1. Introduction

1.1 General

This chapter describes the objectives of the present study and also introduces to the principles of remote sensing, electromagnetic spectrum, characteristics of remotely sensed data, remote sensors, radiometric resolution, temporal resolution, principle geographic information systems (GIS) and integration of remote sensing and GIS.

1.2 Introduction

A. Physical Basis of Satellite Remote Sensing

Remote sensing is a broad earth monitoring technology that gathers, processes, and eventually photographs electromagnetic wave information radiated and reflected by long-range targets using various sensing devices without having to make physical contact with the objects in order to detect and identify various objects on the ground. In remote sensing, the sensors are not in direct contact with the objects. Electromagnetic radiation is commonly used as the information carrier in remote sensing. No matter what the wavelength of the electromagnetic radiation, it is all generated by electrically charged matter. There is no universal radiation generator that provides a useful intensity of radiation at all wavelengths for practical purposes. The spectrum has been divided into regions that bear names related to the sources that produce it. An electromagnetic wave is a moving electromagnetic field. According to Maxwell's electromagnetic field theory, energy exists anywhere in space as long as there is a vacuum. Any change in the electric field will excite the magnetic field nearby, and any change in the magnetic field can cause the electric field to change. As a changing electromagnetic field propagates in space in the form of electromagnetic oscillation, electromagnetic waves are generated. Electromagnetic oscillations, in fact, propagate in a variety of directions. This process of transmitting electromagnetic energy (including radiation, absorption, reflection, and transmission) is known as electromagnetic radiation (Li, (2021)). The electromagnetic spectrum refers to solar energy traveling in the form of waves at the speed of light (denoted as c and equals to 3×10^8 ms^{-1}). The waves move through time and space in the same way that water waves do, but they also oscillate in all directions perpendicular to their path.

Electromagnetic waves have different wavelengths, frequencies, wave numbers, and energies. The electromagnetic spectrum is created by arranging electromagnetic waves in the order of wavelengths, frequencies, wave numbers, or energies as shown in Figure 1.1. The electromagnetic waves that are grouped in increasing band frequency order are radio waves, infrared (far-infrared, mid-infrared, near-infrared), visible light, ultraviolet, X-ray, and gamma ray. Since electromagnetic wave sources differ, the wavelengths of various electromagnetic waves vary. Electromagnetic oscillation, for example, produces radio waves. Microwave antennas triggered and distributed by resonant cavities and waveguide tubes emit microwaves into space.

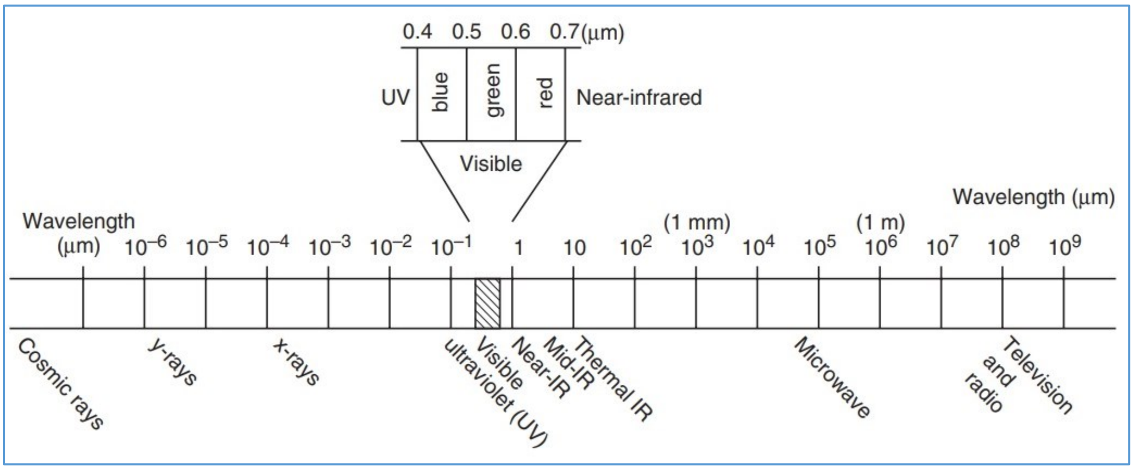

Figure 1.1: Electromagnetic waves in the order of wavelengths, frequencies, wave numbers, or energies.

