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4. Application of Remote Sensing and GIS in Agriculture

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Abstract:

Remote sensing is the art and science of gaining information about things from a distance. The fundamental concept is the spectral signature of all objects detected by remote sensing sensor. Three major spectrums of electromagnetic waves viz; visible, infrared, and microwave spectrums are used in remote sensing technology. Several fields in Earth science in addition to geography, land surveying, and geophysics use remote sensing technology. Application of remote sensing includes different fields like crop monitoring, stress detection, canopy analysis, and more. It also helps empowering stakeholders to sustain food security amidst agricultural challenges. Amongst its other uses are in the military, intelligence, business, economic, planning, and humanitarian domains. In many domains, Geographical Information System (GIS) is also needed with remote sensing for resource management and development. In other words, GIS and remote sensing are complementary to each other for any kind of developmental purpose.

Keywords:

Remote sensing, GIS, Agriculture.

4.1 Introduction:

The art and science of gaining information about things from a distance without touching them is known as remote sensing. The science and technology of remote sensing involves using measurements taken from a distance to draw conclusions about material objects without actually touching them. In 1960, A.D Fischer first used the term "remote sensing". Before we proceed to know what is remote sensing first, we have to know about two words viz; remote and sensing. Firstly, remote is simply something which is far away from us and secondly sensing is simply getting information or getting data. Thus, remote sensing is a tool that captures and process information without physical contact. Several fields in Earth science in addition to geography, land surveying, and geophysics use remote sensing.

Amongst its other uses are in the military, intelligence, business, economic, planning, and humanitarian domains. With remote sensing, information on hazardous or remote regions can be acquired. Furthermore, remote sensing ensures that locations or objects remain unaffected throughout the process of substituting laborious and slow on-the-ground data collection.

In many domains, acquiring or assembling the data/information is not enough to get a complete solution; rather integration, analysis and modeling are required for purposeful fulfillment. For example, you are aware of the availability of water resources but you don't have an idea about their suitability for the particular kind of management and planning purposes. Hence, the Geographical Information System (GIS) which is the most efficient tool for gathering, analyzing, manipulating, modeling and retrieving data is equivalently needed with remote sensing for resource management and optimization. In other words, GIS and remote sensing are complementary to each other for any kind of developmental purpose.

4.1.1 Remote Sensing: Principal:

Each substance in the earth simultaneously absorbs and reflects solar radiation. They also emit a certain amount of internal energy. The energy that is absorbed, reflected, and released is identified using remote sensing devices. The device or sensors mounted on a satellite or on an aircraft. "Spectral signature" and "images" are two distinguishing concepts that are used in the detection process. Three Major Domains of Remote sensing viz; Visible and short-wave infrared (0.4 – 2 µm region), Mid wave and Thermal infrared (at around 3 µm, 5 µm, and 8-14 µm), Microwave/RADAR (0.75 cm to 30 cm).

4.1.2 Remote Sensing: Components

- Energy source which will provide electromagnetic energy (EME) to the target or point of interest (sun or transmitter).
- Interaction between radiation and atmosphere.
- Interaction of the energy with the target.
- Energy recording by the sensor after transmitted back from target.
- Processing of digital or pictorial form of data.
- Interpretation and application of data.

4.1.3 Remote Sensing Platform:

A platform is basically the carrier for remote sensing. Two types of platforms are broadly used in remote sensing viz; a) Static platform b) Moving platform.

a) Static platform: It is used to record detail information about the surface very closely. Sensors are mounted to a pole/stand (sometimes hand-held over targeted object). The height of this platform is up to 50m. These are used in experiments for targeted observations.

b) Moving platform: under this category there are two types of platforms:

i) Air borne platform: It is used to record detailed information and images over any part of planet at any point of time. Height range of this type of platform varies from 100m up to 30-40km. Air born platform generally carries Aerial camera, Laser.

