

A review of uses of satellite imagery in monitoring mangrove forests

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Abstract: Satellite image could provide much information of earth surfaces in a large scale in a short time, thus saving time. With the evolution and development of sensors providing satellite image, resolution of object captured enhanced with advance image processing techniques. In forestry, satellite image has been widely used for resources management, planning, monitoring, predicting, etc. However, the uses of satellite image are reported to be moderate and sometimes poor for mangrove forests due to homogenous species existed in salty and inundation areas. Many researches had been carried out to improve the uses of satellite imagery of either optical or radar data for mangrove forests. This paper reviews the uses of satellite imagery data in mangrove with the main focus of the literature related to mangroves monitoring.

1. Introduction

In 1957, the world witnessed the launch of the first satellite into the orbit of the earth. Subsequently in the early 1960s, satellites associated with other purposes such as weather forecast, communication and commerce were introduced and successful launched. Since the 1970s, data acquired from these satellites have been successfully used for weather prediction, monitoring global environmental conditions, and geographical and geological applications [1]. Data captured from the satellite systems provide information on earth surfaces.

Satellite imageries are beneficial to numerous areas of work such as monitoring work as these imageries cover large areas, virtually any part of the earth, including inaccessible areas which were previously too remote or too dangerous to reach when using conventional aerial photography such as dense forest, peat swamp forest and mangrove forest. Through the usage of satellites, researchers are able to collect data unaffected by local air traffic constraints; they can analyse comparisons of land covers at different times, which is suitable for long-term studies. Research methods based on satellites are time-saving, cost-effective and enhance the possibility of classifying the vegetation through spectral and texture analyses; on the other hand, ground measurement methods are difficult, expensive, time-consuming and labour-intensive [2-6].

Previously, satellite images were expensive and the initial-stage satellite technology was used for military applications such as threat monitoring and assessment; this type of machine was known as reconnaissance satellite, for instance CORONA satellite [7]. The satellite was launched in 1960 and the operation ended in 1972 due to a leakage of confidential images on the internet; these pieces of sensitive information belonging to the United States of America (USA) were related to military



security and defence. CORONA was developed primarily for area surveillance covering the regions of the Soviet Union, China and other parts of the world. The first civilian earth satellite, Landsat was launched in 1972. Landsat 1 to Landsat 5 were successfully launched in the absence of competitors until 1986 when the first commercial satellite, SPOT was introduced. Since the launching of commercial satellites, satellite images have gradually become less expensive and the areas of applications increase. Commercial satellites such as Ikonos and QuickBird provide global, accurate and high-resolution images to individuals, organisations and governments. Satellite imaging systems can be classified into radar and optical systems. Radars provide their own energy to illuminate an area of interest and measure the reflected signals while optical systems acquire the reflected electromagnetic waves of the sunlight and/or the infrared radiation emitted by objects on the ground [8]. Optical satellites are more frequently used than radar satellites. Rapid advancement of satellite technology causes wide usages of these data. In mangrove studies, the optical satellite with medium spatial resolution is normally used. Tables 1 and 2 show the common optical and radar satellites used in mangrove researches in the past 3 decades [9-11]. Table 3 shows their years of launchings and active applications until the current year.

Satellite images are available in different spatial resolutions, from low to high. Satellite images of low-resolution with ground pixels of more than 10 m are useful for applications such as environmental assessment, mapping, forestry management, disaster assessment and urban monitoring. In contrast, images of high-resolution data with ground pixel sizes of less than 5 m provide detailed information of small objects on the earth surface such as buildings, streets, river and trees which are useful for applications such as transportation network mapping, disaster management, urban planning and farming.

Satellite images also can be used to determine the elevation and topographical features of a particular land. Also, it is useful in viewing agricultural fields where farmers are able to monitor the health of their crops. In research, researchers or scientists can study environmental changes to forecast weathers or natural disasters that may happen in the future. Meanwhile, city planners are able to plan developments of new residential areas for communities. In transportation, satellite data can be used for traffic studies and facilitate the planning of new road networks. In disaster management, satellite images can be used to plan evacuation routes during earthquakes or fire events. Lastly, in Forestry, satellite images can provide detailed information about forest status such as species distribution, stand density, forest extend, operational monitoring, and discrimination species at dryland and wetland.

