CHAPTER 2: SATELLITE IMAGES, INSTRUMENTS, AND STUDY AREAS

2.1 REMOTELY SENSED IMAGES

2.1.1. Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG)

AVIRIS-NG is an imaging spectrometer which gives high signal-to-noise ratio (SNR) image compared to its predecessor AVIRIS-Classic, it is developed by the National Aeronautics and Space Administration (NASA), and launched in the year 2013. It is designed for high-performance imaging spectroscopy with high SNR values, the device is also known as push broom spectral imager. Push broom sensor captures the image across the orbital swath and uses the forward motion of the flight to take a new row of image acquisition. It collects spectra in 425 spectral bands with 5nm spectral resolution. The spectra's wavelength range from 0.38 to 2.51μm in VNIR (400–1000nm) and SWIR (970–2500nm) regions with spatial resolution of 8.1m [29]. It measures the spectra with high SNR >2000 at 600nm and >1000 at 2200nm, such high spectral resolution enables the sensor to retrieve precise information for any location. The radiometric resolution of the sensor is 14 bits. The accuracy of the spectrometer is 95% with FOV (field of view) of 36° and IFOV (instantaneous field of view) of 1m rad [30]. The GSD of the images obtained from the AVIRIS-NG depend on different altitude regimes the flight flies at.

- 70 kts at 6,500 ft Above Ground Level (AGL) for 2 m GSD (Minimum ground speed)
- 100 kts at 13,000 ft AGL for 4 m GSD (Average)

- 128 kts at 20,000 ft AGL for 6 m GSD (Maximum)

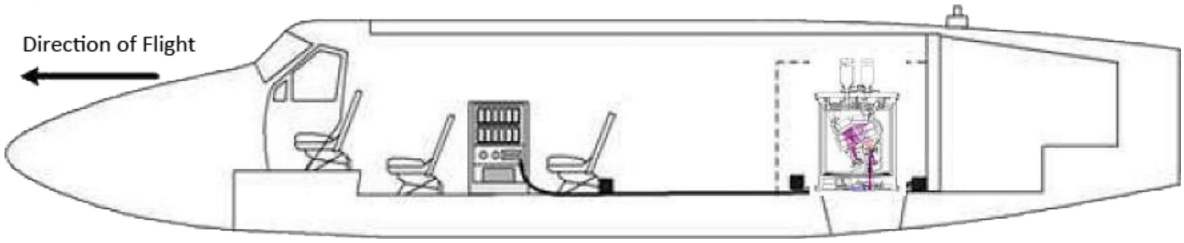

Figure 2.1. The accommodation of AVIRIS-NG instrument in the DHC-6 aircraft

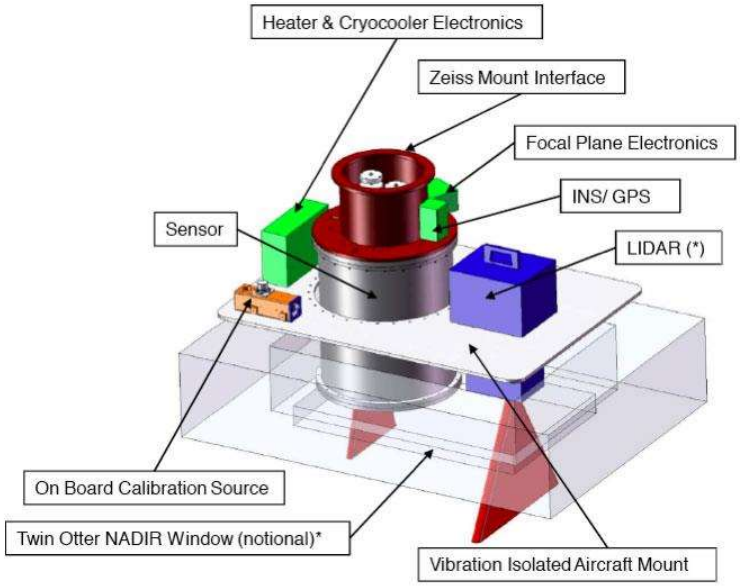

Figure 2.2. Components of the AVIRIS-NG sensor

(Source: https://avirisng.jpl.nasa.gov/platform.html)

Figure 2.1 shows the accommodation of the sensor on an aircraft carrier DHC-6 and the direction of the instrument w.r.t. the direction of flight. Figure 2.2 shows the major components of AVIRIS-NG, with sensor enclosed in a vacuum chamber, optional companion LIDAR instrument along with high precision GPS, on board calibrator, etc.