Ex. Aircraft, Ultra-Light Vehicles (ULVs), Airship or kites, balloons are used as platform.

ii) Space borne platform: Space borne platforms are mainly satellites that revolve around the earth to study detailed information. Height range of this type of platform varies from 150 km up to 36000 km. Space borne platform generally mounted with multi-spectral scanner. There are generally three types of satellite:

- Geostationary (Equatorial) satellite
- Sun synchronous (Polar) satellite
- Low height satellite or Shuttle orbit

A. Geostationary satellite: The satellite rotates in equatorial orbit (inclination angle 0^0) at altitude 36,000 km. The period of the satellite is equivalent to the period of the Earth. As a result, the position of satellite is always fixed relative to the Earth. This kind of satellites is mainly used for meteorological applications. They are also used as telecommunication satellites.

Example:

INSAT- 2E, 3C, 3D, 4A, 4B etc., Kalpana-1 (originally MetSat-1) (from India), Meteosat (from European Union), NOAA series (from NASA, USA)

B. Sun-synchronous satellite: In sun-synchronous satellites rotate through polar orbit (inclination angle about 90^0) and always passes overhead at the same local solar time (around 10:30 h). They are at altitude of about 700 to 900 km. Sun-synchronous satellites are generally used for earth observation. As they are closed to earth surface, they capture high resolution images and they have wide range of application in agriculture like crop monitoring, disease pest monitoring, yield forecasting etc.

Examples:

IRS-1A, 1B, 1C, 1D, Resourcesat-1, 2, 2A, Cartosat-1, 2, 2A, 2B (from India) Landsat (from NASA, USA), SPOT (from France)

C. Low height satellite or shuttle orbit: These are low altitude orbits at 200 to 300 km height, Inclination angle 30^0-60^0. These satellites are mainly used for specific research and exploration purpose.

Example: Skylab, Shuttle Radar Topography Mission (SRTM) from NASA, USA

4.1.4 Remote Sensing Sensors:

Sensor is basically a tool that collects data by measuring or detecting reflected and emitted radiation from the objects at a distance. In remote sensing, two types of sensors are used:

- Passive sensor
- Active sensor

Passive Sensor: It depends on natural radiation, reflected or emitted from surface. The sunlight, being reflected from the target is the primary source of radiation measured by passive sensors.

Example:

Multispectral Scanner (**MSS),** Operational land Imager (**OLI**), Thematic Mapper (**TM**) - Multispectral Used in Landsat

Linear Imaging Self-Scanning Sensor: LISS-II, LISS-III, LISS-IV - Multispectral used in Indian Satellite –Resourcesat

Active Sensor: Active sensor uses their own source of radiation. The reflected or back-scattered radiation is measured for the study of target surface.

Example:

a. Light detection and ranging sensor (**LIDAR)** that uses a light amplification by stimulated emission of radiation (laser). Wavelength: 903 and 905 nm
b. Radio detection and ranging (**Radar)** emits a series of pulses (microwave radiation) from antenna. The backscattered radiation from target is detected, measured, and timed and a 2D image of the surface is produced. Wavelength: 30 cm and 3 mm.
c. **Scatterometer**- A high-frequency microwave radar.

4.2 Image Characteristics: Concept of Resolution:

A. Spatial Resolution: The degree of detail in an image or a sensor's capacity to differentiate between two distinct objects within an image is referred to as spatial resolution. In photography, spatial resolution is often measured in terms of pixels per inch (PPI) or dots per inch (DPI). In remote sensing Pixel size refers to the ground area represented by one element in the image space. If a small area of ground is represented by a pixel it is called high resolution image. If larger area is represented by the pixel, it is called low resolution image.

B. Spectral Resolution: The capacity of sensors to distinguish fine wavelength intervals is known as spectral resolution. A high spectral resolution indicates that there are more bands in the specified wavelength range.