Table 1. Optical satellite [10].

Sensor / System	Platform	No. of band(s)	Spectral range	Spatial resolution		
				MSS	Pan.	
High resolution sensor						
MSS (Multi Spectral sensor)	Landsat 1, 2, 3	4	B, G, R, NIR	~ 80 m		
TM (Thematic Mapper)	Landsat 5	6	B, G, R, NIR, SWIR	30 m		
ETM+ (Enhanced Thematic Mapper Plus)	Landsat 7	6	VNIR, SWIR	30 m	15 m	
HVR (High Resolution Visibility)	SPOT (Satellite Pour l'Observation de la Terre) 1, 2, 3	3	G, R, NIR	20 m	10 m	

HRVIR (High Resolution Visible and Infrared)	SPOT (Satellite Pour l'Observation de la Terre) 4	4	G, R, NIR, SWIR	20 m	10 m
HRG (High Resolution Geometrical)	SPOT (Satellite Pour l'Observation de la Terre) 5	4	G, R, NIR, SWIR	10 m (VNIR); 20 m (SWIR)	2.5 m
ASTER*	Terra	10	G, R, NIR; 6-SWIR	15 m (VNIR); 30 m (SWIR)	
IRS (Indian Remote Sensing Satellite) 1C, 1D		4	G, R, NIR, SWIR	23 m	5.8 m
ALI (Advance Land Imager)	EO-I (Earth Observing)	9	2-B, G, R, 2-NIR, 2-SWIR	30 m	15 m
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Very high resolution sensor		4	VNIR; Pan	2.4 m	0.6 m
Quickbird					
IKONOS		4	VNIR; Pan	4 m	1 m
PRISM**	ALOS (Advanced Land Observation System)	1	Pan	N/A	2.5 m
WorldView-2		8	VNIR; Pan	<2 m ***	<0.5 m ***
GeoEye-1		4	VNIR; Pan	1.65 m	0.41 m
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Other optical sensor					
GLAS (Geoscience Laser Altimeter System)	IceSAT (Ice, cloud and land elevation Satellite)	LiDAR, 2	Green (532 nm), NIR (1064 nm)	70 m footprint; 170 m spacing	
HYPERION	EO-I (Earth Observing)	Hyper-spectral: 220	400-2500 nm	30 m	

B = blue; **G** = green; **R** = red; **NIR** = near-infrared; **SWIR** = shortwave infrared; **V** = visible

*Advanced Spaceborne Thermal Emission and Reflectance Radiometer

**Panchromatic Remote-sensing Instrument for Stereo Mapping

***Maximum resolution limited by US government

Table 2. Radar satellite [10].

Sensor			Platform	Band(s)	Polarization(s)	Spatial resolution
SIR-C (Space-borne Radar)	Imaging		Space Shuttle	C, L, X	HH, HV, VV	10-200 m
ERS-1 (European Sensing Satellite)	Remote-		European Remote-Sensing Satellite	C	VV	25-100 m
JERS-1 (Japanese Resource Satellite)	Earth		Japanese Earth Resource Satellite	L	HH	25-100 m
Radarsat-1				C	HH	8-100 m
Radarsat-2				C	HH, HV, VH, VV	3-100 m
ASAR (Advanced Aperture Radar)	Synthetic		ENVISAT	C	HH, VH, HV, VV	25-150 m
PALSAR (Phased Array L-band Synthetic Radar)	type		ALOS (Advanced Land Observation System)	L	HH, HV, VH, VV	10-100 m

Polarization indicated by transmit and receive polarizations, respectively (**H** = horizontal polarization; **V** = vertical polarization)

Table 3. Year of launch and active application of satellite until current year.

