (Agro-Geoinformatics) 22-27. DOI: <https://doi.org/10.1109/Argo-Geoinformatics.2013.6621872>
- Mahoney, S., James, P., Mauger, A. and Heinson, G., 2002. Geologic and regolith mapping for mineral exploration in the Gawler Craton of South Australia using Hyperion and other remote sensing techniques. *International Geoscience and Remote Sensing Symposium (IGARSS) 02. Proceedings. 2002 IEEE International*, 1779-1781. DOI: <https://doi.org/10.1109/IGARSS.2003.1294248>
- Marcucci, E., Saitet, E. and Hatfield, M. C., 2014. A new hyperspectral designed for small UAS tested in real world applications. In: AGU Fall Meeting, 15-19, December, 2014, San Francisco, California, USA.
- Matese, A., Toscano, P., Gennaro, S. F. D., Genesio, L., Vaccari, F. P., Primicerio, J., Belli, C., Zaldei, A., Bianconi, R. and Gioli, B., 2015. Intercomparison of UAV, aircraft and satellite remote sensing platforms for precision viticulture. *Remote Sens.*, 7, 2971-2990. DOI: <https://doi.org/10.3390/rs70302971>
- McCabe, M. F., Rodell, M., Alsdorf, D. E., Miralles, D. G., Uijlenhoet, R., Wagner, W., Lucieer, A., Houborg, R., Verhoest, N. C., Franz, T. E., Shi, J., Gao, H., and Wood, E. F., 2017. The future of Earth observation in hydrology. *Hydrol. Earth Syst. Sci.*, 21, 3879-3914. DOI: <https://doi.org/10.5194/hess-21-3879-2017>
- Murthy, K., Shearn, M., Smiley, B.D., Chau, A.H., Levine, J. and Robinson, D., 2014. SkySat-1: very high-resolution imagery from a small satellite. *SPIE Remote Sensing. International Society for Optics and Photonics*, 92411E-92411E. DOI: <https://doi.org/10.1117/12.2074163>
- Nebiker, S., Annena, A., Scherrerb, M. and Oeschc, D., 2008. A light-weight multispectral sensor for micro UAV - opportunities for very high resolution airborne remote sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 37, Part- B1, 1193-1199.
- Ninomiya, Y., Fu, B. and Cudahy, T. J., 2005. Detecting lithology with advanced spaceborne thermal emission and reflection radiometer (ASTER) multispectral thermal infrared 'radiance-at-sensor' data. *Remote Sens. Environ.*, 99 (1-2), 127-139. DOI: <https://doi.org/10.1016/j.rse.2005.06.009>
- Onojeghuo, A. O., Blackburn, G. A., Huang, J. and Kindred, D., 2018. Applications of satellite 'hyper-sensing' in

- Chinese agriculture: Challenges and opportunities. *Int J. Appl. Earth Obs. Geoinformation*, 64, 62-86. DOI: <https://doi.org/10.1016/j.jag.2017.09.005>
- Pan, Z. K., Huang, J. F., Zhou, Q. B., Wang, L. M., Cheng, Y. X., Zhang, H. K., Blackburn, G. A., Yan, J. and Liu, J. H., 2015. Mapping crop phenology using NDVI time-series derived from HJ-1 A/B data. *Int. J. Appl. Earth Obs. Geoinf.*, 34, 188-197. DOI: <https://doi.org/10.1016/j.jag.2014.08.011>
- Patterson, M. C. L. and Brescia, A., 2010. Operation of small sensor payloads on tactical sized unmanned air vehicles. *The Aeronautical Journal*, 1149(1157), 427-436. DOI: <https://doi.org/10.1017/S0001924000003900>
- Peng, J. and Loew, A., 2017. Recent advances in soil moisture estimation from remote sensing. *Water*, 9, 1-5. DOI: <https://doi.org/10.3390/w9070530>
- Ray, R., Fares, A., He, Y. and Temimi, M., 2017. Evaluation and inter-comparison of satellite soil moisture products using in situ observations over Texas, U.S. *Water*, (9), 372-376. DOI: <https://doi.org/10.3390/w9060372>
- Rosette, J. A. B., North, P. R. J., Suarez, J. C. and Los, S. O., 2010. Uncertainty within satellite LiDAR estimations of vegetation and topography. *Int. J. Remote Sens.*, 31 (5), 1325-1342. DOI: <https://doi.org/10.1080/01431160903380631>
- Singh, D., Prakash, R., Pathak, N. P., Mohan, S. and Singh, K. P., 2011. SAR and optical data utilization for soil moisture retrieval in vegetated region. 2011 3rd International Asia-Pacific Conference on Synthetic Aperture Radar (AP SAR), 1-4.