The AVIRIS-NG sensor gathers information that can be used to characterize the Earth's surface and atmosphere. The images acquired find application in different field as shown in Section 1.8.1.

2.1.2 Sentinel-2

Sentinel-2 flies under Copernicus mission owned by European Space Agency (ESA). It consists of the pair of polar satellites positioned at 180° from one another and placed at a mean altitude of 786km in a sun-synchronous orbit. In sun synchronous orbit, the angle of sunlight on the earth surface is maintained constantly such that the satellite captures the same position of an area in each visit at the same local time. It monitors change in Earth atmosphere with swath width of 290km and temporal resolution of 10 days. Mounted on it is MultiSpectral Instrument, that takes image in 13 bands with different spatial resolution (10m, 20m, 60m), and spectral range of 443nm to 2190nm.

The sensor captures images passively and uses the push broom concept for data acquisition. the incoming light beam is divided by a beam splitter into two distinct focal planes assembled inside the instrument, one for the Visible and NIR bands and the other for the SWIR bands.

Figure 2.3. Sensor of Sentinel-2

(Source: https://sentinel.esa.int/web/sentinel/missions/sentinel-2/satellite-description)

Figure 2.3 shows the sensor of the satellite sensor along with the direction of the flight with respect to the nadir position.

The radiometric resolution of the images acquired by Sentinel-2 is 12 bits, which gives greyscale values of 4096.

Table 2.1. Bands specification of Sentinel-2

Bands (B)	Central wavelength (nm)	Spatial resolutions (m)
B1 (Ultra blue)	443	60
B2 (Blue)	490	10
B3 (Green)	560	10
B4 (Red)	665	10
B5 (Vis and NIR)	705	20
B6 (Vis and NIR)	740	20
B7 (Vis and NIR)	783	20
B8 (Vis and NIR)	842	10

B8a (Vis and NIR)	865	20
B9 (SWIR)	940	60
B10 (SWIR)	1375	60
B11 (SWIR)	1610	20
B12 (SWIR)	2190	20

Table 2.1 shows the spatial resolution of different bands of Sentinel-2. The image contains thirteen bands with three spatial resolutions and bands specifications.

2.1.3 Micasense RedEdge MX

Micasense RedEdge MX is a MS camera that capture images in five optical bands as shown in Table 2.2 and a thermal band, and it is mounted on an UAV, which was used in the study area.

Table 2.2. Bands specification of RedEdge MX

Band No.	Band Name	Centre Wavelength (nm)	Bandwidth FWHM (nm)
1	Blue	475	20
2	Green	560	20
3	Red	668	10
4	NIR	840	40
5	Red Edge	717	10

The MS camera is mounted on a drone named Lookout VTOL-Lite TALV-2400 (manufactured by Throttle aerospace systems, India) shown in Figure 2.4 (a) and (b). The GSD is decided by the altitude at which the drone flies, at the AGL of 200ft (~60ft)

it has the GSD of 4.2cm and 8.2cm/pixel at the height of 120m (400 ft.), with FOV of 47.2°. It captures image with radiometric resolution of 16 bit with capturing speed of 1 per second. The data acquisition was done keeping the front and side overlap at 70%, above-ground flight height at 60m, and cruise speed at 6m/s, resulting in a GSD of ~4.2cm/pixel.

(a) (b)

Figure 2.4. (a) RedEdge MX camera **(b)** VTOL-Lite TALV-2400

(Source: (a) https://uavgarage.com/product/micasense-rededge-mx-multispectral-camera-kit/)

UAV data was processed (such as ortho imaging, mosaicking, stitching, etc.) using Pix4D mapper. Pix4D employs the structure from motion (SFM) method to analyse the imageries. SFM is a photogrammetric approach used to determine an object's 3D structure from a set of 2D offset image collections obtained by the motion camera mounted on a UAV platform.

2.2 HAND-HELD INSTRUMENTS

(a) **(b)** **(c)**

Figure 2.5. (a) FieldSpec 4; **(b)** SPAD-502Plus; **(c)** LI-COR

(Source: (a) https://analytik.co.uk/product/portable-remote-sensing-spectroradiometry-fieldspec/ (b) https://www.specmeters.com/nutrient-management/chlorophyll-meters/chlorophyll/spad502p/ (c) https://www.licor.com/env/products/leaf_area/LAI-2200C/)

2.2.1 FieldSpec 4

FieldSpec 4 is a hand held hi-res spectroradiometer manufactured by ASD Malvern Panalytical Ltd, United Kingdom. It takes spectra of a subject in the wavelength range from 350-2500nm with sampling rate of 0.2 seconds per spectrum. The spectral resolution is 3nm in very short and 10nm in the far IR wavelengths, these resolutions are resampled to 1nm, the device records spectra in 2151 bands (Figure 2.5 a).