Satellite(s)	Year of Launch	Active Application	Satellite(s)	Year of Launch	Active Application
SPOT 1	1986	Inactive (2002)	ASTER	1999	Active
SPOT 2	1990	Inactive (2009)	IKONOS	1999	Inactive (2015)
SPOT 3	1993	Inactive (1996)	QuickBird	2001	Active
SPOT 4	1998	Inactive (2013)	RADARSAT-1 SAR	1995	Inactive (2013)
Landsat 1	1972	Inactive (1978)	ENVISAT ASAR	2002	Inactive (2012)
Landsat 2	1975	Inactive (1982)	ERS-1 SAR	1991	Inactive (2000)
Landsat 3	1978	Inactive (1983)	JERS-1	1992	Inactive (1998)
Landsat 5	1984	Inactive (2011)	AIRSAR	1990	Inactive (2004)
Landsat 7	1999	Active	ALOS PALSAR	2006	Inactive (2011)
IRS 1C	1995	Inactive (2004)			
IRS 1D	1997	Inactive (2006)			

2. Mangrove forest

Mangrove forests flourish in intertidal zones and coastlines between the sea and the land within tropical and subtropical regions of the world (Figure 1), approximately located 30° N and 30° S latitude [12-13]. They grow in harsh environmental conditions with high levels of salinity, high temperature, extreme tides, high rates of sedimentation and muddy anaerobic soils [13-15].

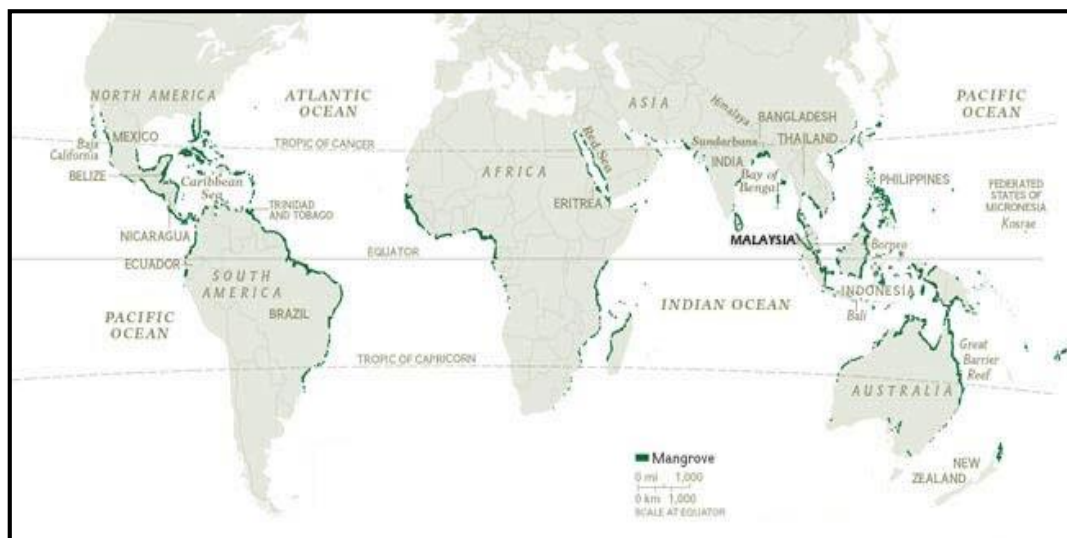


Figure 1. The world's mangrove distribution (Source: [13]).

Mangrove forests are among the most productive and biologically important ecosystems as they provide various goods and services to the society as well as benefits to coastal and marine systems; in fact, they are one of the most valuable ecosystems in the world [13][16-17]. [17] further comment that mangroves constitute less than 0.4% of the world's forests; they provide habitats for thousands of marine life, and serve the local communities with food, medicine, fuel and building materials. They are among the most carbon-rich forests in the tropics and important factors in mitigating the impact of climate change by sequestering carbon dioxide (CO₂) (the main greenhouse gas, apart from water vapour) from the atmosphere [18-19]. They also act as a security barrier in protecting the coastal areas from tidal waves, tsunamis and cyclones [15][20-22].

