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GIS & Remote Sensing Techniques in Agriculture

Sukhbir Kaur Gujral
Associate Professor, SGTB Khalsa College, University of Delhi
Email id: sukhbirkaurgujral@gmail.com

Abstract: Geographic Information Systems (GIS) is a system that allows us to display and analyze geographic and tabular data. GIS application in agriculture has been playing an increasingly important role in crop production throughout the world by helping farmers in increasing production, reducing costs, and managing their land resources more efficiently. Using data collected from remote sensors, and also from sensors mounted directly on farm machinery, farmers have improved decision-making capabilities for planning their cultivation to maximize yields. Agricultural mapping plays a vital role in monitoring and management of soil and irrigation of any given farm land. GIS agriculture and agricultural mapping act as an essential tools for management of agricultural sector by acquiring and implementing the accurate information into a mapping environment. GIS agriculture technology helps in improvement of the present systems of acquiring and generating GIS agriculture and resources data. The increased efficiency and profitability that the proper application of technology can provide, has made precision agriculture the hottest developing area within traditional agriculture.

Keywords: Drone, Satellite, Precision farming, CropScape, Real-time mapping.

Introduction

A geographic information system (GIS) is a computer-based tool for capturing, storing, checking, and displaying data related to positions on Earth's surface. It was used back in 1854 (without computers) to map a disease outbreak in the City of London. The first Geographical Information System (GIS) was developed in the early 1960s by the Canadians to store geospatial data and produce maps for the Canadian Land Inventory. This data provided an indication of the land's capability to support agriculture, wildlife, forestry and recreational activities (Longley et al, 2005). Over the past few decades, Remote sensing and GIS has grown exponentially in many sectors of visualization, monitoring, management and potential development. Remote sensing and GIS technology enable agencies to get reliable information of natural and manmade features and interpret appropriately phenomenon occurring over the earth's surface without making any physical contact.

In the present times, GIS is a widely used technology with significant relevance for farmers and the agriculture industry. Satellites, drones, and manned aircraft are used for remote sensing, which is the gathering of information about the earth's surface by scanning it from high altitudes. Drones can help farmers to optimize the use of inputs (seed, fertilizers, water), to react more quickly to threats (weeds, pests, fungi), to save time crop scouting (validate treatment/actions taken), to improve variable-rate prescriptions in real time and estimate yield from a field. In just the past few years, the online (and offline) power and accessibility of GIS and digital mapping both has changed the way farmers are managing their land and performing their most basic tasks (Takor Group, 2017). GIS applications play an important role in the production of crops, both locally and across the globe. Through assisting farmers in increasing production, reducing costs, and providing an effective means of managing land resources, GIS has become an increasingly invaluable resource (AABSyS IT, 2018).

Components of GIS

A working GIS consists of five key components: computer hardware, software, geographic data, people, and methods (Fig 1). GIS software permits users to input data corresponding to a geographic location and create maps and other geographic displays to analyze and present information. The displays typically include points, lines, areas or raster images (from photos or scanned images). GIS mapping is the process of inputting data layers into GIS software to produce a map. Maps present users with legible information that raw data can't display on its own. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation. Maps can be drawn through physical survey, aerial survey, satellites, and drones. GIS has database capability that allows users to store and manipulate entered data and maps. The data can be captured in various scales depending on the use. For example in agriculture, a scale of 1: 2,50,000 is good for macro level planning, while for utilities it has to be of 1 meter resolution. In nutshell, when spatial information or datasets are linked to a map it creates an intelligent map which becomes a versatile tool in the hand of decision makers.