There are three detectors present inside the device to take the spectra in three regions;

VNIR detector (350-1000nm): 512 element silicon arrays.

SWIR 1 & 2 detector (1001-1800nm) & (1801-2500nm): Graded Index InGaAs Photodiode.

2.2.2 Soil Plant Analysis Development (SPAD)

SPAD 502Plus is a lightweight portable device manufactured by Konica Minolta, to measure the leaf chlorophyll content using non-invasive method (Figure2.5(b)). Chlorophyll has absorbance in the blue (400-500nm) and red region (650nm) with no absorbance in infrared region (940nm) (Figure (2.6)).

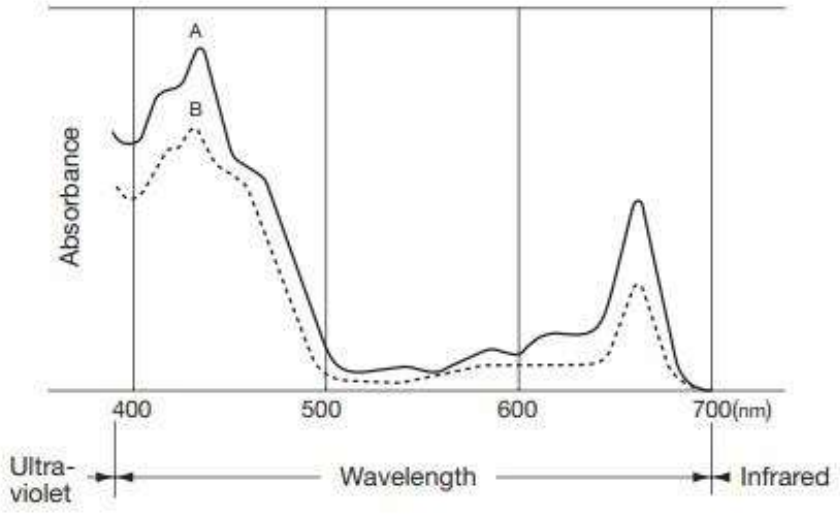

Figure 2.6. Absorbance of visible light by chlorophyll

(Source: https://www.konicaminolta.eu/eu-en/hardware/measuring-instruments/colour-measurement/chlorophyll-meter/spad-502plus/downloads)

The device exploits this characteristic by measuring the absorbance in red and infrared region and it gives a chlorophyll content value in three significant digit values [31].

2.2.3 LAI-2200C Plant Canopy Analyzer

Figure 2.5 (c) shows LAI-2200C Plant Canopy Analyzer manufactured by LI-COR Biosciences, USA, it is used to measure LAI without destructively sampling the vegetation canopy.

The working of the device is based on four presumptions:

(a) All light is absorbed by the foliage;

(b) The foliage is randomly distributed;

(c) The foliage is oriented randomly;

(d) The foliage pieces are constrained by the view ring.

However, in reality canopies do not precisely fit these presumptions. Vegetation absorbs all the blue waveband radiation detected by the sensor (320-490nm). In diffuse light situations, such as uniform overcast, soon before sunrise or immediately after sunset, this is often a reasonable assumption. Reflection off foliage in direct sunlight generates significantly bigger overestimation of the gap fraction and an overestimate of the leaf area index.

2.2.3.1 Measurement of LAI

LAI-2200C calculates LAI using measurements taken below and above the canopy to calculate the light intercepted by the canopy at five different angles as shown in Figure 2.7.