Even though they are important sources of goods and services, FAO (2007) reported that the total global area of mangroves decreases at about 1% per year. Mangrove forests experienced a significant worldwide loss estimated at about 35% to 36% in the period from 1980 to 2005; this rate of decline is faster than that of the tropical rain forest and coral reef [12][16][23-24]. Natural disasters such as increased sea level, cyclones, storm, lightning strikes, tsunami, and flood cause negative impacts on the growth of mangrove forests; on the other hand, human interferences such as overexploitation, conversion to aquaculture, urbanisation, developments related to agriculture, infrastructure and tourism bring about shrinking area of the mangrove forests [12][16][20][23][25-27]. [24] predict that the mangrove forest could be 100% vanished if the present rate of loss continues. As a consequence, the important goods and services provided by the ecosystem of mangrove forests will diminish [24].

3. Remotely sensed imagery data

Basically, there are two types of remotely sensed satellite images depending on the main source of energy: active and passive [28-29]. An active system controls its own electromagnetic radiation source, which is known as radar. A passive system uses natural energy from the sun as the source of electromagnetic radiation, which is known as optical system.

3.1 Radar satellite image

A radar imagery system or Radio Detection and Ranging is a method for the detection and ranging of earth surface features. Radar is an active remote sensing system which means that it provides its own source of energy to produce an image; it is commonly referred to as synthetic aperture radar (SAR). Radar carries its own electromagnetic radiation source, which is then directed to the surface and the energy reflected back from the surface is recorded [29]; this is expressed in Figure 2. Some examples of radar satellites are TerraSAR, RazakSat, ENVISAT and RADARSAT. The data are

acquired either by day or by night. Due to the specific wavelength of radar, cloud covers can be penetrated without any adverse effect on the imagery. According to [30], radar has special properties that make it a viable alternative and/or partner to the optical remote sensing technique. For instance, microwave energy is capable of penetrating atmospheric conditions that render traditional space borne optical and multispectral systems useless [31]. Therefore, radar has the ability to produce images through rain, fog, hail, smoke, and, most importantly, clouds and it does not depend on daylight [28][32]. These characteristics hold enormous data collection potential in many countries around the world [32].

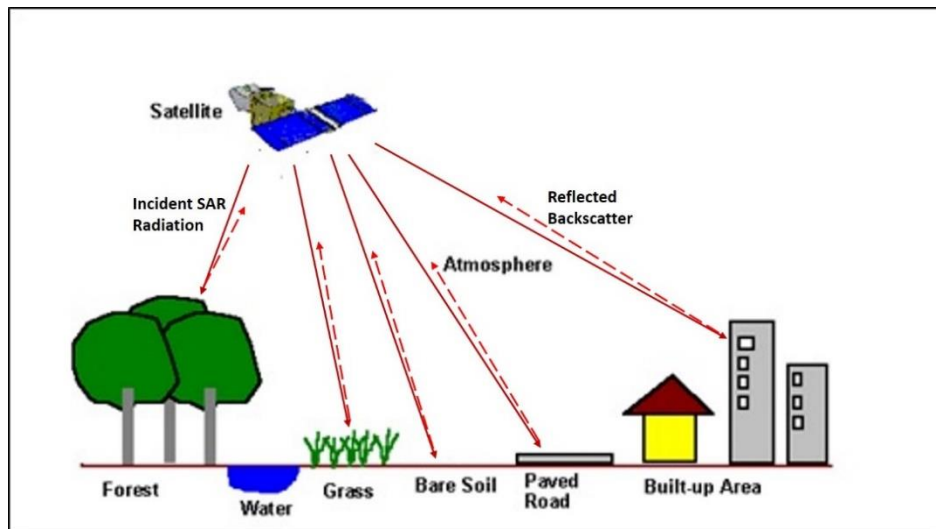


Figure 2. Principal of radar satellite (modified from [33]).

Advantages of radar satellite [8]:

- all weather capability (small sensitivity of clouds, light rain)
- day and night operation (independent of sun illumination)
- no effects of atmospheric constituents (multi-temporal analysis)
- sensitive to dielectric properties (water content , biomass, ice)
- sensitive to surface roughness (ocean wind speed)
- accurate measurements of distance (interferometry)
- sensitive to man-made objects
- sensitive to target structure (use of polarimetry)
- subsurface penetration

3.2 Optical satellite image

Optical imageries are acquired during the daylight since the satellite depends on the reflections of sunlight from objects on the Earth's surface in the absence of cloud cover [28][33]. Some examples of optical satellite systems include Landsat, SPOT, Ikonos, GeoEye and WorldView.