C. Radiometric Resolution: The amount of information a pixel may contain is referred to as radiometric resolution. Radiometric resolution is expressed in bit. For example, The digital number (DN value) of an 8-bit image ranges from 0 to ($2^8 – 1$), or 0 to 255. This indicates that the specific band reflectance is quantified on a scale from 0 to 255.

D. Temporal Resolution: Temporal refers to revisit time of the satellite with respect to specific ground area. In imaging, temporal resolution refers to the frequency at which consecutive images or frames are captured. The term "temporal resolution" in signal processing describes the precision with which one can estimate the time of signals or events. This is critical in industries like telecommunications, where data transmission and reception depend on the exact timing of signals.

4.3 GIS: Concepts and Definition:

Now a days, people around the globe might be interested in retrieving data in digital format for enriching their knowledge as well as serving their various purposes. In searching of geo-referenced digital information, some tools designed to acquire, present and interact with information that correlates location with measured values are needed. Geographic Information System (GIS) is one of such tools that can capture, store, analyze and manage geographically referenced information and their attributes.

4.3.1 Components of GIS:

Five basic components such as data, hardware, software, method and people are needed for GIS to perform various operations.

- **Data:** In GIS, the primary component is data. The spatial data and the tubular data related to it, can be obtained endogenously or from any secondary source. Spatial data can be integrated with other data resources by GIS and a database management system (DBMS) can also be used for maintaining and managing large data pools.
- **Hardware:** It is basically the computer system on which various GIS software works. From server-based computers to stand alone desktops, GIS runs on a different range of hardware. Several hardware components like digitizer, scanner, plotter, printer, servers etc. function together to operate GIS software smoothly.
- **Software:** The functions and tools that are necessary for storing, analyzing and visualizing the data are provided by GIS. GIS software consists of several components: i) a database management system (DBMS) ii) tools for data input and manipulation iii) tools supporting geographic query, analysis and visualization iv) a graphical user interface (GUI) for accessing the tools easily. Software can be both commercial and open source.
- **Method:** A successful GIS runs based on a well-structured plan and business strategies and these protocols are unique to each organization.
- **People:** The usefulness of GIS technology is limited in the absence of users as they are accountable for maintaining the system and development of practical application. The users can be both who set up and maintain the system (technical expert) and to who leverage it to facilitate their routine work.

4.4 GIS Data Formats:

Raster and Vector are two basic formats of data in GIS.

1.Raster format: Raster data is consisting of a series of cells or pixels arranged in arrays and each of them stores a single value. Essentially, a raster data type refers to any form of digital image such as a scanned image (obtained through an optical scanner from any hard copy), an aerial photograph (collected by an aerial survey), or a satellite image (captured by satellite sensors). The most common file extension types that are used for raster formats are Joint Photographic Expert Group (JPEG), Tagged Interchange File Format (TIFF), Bit Map Image (BMP). Raster data may be categorized into two types based on the colour concept:

a. Binary image: It is a bitonal image where each pixel carries 1bit of information.
b. Grayscale Image: This image is expressed in various tones of gray shades and each pixel contains eight bits of information.

2.Vector Format: Vector data is generally expressed in the forms of points, lines or polygons. Points are kept as coordinates. Lines are represented by an equation or as a series of interconnected vector points. Polygons are delineated through a vector series encircling the area. There are two files which are used to store data: a file encompassing geographic information and a file encompassing attribute information. A third file is also used which stores information for linking positional data with their attributes.

Table 4.1: Comparison of Raster and Vector Formats

Raster	Vector
File size is large	File size is small
High spatial resolution	Low spatial resolution
Data editing and controlling is complicated as it contains huge information	Data editing and controlling is easy as it contains less information
Data can be distorted if scaling is done beyond its native resolution	Resizing of data is flexible without losing resolution