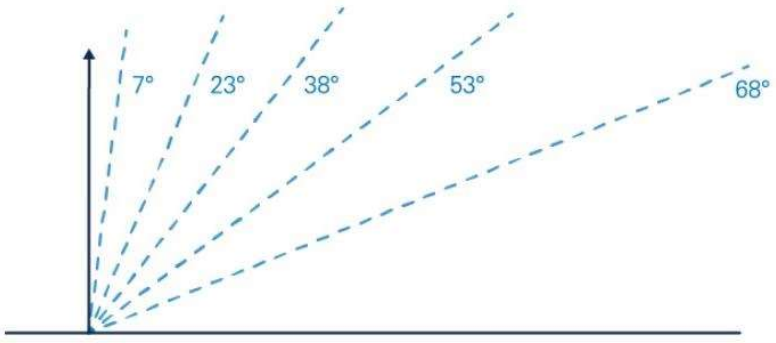

Figure 2.7. Light interception by LAI-2200C at five different angles

(Source: https://www.licor.com/env/products/leaf_area/LAI-2200C/science)

This device contains fisheye lens as an optical sensor, the lens sees a hemispherical image which the optical system focuses on a photodiode sensor, that is made up of consecutive rings.

Any two-dimensional satellite image often ignores the lower and upper canopy of the leaf area, due to which there is an omission of some leaf area information. To avoid this a UAV photo taken from different angles can be used to reconstruct the leaf area information which may overcome the limitation of traditional photogrammetry.

2.3 STUDY AREAS

For the present studies there are two study area used, one situated in Anand district, Gujarat, and another in situated in agricultural farm of BHU, Varanasi district, Uttar Pradesh. The Anand district contains a variety of soil types, including lateritic, red, and black mixed, residual sandy, and black cotton, Thus, in this district there is a variety of agricultural species grown making it useful for agricultural studies. The Varanasi city is situated near the banks of river Ganga, due to its good soil and mild temperature changes, the Gangetic plains can farm crops from both tropical and temperate zones.

2.3.1. ANAND DISTRICT, GUJARAT (Study area 1)

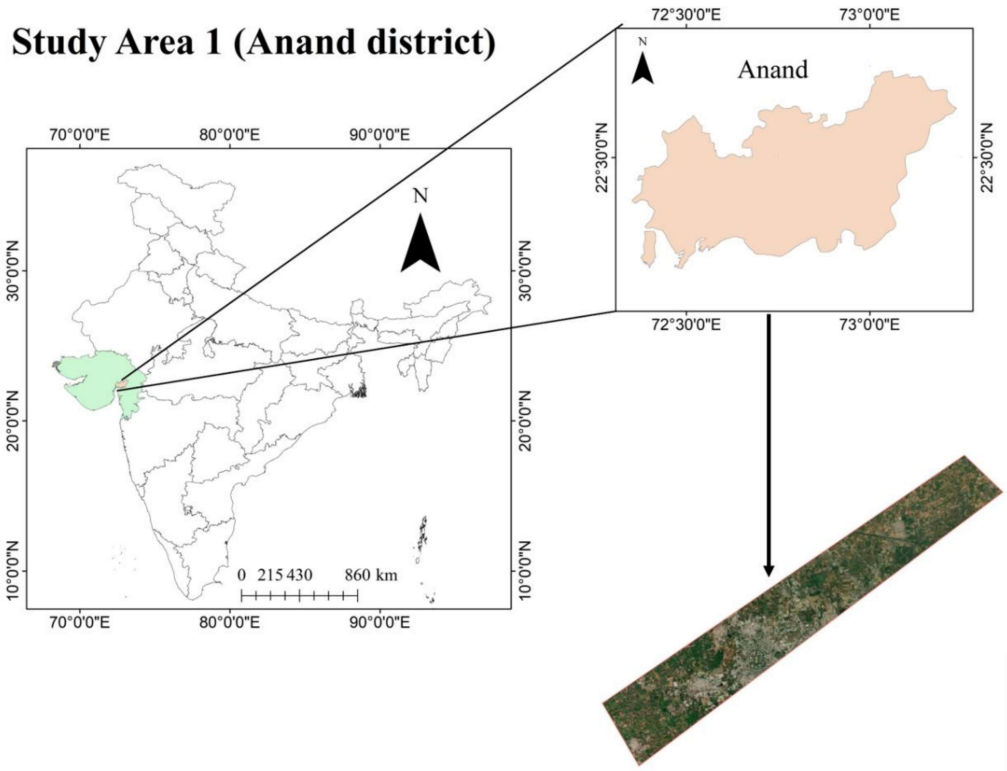

Figure 2.8. Study area 1 in Anand, Gujarat

The first study site is present in Anand district of Gujarat, it is located in the western part of the country. This site was AVIRIS-NG Indian campaign along with the collaboration with ISRO, India. In Figure 2.8, the strip of the image is shown which was the part of the district above which AVIRIS-NG flight passed. The district is at an elevation of 39m with geographical coordinates lying between 72°00′N to 72°99′N and 22°46′E to 22°56′E, covering an area of 2,951km^2. The annual rain-fall that the district records vary from 287mm to 1693mm with highest rainfall recorded as 687mm from June to September in southwest monsoon. The area contains a variety of soil types, including lateritic, red, and black mixed, residual sandy, and black cotton. However, in the study area major soil type found is Goradu and black.