[33] describes an optical satellite as using visible, near infrared and short-wave infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground (Figure 3). With different wavelengths, different materials reflect and absorb them differently. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images.

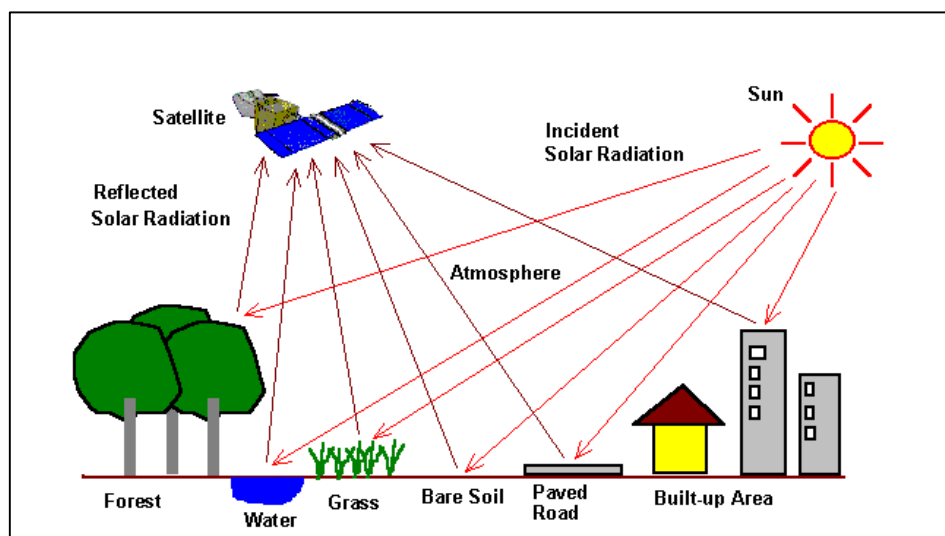


Figure 3. Principal of optical satellite [33].

Advantages of optical satellites [8]:

- specific wavelength sensitivity
- recent innovations with some satellite systems enable mission operators to more frequently update tasking plans to accommodate cloud-coverage forecasts
- manoeuvrable, with varying speed levels to move from one target to another
- several images can be collected during the same pass at the same latitude

4. The role and needs of satellite imagery data in mangroves monitoring

In the last 3 decades, a significant decline in mangrove forests has become a major environmental issue. The increased awareness of people, particularly environmentalists exerts a pressure on the need for conservation and restoration. As such, retrieving up-to-date information with regard to the extent of damage and condition of mangrove ecosystems is an essential aid to management as well as policy- and decision-making processes [9].

Remotely sensed satellite images have been used to characterise mangrove ecosystems for more than two decades; aerial photographs has gradually become obsolete because high resolution images are more advanced, and promise detailed and accurate data [9][34-35]. The benefits and limitations are listed in Tables 4, 5 and 6. With high resolution images, it is relatively easy to study the coastal ecosystems. The embedded detailed information provides a synoptic view, multi-temporal, coverage and multi-spectral ability in the whole range of wavelengths, from visible to microwave. These advantages can effectively act as a tool par excellence in providing advance and reliable information on mangrove extent and status of its growth along the coastal areas [36], which would not be possible by using ground based techniques. The reflectance patterns of vegetation in visible and near infrared (NIR) spectral region give information on the conditions of vegetation covers [36].

In mangrove monitoring, satellite imagery data are able to deliver information such as land cover changes, disaster observation, species distribution, zonation pattern, etc. [37] state, a particular advantage of using optical data that mangroves are relatively distinct from non-mangrove areas, although confusion with adjoining tropical forests often leads to errors in the mapping of mangrove extent. [9] state that the interpretation of radar data over mangrove ecosystems is very complex because in radar data, the backscatter signal of mangrove ecosystems is influenced by the geometric properties of the stand such as canopy closure, canopy geometry, leaf structure, cell structure, stem structure, and the underlying surface component and its roughness: soil mudflats water; it is also affected by dielectric properties, which vary, depending on the soil moisture, plant moisture, and

underlying water surfaces. The responses of these different conditions fluctuate, depending on the incidence wavelength, the polarisation of the radar beams, and the incidence angle of the radar waves.