A. GIS Tasks: There are five tasks crucially performed by GIS:

- **Input:** Geographic data needs a conversion into a compatible digital format before being utilized on a GIS platform. The conversion method of data from paper maps to computer files is known as digitization. The updated GIS technology is capable enough to fully automate this process for extensive projects through scanning technology. Presently, various types of geospatial data are already available in GIS-compatible formats. From data suppliers, these data can be collected and loaded into a GIS platform without additional conversion steps.
- **Manipulation:** Data types can be manipulated or transformed according to the needs of a particular project in various ways like rescaling, reprojecting etc. The transformation could be temporary for the purpose of visualization or permanent one needed for analysis. For manipulating spatial data as well as removing unnecessary data, GIS platform provides many tools.
- **Management:** When there are large volumes of data and multiple users are needed, a database management system (DBMS) is more convenient for storing, organizing, and managing the data. The relational design of DBMS is mostly used in GIS where data is stored as compilation of tables and the common fields of distinct tables are used to join them together.
- **Query and Analysis:** GIS has smooth point-and-click query capabilities. Besides, it is a sophisticated analysis tool that can deliver timely information to managers as well as to analysts. GIS truly shows its capabilities during the analysis of geographical data, pattern identification and conducting "what if" situations.
- **Visualization:** At the end, the results of geographic operations can be visualized in various formats (maps, graphs etc.) in GIS. Maps have the potential in store and convey

geographic information efficiently. GIS provides a novel and thrilling tool to advance the science and art of cartography during the map creation process for millennia. The display of a map can be coupled with reports, photographic images, 3D views and other output, including multimedia.

4.5 Applications of Remote Sensing in Agriculture:

Remote sensing is a great tool in modern technology and over all environmental study, involves space-based sensors and sometimes aircrafts for monitoring crop and environment without any physical contact. It can sense the crop characteristic in the form of spectral signature and also able to monitor some unseen factors like soil moisture.

Application of remote sensing includes different fields like crop monitoring, stress detection, canopy analysis, and more, empowering stakeholders to sustain food security amidst agricultural challenges. Some of the uses of remote sensing techniques in different fields in agriculture are discussed below:

4.5.1 Crop Condition Monitoring:

Crop condition monitoring throughout the growing period is very much crucial for management of agricultural produces. Moisture stress due to drought, nutrient stress, excessive moisture stress, high soil salinity levels are the main threats for crops. Remote sensing can detect the changing spectral signature caused by these stresses. This technology can also detect the soil spectral characteristic change due to change in the present nutrient in it. Significant change due to biotic stress like pest and diseases can also be detectable by this technology. For detail study space craft based remote sensing is used now a days. Many scientists have already used remote sensing along with modeling for monitoring the crop condition (Lee et al.,2017).

4.5.2 Stress Detection in Vegetation:

Plant stress can be detected by changing behavior of some plant pigments specially chlorophyll. In stress free condition chlorophyll and other pigments in plant reacts in the visible range of spectrum and high reflectance in the near infra-red range occurred due to multiple scattering in the intercellular air spaces of the spongy mesophyll tissue in leaves. In stressed condition the air spaces reduced as a result reflectance in near infra-red range decreased. Stress causing reduced pigments in leaves also increases the reflectance in red and other visible bands. This changing reflectance characteristic is used as an indicator of stress in this technology. Zhang et al. in year 2003 in California uses hyperspectral remote sensing for detecting the biological stress caused by late blight in tomato.

4.5.3 Canopy Analysis:

The structure and characteristics of vegetation cover is analyzed in remote sensing for canopy analysis typically by using satellite or aerial imagery. Various aspects of vegetation including spatial distribution, biomass, health and over time phenological changes are analyzed in this technology.

Some common methods used in canopy analysis include vegetation indices, canopy height and structure and biomass estimation. Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) or Enhanced Vegetation Index (EVI) are calculated from remote sensing data to quantify vegetation vigor and health. It is one of the oldest methods, Wiegand et al. uses this remote sensing indices in year 1991 for assessing vegetation.

4.5.4 Cropping System Assessment:

Remote sensing is widely used in cropping system assessment and various aspects of agricultural land use and management practices. This approach provides valuable information about the spatial and temporal patterns of the cropping systems.