In the electromagnetic spectrum, visible light occupies a very narrow band. Visible light is an electromagnetic wave that human vision perceives as bright. The human eye has the ability to continually respond to electromagnetic radiation in the visible band. This ability allows it to identify and differentiate the radiation properties of different visible-band materials. Despite its narrowness, the visible spectrum is highly useful in satellite remote sensing and imaging for distinguishing various objects based on their visible colors. The wavelength of visible light ranges from 0.38 to 0.76 μm. The wavelength of near to shortwave infrared (N-SWIR) is between 0.76 and 3.00 μm, which is very similar to visible light in nature. The N-SWIR band is widely used in remote sensing technologies. N-SWIR is also known as reflective infrared because it mostly reflects the infrared radiation of the sun from the earth as well as the reflective radiation properties of ground surfaces. Medium-wave infrared in wavelengths range from 3.0 to 6.0 μm. In contrast to the features of shortwave infrared reflections, medium infrared radiation is thermal. When the temperature is higher than the absolute temperature (-273.15 °C), any object in nature will emit infrared rays. The strength and location of its radiant energy is linked to the surface condition of the material, which depends on the internal structure and temperature of the material. The 3–6 μm medium-infrared range is primarily used in the remote sensing of medium-infrared. This band is particularly susceptible to high-temperature targets such as fires and active volcanoes. It can work at any time of day or night, but it is often affected by atmospheric absorption and scattering. Medium-wave infrared cannot work in the presence of clouds, rain, or fog. Longwave infrared is a form of thermal radiation with the longest wavelength of all infrared rays. Because of the long wavelength and high penetrating capability of longwave infrared rays in the atmosphere, far-infrared imaging is less influenced by smoke. Longwave remote sensing mainly uses the 8 to 14 µm band because ultra-far infrared rays with wavelengths of 15 µm or more are readily absorbed by the atmosphere and water molecules.

Microwave band

The wavelengths of microwaves, also known as ultrahigh frequencies, range between 1 mm to 30 cm. In applications, they are divided into decimeter waves, centimeter waves, and millimeter waves, and are defined as S band (10 cm), C band (5 cm), X band (3 cm), and K band (1.25 cm). Microwaves have the following properties that set them apart from other types of electromagnetic waves:

(i) High-frequency properties: The frequency of microwave oscillation is extremely high, exceeding 300 million times per second. Since the frequency is many orders of magnitude higher than that of low-frequency radio waves, certain effects that are not noticeable in low-frequency bands can be very noticeable in the microwave band. The microwave remote sensing can clearly outline those target characteristics that cannot be distinguished by visible light or infrared bands.

(ii) Shortwave properties: Microwave wavelengths are significantly shorter than the wavelengths of general macroscopic objects such as structures, ships, and aircraft, resulting in large reflections when the microwave beam is illuminated onto these objects. For applications like radar, navigation and communication, this feature is significant.

(iii) Scattering properties: When an electromagnetic pulse strikes an object, it not only partially reflects in the opposite direction of the incident wave, but also scatters in other directions. Since scattering is the product of an encounter between the incident wave and the scatterer, the scattering wave contains a wealth of knowledge about the scatterer, including frequency domain, time domain, phase, and polarization. The target information can be derived by detecting the scattering properties of various materials, and then target identification can be performed. This property is the foundation of microwave remote sensing and radar imaging.

(iv) Penetration: Microwaves have the ability to reach the upper ionosphere and are used for satellite communication. Greater wavelength, lower scattering, lower attenuation in the atmosphere, greater capacity to enter clouds and the rainy areas, as opposed to infrared waves.

Characteristics of Remotely Sensed Data

All sensing systems detect and record energy signals from earth surface features and/or the atmosphere, regardless of whether they are passive or active remote sensing systems. Aerial cameras and video recorders are common examples of remote sensing systems. Electronic scanners, linear/area arrays, laser scanning systems, and other more complex sensing systems are examples. These remote sensing systems may collect data in either analog or digital format (for example, copy of aerial photography or video data) (e.g., a matrix of brightness values corresponding to the average radiance measured within an image pixel). Digital remote sensing images may also be entered in a GIS directly for use; GIS can also be made using analog to numerical conversion or scanning with analog data. Remote sensing data are more often first interpreted and analysed using various methods for extracting information, so that data layers for GIS are available. For remote sensing data to be collected successfully, there is a need to grasp four fundamental resolution features: spatial, spectral, radiometric, and temporal.