Various image processing and analysis techniques have been developed to facilitate remotely sensed imagery interpretation and to extract as much information as possible from the images. Based on a review study by [9], several methods have been employed to classify remotely sensed data on mangroves which are visual interpretation, pixel based classification (supervised and unsupervised), object-based methods, vegetation indices, and leaf area index (LAI). According to [38], visual interpretation highly depends on an interpreter's ability to recognise and analyse several characters of a satellite image, for example shape, size and pattern. Supervised and unsupervised classifications are common pixel based techniques of satellite image processing. In these techniques, spectral properties of every pixel within the area of interest are analysed without taking into account the spatial or contextual information related to the pixel of interest while object-based method is based on information of a group of similar pixels [39]. A vegetation index is a number generated by some combinations of remote sensing bands and may have some relationships to the amount of vegetation in a given image pixel; and normalised difference vegetation index is most widely used to separate vegetation from non-vegetation [9].

In Malaysia, [17] used Landsat images to monitor and analyse the changes over a period of 25 years of mangrove areas in Iskandar Malaysia. Two techniques were applied: the maximum likelihood classification (MLC) was used to compare and support vector machine (SVM). As a result, 6 land use/land cover (LULC) have been classified, which are forest, oil palm, rubber, mangrove, urban, and water bodies for both techniques. The comparisons of accuracies are between 62% (for SVM) and 95% (for MLC) from the years 1989, 2000, 2005, 2007, 2009, 2013 and 2014. Thus, MLC achieved the highest overall classification accuracy compared to with SVM for all the seven years considered.

In recent years, unmanned aerial vehicles (UAVs) grow in popularity as a monitoring technique. UAV is an unmanned aerial vehicle or aerial vehicle without a pilot [40]; it is also known as drone. UAVs can fly using a manual remote controller, semi-automatic and automatic or combination of these methods. As an alternative way to acquire images from the space, UAVs can carry many types of sensors such as LiDAR, multispectral camera, or hyper spectral camera to capture images. As for viewing, sensors such as Synthetic Aperture Radar (SAR) can be applied to view through cloud and Daylight (RGB) Video Sensor to see what is going on at the ground. However, it all depends on the capability of UAV payload. The application of UAVs has widely spread and they are used in vegetation monitoring. For example, in a study conducted by [41], a high altitude long endurance (HALE) UAV, Pathfinder Plus was used to demonstrate this technique in monitoring a coffee plantation in Hawaii. The UAVs also have been applied in wetland observation, such as platform option of free-flying satellite, UAVs and International Space Station (ISS) for remote sensing assessment of the littoral zone; this work was carried out by [42]. He found that UAVs have much greater efficiency since they can be deployed as needed directly to the object areas and avoid poor weather conditions. Next, in a study on hazard detection and analysis at natural wetland of Taijiang National Parks, [43] utilised UAVs to collect ground truth data.

Table 4. The benefit and limitation of medium resolution of optical imagery data [9]

Medium-resolution imagery	Benefits	Limitation
Spectral resolution	Several multispectral bands, always including R, G, B; near-infrared; and oftentimes even mid-infrared; and thermal bands	Skilled trained personnel are required to best exploit the information content of the multiple bands (considering transformation, etc.)
Spatial resolution	Ideal for mapping on a large regional scale	Too coarse for local observation requiring in-depth species differentiation and parameterization
Temporal resolution	Frequent mapping (e. g., rainy season and dry season within 1 year; or repeated annual mapping) is possible	Repetition rate may be too low to record impact of extreme events (e. g., cyclones, floods, tsunami); furthermore, very weather dependent (clouds) = critical in subtropical and tropical regions
Costs	Depending on sensor, freely available (e. g., Landsat), very cost efficient (ASTER), or expensive (e. g., SPOT); but all are cost efficient compared with field surveys and airborne campaigns	Software for image processing need (common software, such as erdas, ENVI, and ArcGIS, have high license fees), but usually not real limitation
Long-term monitoring	Data availability over three decades	depending on the future duration of the systems and subsequent comparable sensors
Purposes	Inventory and status maps; change detection, such as assessment of impact damages; assessment of forestation and conservation success	For some species-oriented botany-focused studies, resolution may already be too coarse
Discrimination level	Mangrove-non-mangrove, density variations, condition status, mangrove zonation, in rare cases also species discrimination	High regional differences; classification result depends highly on the ecosystem conditions, such as biodiversity, heterogeneity of forest, adjacent targets; species identification is rarely possible
Methods	visual interpretation with on screen digitizing, pixel-based, object-based, and hybrid classification approaches; image transformation and analyses (PCA, TCT, HIS indices, etc)	To exploit the full potential of the data skilled analysts needed