- Smith, R. B., 2001. Introduction to hyperspectral imaging.
- Solberg, A. H. S., 2012. Remote sensing of ocean oil-spill pollution. *Proceedings of the IEEE*, 100(10), 2931-2945. DOI: 10.1109/JPROC.2012.2196250
- Srivastava, H. S., Patel, P., Navalgund, R. R. and Sharma, Y., 2008. Retrieval of surface roughness using multi-polarized Envisat-1 ASAR data. *Geocarto International*, 23(1), 67-77. DOI: <https://doi.org/10.1080/10106040701538157>
- Starek, M. and Jung, J., 2015. The state of LiDAR for UAS applications. *LiDAR's Next Geospatial Frontier*, UAS Special of GIM International, 25-27.
- Toth, C. and Józków, G., 2016. Remote sensing platforms and sensors: A survey. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115, 22-36. DOI: <https://doi.org/10.1016/j.isprsjprs.2015.10.004>
- Trancon, J., d'Andrimont, R., Maignard, A., and Defourny, P., 2018. Survey of hyperspectral earth observation applications from space in the Sentinel-2 context. *Remote Sensing*, 10 (157), 1-32. DOI: <https://doi.org/10.3390/rs10020157>
- Ustin, S. L., 2004. Manual of remote sensing. Remote Sensing for Natural Resource Management and Environmental Monitoring, 4, 3rd Edition, 768.
- Villien, A., Pedersen, G., Charvet, P., and Maliet, E., 2014. Geostationary observation space surveillance system (GO3S) - Real time video from space, *Proceedings of the International Astronautical Congress, IAC*, 29 September-3 October, 2014, Toronto, Canada, 2460-2464.
- Wang, L. and Qu, J. J., 2009. Satellite remote sensing applications for surface soil moisture monitoring: A review. *Frontiers of Earth Science in China*, 3(2), 237-247. DOI: <https://doi.org/10.1007/s11707-009-0023-7>
- Wen, J., Jackson, T. J., Bindlish, R. and Su, Z. B., 2006. Evaluation of the Oceansat1 multi-frequency scanning microwave radiometer and its potential for soil moisture retrieval. *Int.J. Remote. Sens.*, 27(18), 3781-3796. DOI: <https://doi.org/10.1080/01431160500075642>
- Wigneron, J.-P., Calvet, J.-C., Pellarin, T., Van de Griend, A. A., Bergerd, M. and Ferrazzoli, P., 2003. Retrieving near surface soil moisture from microwave radiometric observations: Current status and future plans. *Remote Sens. Environ.*, 85, 489-506. DOI: [https://doi.org/10.1016/S0034-4257\(03\)00051-8](https://doi.org/10.1016/S0034-4257(03)00051-8)
- Wiseman, G., McNairn, H., Homayouni, S. and Shang, J., 2014. RADARSAT-2 polarimetric SAR response to crop biomass for agricultural production monitoring. *IEEE J-STARS*, 7 (11), 4461-4471. DOI: <https://doi.org/10.1109/JSTARS.2014.2322311>
- Yang, G., Liu, J., Zhao, C., Li, Z., Huang, Y., Yu, H., Xu, B., Yang, X., Zhu, D., Zhang, X., Zhang, R., Feng, H., Zhao, H., Li, Z., Li, H. and Yang, H., 2017. Unmanned aerial vehicle remote sensing for field-based crop phenotyping: Current status and perspectives. *Front. Plant Sci.*, 8, 26. DOI: <https://doi.org/10.3389/fpls.2017.01111>
- Zhao, L., Yang, K., Qin, J. and Chen, Y., 2013. Optimal exploitation of AMSR-E signals for improving soil moisture estimation through land data assimilation. *IEEE Trans. Geosci. Remote Sens.*, 51(1), 399-410. DOI: <https://doi.org/10.1109/TGRS.2012.2198483>
- Zhao, L., Yang, K., Qin, J., Chen, Y., Tang, W., Lu, H. and Yang, Z.-L., 2014. The scale-dependence of SMOS soil moisture accuracy and its improvement through land data assimilation in the central Tibetan Plateau. *Rem. Sens. Env.*, 152, 345-355. DOI: <https://doi.org/10.1016/j.rse.2014.07.005>
- Zhu, L., Suomalainen, J., Liu, J., Hyypä, J., Kaartinen, H. and Haggren, H., 2018. A review: Remote sensing sensors. *Multi-purposeful Application of Geospatial Data*, 19-42. DOI: <https://doi.org/10.5772/intechopen.71049>