Spatial resolution is a minimum distance measurement between two objects that allows the images to be distinguished and depends on sensor altitude, detector size, focus size and system configuration. Spatial resolution in aerial photography is measured in resolvable line pairs per millimetre, while spatial resolution in other sensors refers to the measurements (in meters) of the ground area that falls within the instantaneous field of view (IFOV) of a single detector within an array or pixel size. The level of spatial detail that can be observed on the earth's surface is determined by spatial resolution. Coarse spatial resolution data may contain a large number of mixed pixels, which contain more than one land-cover type. Though fine spatial resolution data reduce the mixed-pixel problem significantly, they can increase internal variance within land-cover forms. Higher resolution often necessitates more storage space at a higher cost, and it can complicate image processing for a wide study region. On a local scale, high spatial-resolution imagery, such as that derived from IKONOS and QuickBird data, is more accurate. On a regional scale, medium-resolution imagery, such as that derived from Landsat Thematic Mapper/Enhanced Thematic Mapping Plus (TM/ETM+) and Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data, is most commonly used. On a continental or global scale, coarse-spatial-resolution imagery, such as that generated by the Advanced Very High Resolution Radiometer (AHVRR) and Moderate Resolution Imaging Spectrometer (MODIS), is best suited.

Each remote sensor is distinct in terms of the portion(s) of the electromagnetic spectrum that it detects. Different remote sensing instruments record different parts of the electromagnetic spectrum, or bands. A sensor's spectral resolution refers to the number and size of bands it can record. For example, AVHRR, onboard National Oceanographic and Atmospheric

Administration's (NOAAs) Polar Orbiting Environmental Satellite (POES) platform, collects four or five broad spectral bands (depending on the individual instrument) in the visible (0.58–0.68 µm, red), near-IR (0.725–1.1 µm), mid-IR (3.55–3.93 µm), and thermal IR portions (10.3–11.3 and 11.5–12.5 µm) of the electromagnetic spectrum. AVHRR, acquiring image data at the spatial resolution of 1.1 km at nadir, has been used extensively for meteorologic studies, vegetation pattern analysis, and global modeling. The Landsat TM sensor collects seven spectral bands, including (1) 0.45–0.52 µm (blue), (2) 0.52–0.60 µm (green), (3) 0.63–0.69 µm (red), (4) 0.76–0.90 µm (near-IR), (5) 1.55–1.75 µm (short IR), (6) 10.4–12.5 µm (thermal IR), and (7) 2.08–2.35 µm (short IR). Its spectral resolution is higher than early instruments onboard Landsat such as the Multispectral Scanner (MSS) and the Return Beam Vidicon (RBV). Hyperspectral sensors (imaging spectrometers) are instruments that acquire images in many very narrow contiguous spectral bands throughout the visible, near-IR, mid-IR, and thermal IR portions of the spectrum. Whereas Landsat TM obtains only one data point corresponding to the integrated response over a spectral band 0.27 µm wide, a hyperspectral sensor, for example, is capable of obtaining many data points over this range using bands on the order of 0.01 µm wide (Weng, (2007)). The National Aeronautics and Space Administration (NASA) Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) collects 224 contiguous bands with wavelengths from 400–2500 nm.

Radiometric resolution refers to the sensitivity of a sensor to incoming radiance, that is, how much change in radiance there must be on the sensor before a change in recorded brightness value takes place. Coarse radiometric resolution would record a scene using only a few brightness levels, that is, at very high contrast, whereas fine radiometric resolution would record the same scene using many brightness levels. For example, the Landsat-1 Multispectral Scanner (MSS) initially recorded radiant energy in 6 bits (values ranging from 0 to 63) and later was expanded to 7 bits (values ranging from 0 to 127). In contrast, Landsat TM data are recorded in 8 bits; that is, the brightness levels range from 0 to 255 (Awange & Kiema, (2013)).