To identify different crop types and map their spatial distribution across agricultural landscapes, this technology is being successfully used worldwide. The assessment of crop health and vigor is done by spectral indices such as the Normalized Difference Vegetation Index (NDVI) or Enhanced Vegetation Index (EVI).

Combination of different information like crop type health and biomass contain with different field-based observation data are used for estimating the crop yield. This estimation is very much helpful is crop management, marketing, and decision making.

Land use land cover change under different class including different crop type and changes in distribution of land among the land use classes and shifts in cropping intensity can also be monitored using this technology.

Crop water productivity, evaporation rates and soil moisture level can also be evaluated by remote sensing data. It can also successfully assess the crop rotation patterns and cropping system intensification strategies.

4.5.5 Flood and Drought Monitoring:

Flood and drought monitoring using remote sensing involves the use of satellite or aerial imagery to assess and monitor water-related phenomena such as floods and droughts. This approach provides timely and spatially comprehensive information, enabling early detection, assessment, and management of these natural disasters.

- **Flood Monitoring:**

Remote sensing can detect the change in surface water level, and also able to measure the inundated areas. The flooded area is revealed by comparing the pre and post event images. In this case mostly microwave data is used as this wave can penetrate through the clouds. This technology also enables the mapping of the flood affected area and the delineation of flood basins which is a valuable information for emergency services. The evolution of inundation patterns over time, flood dynamics can be monitored by time series analysis of this data. Very recently remote data was used with multi criteria decision making method for assessing flood vulnerability by Farhadi et al. (2022) in Iran.

- **Drought Monitoring:**

Different vegetation indices like Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI) can detect the changes in the vegetation condition associated with water stress.

With the help of passive and active microwave sensors soil moisture levels across large areas can also be estimated. Monitoring soil moisture dynamics helps in assessing drought severity and impacts on agriculture and water resources. The integration of remotely sensed data with ground-based observation data and hydrological models provides spatiotemporal explicit for disaster management, risk assessment.

Remote sensing also facilitates yield forecasting. Ali et al. successfully reviewed different remote sensing tools that could be used for crop yield prediction in 2022. By compiling every aspect of application of remote sensing it is fully established that it is a great tool for agricultural risk management and yield variability and climate change study.

4.6 Applications of GIS in Agriculture:

Geographic information systems (GIS) are an essential tool for crop monitoring and the implementation of targeted and ideal management practices that increase crop productivity. GIS works in tandem with other allied technologies like data analytics, global positioning systems, computational systems, artificial intelligence and remote sensing. Here, some applications of GIS in agriculture are discussed-

4.6.1 Land Suitability Assessment and Land Use Planning:

GIS offers an excellent tool to assess the land quality for particular applications. The GIS-based multi-criteria decision-making (MCDM) method is the most common choice for land use planning researchers. In a study, the weight sensitivity of the GIS-based MCDM model was evaluated for land suitability assessment for irrigated agriculture (Y. Chen et al., 2010). Two-step and three scales and analytic hierarchy processes (AHP) were applied in another study for GIS-based crop suitability assessment (G. Pan and J. Pan, 2011).

4.6.2 Water Resource Management:

One of the most important conditions for satisfying the growing global population's demand for food production is an ample supply of water. Irrigation is the most effective way to meet agriculture's water requirement. The benefits of using GIS technology with remote sensing have already been demonstrated for managing water resources (Teeuw RM, 1995, Brahmabhatt et al. 2000). The combination of GIS and remote sensing was used to do groundwater potential zoning in one of the works (Singh and Prakash, 2002). GIS was connected with the ISAREG irrigation scheduling model in order to produce effective irrigation scheduling recommendations and identify methods to take into account salinity management and water economy (Fortes et al., 2005).