The agricultural crops present in the district is wheat, tobacco, maize, Amaranthus, tomato, chickpea, sorghum, etc. with tobacco and wheat as the major growing crops in the study area. Rigorous ground data sampling was done during the overpass of AVIRIS-NG flight i march 2018 [32, 33].

2.3.2. VARANASI DISTRICT, UTTAR PRADESH (Study area 2)

The study was primarily conducted in the agriculture farm of BHU, the farm mostly has Alluvial soil type, during rabi season crops that are grown here are wheat, mustard, linseed, etc., and in kharif season, rice, and maize are grown primarily.

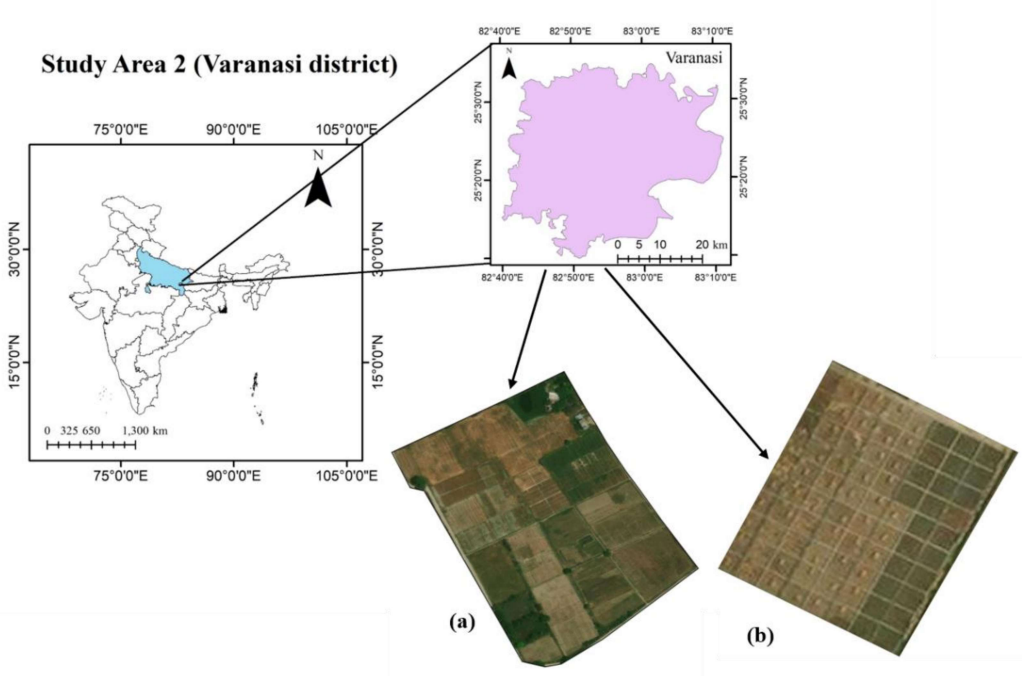

Figure 2.9. Study area 2 in Varanasi district, Agricultural farm, (BHU)

Two parts of agricultural farm was chosen for couple of studies, present in Banaras Hindu University (BHU) Varanasi district, Uttar Pradesh. The centre of the district is located at 25°15′ 55.27″ N and 82°58′ 56.92″ E. The city expands in approximately

1,500km^2 and it is a part of Indo-Gangetic Plain, due to which it has significant alluvial deposits making it very fertile and suitable for farming. The annual rainfall that the city sees is around 1000mm, with the monsoon season, which normally lasts from July to September, accounting for over 80% of the total. Temperature of the district varies somewhere from 8°C to 43°C throughout the year in different weathers. The Gangetic plains can grow any crop from a tropical or temperate location due to the soil's capacity and the tolerable temperature variance. Major agricultural crops grown here are wheat, rice, sugarcane, and maize [34]. Figure 2.9 (a) is the part of Agricultural farm over which UAV was flown for the study used in chapter 4 and Figure 2.9 (b) is a specially prepared crop beds of dimension 4×4m in which different crops are sown, which is studied in chapter 6.