Temporal resolution refers to the amount of time it takes for a sensor to return to a previously imaged location. Therefore, temporal resolution has an important implication in change detection and environmental monitoring. Many environmental phenomena constantly change over time, such as vegetation, weather, forest fires, volcanoes, and so on. Temporal resolution is an important consideration in remote sensing of vegetation because vegetation grows according to daily, seasonal, and annual phenologic cycles. It is crucial to obtain anniversary or near-anniversary images in change detection of vegetation. Anniversary images greatly minimize the effect of seasonal differences. Many weather sensors have a high temporal resolution: the Geostationary Operational Environmental Satellite (GOES), 0.5 images/h; NOAA-

9 AVHRR local-area coverage. 14.5 images/day; and Meteosat first generation, every 30 minutes. In many situations, clear trade-offs exist between different forms of resolution. For example, in traditional photographic emulsions, increases in spatial resolution are based on decreased size of film grain, which produces accompanying decreases in radiometric resolution; that is, the decreased sizes of grains in the emulsion portray a lower range of brightness values. In multispectral scanning systems, an increase in spatial resolution requires a smaller IFOV, thus with less energy reaching the sensor. This effect may be compensated for by broadening the spectral window to pass more energy that is, decreasing spectral resolution, or by dividing the energy into fewer brightness levels, that is, decreasing radiometric resolution (Campbell & Wynne, (2011)).

B. Principles of GIS

A geographic information system is a system specifically designed to use with geographic data that performs a comprehensive range of data handling tasks. These tasks include data input, storage, retrieval and output, in addition to a wide variety of descriptive and analytical processes. From the definition, it becomes clear that GIS handles geographic data, which include both spatial and attribute data that describe geographic features. The basic functions of GIS include data input, storage, processing, and output. The basic concept of GIS is one of location and spatial distribution and relationship. The backbone analytical function of GIS is overlay of spatially referenced data layers, which allows delineating their spatial relationships. Over the course of development, many disciplines have contributed to GIS. Therefore, GIS has many close and far relatives. Disciplines that traditionally have researched geographic information technologies include cartography, remote sensing, geodesy, surveying, photogrammetry, etc. Each application area of GIS requires a special treatment and must examine data sources, data models, analytical methods, problem-solving approaches, and planning and management issues.

C. Integration of Remote Sensing to GIS

Remotely sensed data can be used to extract thematic information to create GIS layers. There are three ways to incorporate so derived thematic layers. First, manual interpretation of aerial photographs or satellite images produces a map or a set of maps that depict boundaries between a set of thematic categories (e.g., soil or land-use classes). These boundaries then are digitized to provide digital files suitable for entry into the GIS. Digital remote sensing data are analyzed or classified using automated methods to produce paper maps and images that are then digitized for entry into the GIS. Finally, digital remote sensing data are analyzed or classified using automated methods and then retained in digital format for entry into the GIS.

Alternatively, digital remote sensing data are entered directly in their raw form for subsequent analyses. In more than three decades, the remote sensing community has been continuously making efforts to extract thematic information more effectively and efficiently from digital remote sensing imagery.

Research Objectives of the Present Study:

1. **Objective:** To demonstrate a comparative assessment of discrepancy in the hydrological behaviour of the DEMs in terms of terrain representation at the catchment scale.

   Hydrological research on watersheds in developing countries is considered a relatively new field. Therefore, for the development of mathematical watershed models that can simulate and evaluate the existing and proposed management scenarios, the application of hydrologic data is considered necessary. Thus, the evaluation of the accuracy of watershed boundaries derived from different sources of elevation data becomes necessary. To evaluate the sensitivity of data sources and their vertical accuracies, two hydrologic applications, watershed boundary and river network extraction, were used along with various statistical measures. Hydrologic applications are selected because they heavily rely on DEM data.

   The specific objectives of this study are:

   I. To compare Digital Elevation Models of satellites ASTER, SRTM and Cartosat of 30 meter resolution for the selection of most appropriate DEM for Vishwamitri watershed.

   II. To delineate watershed and sub - watersheds of Vishwamitri river using remote sensing and GIS.

2. **Objective:** To develop an approach to analyze Sentinel–2 satellite data using traditional and Principal Component Analysis (PCA) based approaches to create land use and land cover map of entire watershed, which is a prerequisite for developing the curve number.