4.6.3 Soil Fertility and Soil Health Management:

Soil fertility and productivity are proportionally related to each other. Determining soil fertility and health is important for site-specific management planning efficiently. In a study, remote sensing and GIS technology were combined to determine soil fertility status (AbdelRahman et al., 2016). The fertility condition and soil maps derived using GIS provide advanced knowledge regarding the suitability of crops for certain land. Soil fertility maps, made by combining GPS and GIS technology are excellent tools for in-depth study of soil condition and these maps have shown to be a useful decision support system when it comes along the issues with food production due to land degradation (Mishra et al., 2014).

4.6.4 Biotic and Abiotic Damage Evaluation and Intervention:

GIS technology offers a potential tool for site-specific pest management. According to a study, information on the geospatial density of the oriental fruit moth, *Grapholitamolesta*, aims to reduce crop damage and pest numbers by applying appropriate mitigation in geographical aspects (Duarte et al., 2015). Besides, GIS is a cost-effective and rapid technology for evaluating the extent of crop damage by pests and diseases. Rapid mapping and quantification of damage caused by natural disasters contributes to overcoming economic losses and serves as a decision support system. In a case study, the effects of severe floods on agricultural output in the Vietnamese province of Quang Nam were evaluated using geographic modelling (Chau et al., 2013). On the other hand, drought risk categories derived from the Normalized Difference Vegetation Index (NDVI) of the MODIS satellite were prepared to assess the spatial pattern of drought (Murad and Islam, 2011).

4.6.5 Crop Health Monitoring and Yield Prediction:

The latest technology such as remote sensing (RS), GPS, and GIS may be utilized to assess and determine the spatiotemporal dynamics of crop production and yield potential. The application of two fundamental partnership techs, RS and GIS, from other partners is said to be the most effective solution for the monitoring of crop health and creating models that can predict crop yield at different spatial scales. NDVI (the most commonly used vegetation index), is found to be efficient for monitoring the crop health and the yield prediction, where GIS tools are utilized to provide spatial context (Maloom et al., 2014).

4.6.6 Precision Farming:

Precision farming, also known as site-specific crop management (SSCM), is the application of technologies and principles to manage the temporal and spatial variability related to all elements of agricultural production. The essential instruments and systems needed to get timely geospatial data on soil, plant, and animal requirements are GPS, GIS, and RS. With the help of these tools, Variable Rate Technology (VRT) systems take all the essential information about a field such as yield, and infestation of pests, diseases, weeds, soil maps and in addition to lowering input costs and increasing agricultural output, they also assess the number of fertilizers, herbicides, insecticides, and other inputs and make sure they are applied correctly, when, and where needed (Strickland et al., 1998).

4.6.7 Biomass Assessment:

When used in conjunction with remote sensing, GIS may be a very useful tool for accurately identifying and evaluating crop wastes as well as for planning the feedstock material for renewable energy projects in a particular region and its economical transportation to power plants. Agricultural production statistics along with rice cropland maps were analyzed in GIS to assess the availability of rice straw as a bioenergy production feedstock (Hiloidhari and Baruah,2014).

4.6.8 Supply Chain Management:

As GIS technology has shown to be extremely helpful in assessing and improving Agricultural supply chains, it is now being used for a greater range of crops and places. The description of the spatial components of safe crop products (SCP) in China and the analysis of supply chain patterns are two significant applications of GIS (Qu XH et al., 2007). It is very desirable to find the best sites for biofuel factories and to create an affordable supply chain for getting biomass to the facility. To do this, one way has integrated two modelling techniques, namely simulation and optimization, with a GIS-based method to create a decision support system (Zhang et al., 2016).

4.7 Conclusion:

The field of remote sensing technologies is expanding daily. Remote sensing is becoming more and more useful for societal purposes owing to new platform types, superior observation with powerful sensors, and contemporary data analysis tools. GIS is still changing our understanding of and relationship to our surroundings. Its multiple applications have the ability to address difficult spatial challenges and promote sustainable growth in a number of industries. In the future, remote sensing and GIS will be extremely helpful for identifying the problems associated with global change as well as for making decisions at localized levels.

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