Other	Data easy to access or order; best explored data type and , thus, most literature available; long-term monitoring granted
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Table 5. The benefit and limitation of high resolution of optical imagery data [9]

High-resolution imagery	Benefits	Limitation
Spectral resolution	Red-near-infrared spectral information with red-edge slope; usually panchromatic band allowing image fusion (pan-sharpening)	Relatively few spectral bands
Spatial resolution	High resolution (0.5-4 m range) for mapping on a local scale	Only small area is covered
Temporal resolution	Regular mapping is possible on demand	Weather dependent (clouds); cost intensive if repeated monitoring is required
Costs	Moderate costs for single acquisitions (depending on are)	Very high costs if repeated monitoring is requested. Also, high costs of object-oriented image processing software
Long-term monitoring	Theoretically possible, but usually not used because of expense. Sensors, such as Ikonos, QuickBird, etc, available since late 1990s/2000.	Depending on the future duration of the systems and subsequent comparable sensors. Only back to the late 1990s.
Purposes	Discrimination of mangrove species, spatial distribution and variability, health status, parameterization.	Single tree species discrimination usually not possible.
Discrimination level	Down to species communities; detailed parameterization	Regional differences; classification result depends highly on the ecosystem conditions, such as biodiversity, heterogeneity of forests, adjacent targets
Methods	Visual interpretation with on screen digitizing, pixel based, object-based, and hybrid-classification approaches.	Skilled analysis needed to exploit the full potential of the data.
Other	Valuable information source to support field survey and accuracy assessment. Easy to close the scale gap to <i>in situ</i> investigations	In some countries, data of the relevant sensors very difficult to purchase, few studies published based on the data type.

Table 6. The benefit and limitation of radar imagery data [9]

Radar Imagery	Benefits	Limitation
Spectral resolution	Active microwave radiation; delivers alternative information about surface structure; various wavelengths and polarizations are selectable	No spectral information
Spatial resolution	Varies	Usually low, except TerraSAR-X
Temporal resolution	High; weather independent	None
Cost	Many data types available at low cost in the context of science proposal	Restricted access to data (certain number of scene; also some data not sharable with certain developing countries)
Long-term monitoring	Good; long duration systems	None
Purposes	Mangrove extent, condition, canopy properties, deforestation, biomass estimation	No information derivable from spectra
Discrimination level	Age structure, forest parameters, biomass estimation	Vegetation forms without a prior knowledge; no separation among species
Methods	Analyses of the backscatter signal using advanced image-processing technique; very quantitative physics-based manner of image analysis	Extremely skilled analysis with experience in radar image processing needed
Other	Most promising results when SAR data combined with optical imagery	Relatively few studies have been conducted; special software or modules are needed for radar image processing.

5. Conclusion and prospective

In short, usages of satellite images for mangrove forests management are crucial in obtaining information. Satellite imagery data offer considerable advantages in mangrove studies and are useful to monitor mangrove ecosystems. Options to use either optical or radar satellite images depend on a study's needs. The output of a satellite imagery analysis can provide accurate information to facilitate conservation planning and policy-making as the technology is currently in an advanced stage. In the future, the quality of images processing can be improved further if radar and optical data are integrated. These images can be utilised to explore and monitor the development of mangrove forests in a more effective manner, as [44] aptly state that radar data complement optical data.

6. References

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