   In this study, PCA is used to condense the information of high dimensional Sentinel–2 multispectral satellite data into fewer channels (represented by the higher-order components) and use the principal components as inputs to the classifiers, thus reducing the computational demands and possibly improving performance. The study will also show the performances of state-of-the-art classification methods, the Maximum Likelihood Estimation, Random Forest Tree, and Support Vector Machine tested on Sentinel–2 multispectral satellite data in order to observe if principal component analysis improves land use and land cover classification.

3. **Objective:** To perform Morphometrical analysis of Vishwamitri watershed and prioritization of sub-watersheds for assessing the flood influencing characteristics of the five sub-watersheds of the Vishwamitri watershed.

   The research is focused on the integrated use of satellite remote sensing, the Geographic Information System (GIS) and extensive field observation techniques for a better understanding of the impacts of watershed characteristics on hydrological processes and floods. Single or limited parameters cannot present the comprehensive picture of the flood hazard potential of any sub-watershed, and hence, each of the linear, aerial, and relief morphometric parameters along with curve number is taken into consideration for assessing the flood influencing characteristics of the five sub-watersheds of the Vishwamitri watershed.

4. **Objective:** To identify potential runoff storage zones based on the various physical characteristics of the Vishwamitri watershed using a GIS-based conceptual framework that combines through Analytic Hierarchy Process (AHP) using Multi Criteria Decision Making (MCDM) method to produce suitability map of potential runoff storage zones within the watershed. The conceptual framework will help to identify potential runoff storage zones for water storage sites based on the various physical characteristics (rainfall, slope, land use/land cover, height above the nearest drainage, stream order, curve number, topographic wetness index) of the watershed.

5. **Objective:** To develop an approach for operational flood extent mapping using Synthetic Aperture Radar (SAR) and preparation of flood inundation map for data scarce region using 2D flow modelling using rain on grid model.

The specific objectives of this study are:

I. To develop an approach for operational flood extent mapping using SAR.

Despeckling is an important preprocessing step as speckle complicates the interpretation of visual images making automated digital image classification a challenging task. The choice of filter relies on the particular application requirements and the data set characteristics used. Despeckle filters with excellent noise extraction capacities often appear to degrade the spatial and radiometric accuracy of the actual image and trigger image reflection deterioration. This may be acceptable for applications involving large-scale interpretation or mapping of images. However, in many cases where the preservation of the subtle structures of the image is essential, the efficiency of noise suppression must be balanced with the effectiveness of the filter in order to keep fine detail. The most preferred speckle filters are, therefore, assessed in the current study over the data from Sentinel-1, intended for flood mapping applications. The Sentinel-1 (VV-vertical transmit, vertical receive and VH-vertical transmit, horizontal receive) polarized filtered data were later used for performance evaluation of machine learning algorithms, namely, random forest (RF) and support vector machine (SVM), to classify an inundated area. The accuracies of the classifications were assessed by the confusion matrix parameters, which include kappa coefficient, overall accuracies, producer’s and user’s accuracies.

II. To develop rain-on-grid model at the watershed scale to simulate flood events and predict flood-prone areas, considering multiple rain gauge data, which will facilitate more accurate flood inundation where ground-based observational data are unavailable or limited. As there is a significant lack of local-level information in the data-scarce region on rating curves and inundation mapping. The framework may effectively allow early warning systems to perform better during support decision making to reduce fatalities and economic losses due to inundation hazards.

6. **Objective:** To quantify the effects of urban land forms on land surface temperature and modeling the spatial variation using machine learning. The models can help to predict land surface temperature under temporary cloud cover spots, which are present in the data at the time of the acquisition, using neighbouring biophysical (cloud-free) independent variables relationship with land surface temperature.

   The specific objectives of this study are:

I. To derive land surface temperature from the Landsat 8 thermal band.

II. To examine the distributions of land surface temperature and land use/land cover types in the study area and also, to understand the overall relationship between the land surface temperature and urban landforms in summer and winter seasons in Vadodara city, India

III. To determine contribution indices of land use/land cover classes to land surface temperature under different temperature conditions;

IV. To examine the relationship between LST with Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Dry Bare-Soil Index (DBSI);

V. To evaluate the machine learning models' performances for K-Nearest Neighbor (K-NN) regression, Neural Networks (NN), Random Trees (RT) regression and Support Vector Machine (SVM) regression with the mean moving kernel (observation grid) of 2×2 and 5×5 for each explanatory variable (NDVI, NDWI and DBSI).