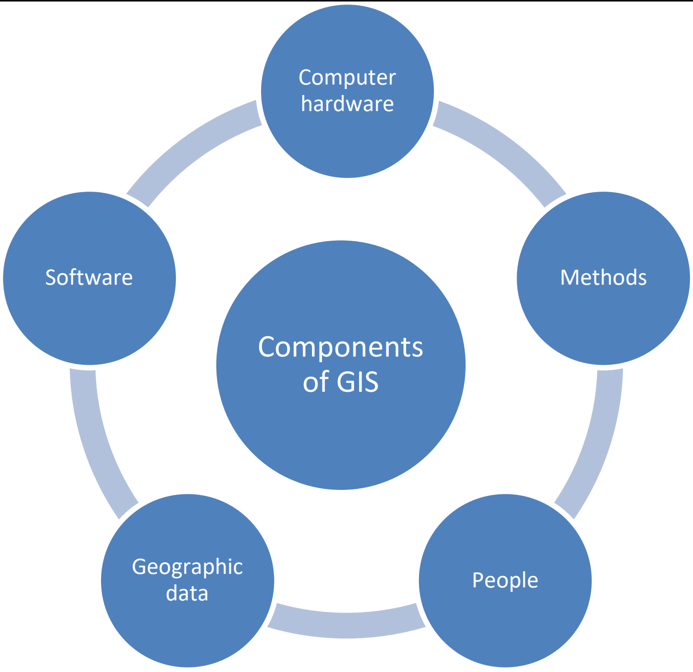

Fig 1: Five Components of Geographical Information System (GIS)

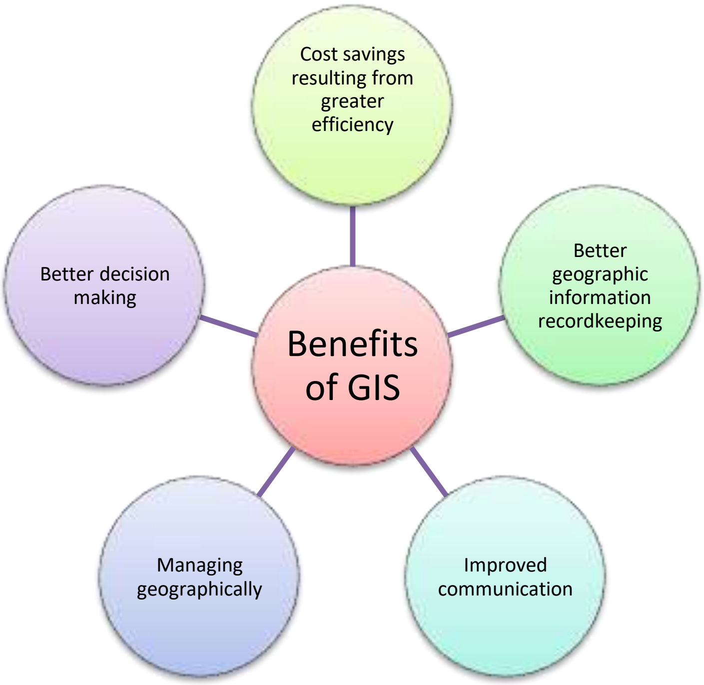

Fig 2: Benefits of Using GIS technology

Applications of GIS

Geographic Information Systems are powerful decision-making tools for any business or industry since these allow the analyzation of environmental, demographic, and topographic data. Data intelligence compiled from GIS applications help various companies, industries, and consumers make informed decisions. Some of the benefits of using GIS technology have been shown in Figure 2.

GIS data can be used in the following everyday life and business sector:

- *Agriculture* – GIS is being used today to analyze cropping patterns, soil data to help determine which crops would do best in certain areas. In the United States, GIS systems are used by the USDA to protect crops, solve crop issues, and investigate fraudulent claims of crop damage as well as give farmers an easy way to access information about their crops season by season.
- *Forest management* - GIS enhances forest management by assisting land owners and forest managers to evaluate and analyze the forest cover, species diversity, age and size of timber, timber density, and volume.
- *Urban planning* – GIS data can help both with the human side of urban expansion and understanding the geographical area.

- *Navigation* – Map applications that are used on smartphones and in vehicles rely heavily on GIS data to keep their maps updated to the second for establishing and monitoring routes.
- *Environment mapping & Pollution control* - Using GIS, a single map could include sites that produce pollution, such as factories, and sites that are sensitive to pollution, such as wetlands and rivers. Such a map would help people determine where water supplies are most at risk.
- *Natural resources management*
- *Crime mapping*
- *Accident analysis and Hot Spot analysis*
- *Disaster management and Mitigation*
- *Management of telecom and network services*
- *Infrastructure mapping*
- *Transportation planning*
- *Municipal GIS : properties as well as other assets management and maintenance*
- *Locating and targeting customers*
- *Flood damage estimation*
- *Planning and Community Development*
- *Dairy industry*
- *Irrigation water management*
- *Pest control and management*
- *Banking*
- *Taxation*
- *Surveying*

Role of GIS in Agriculture

GIS in agriculture has been boosted by the general advancement of technology in the past few decades and has been used for analyzing the land, visualizing field data on a map, and putting those data to work. Powered by GIS, precision farming enables informed decisions and actions through which farmers get the most out of each acre without damaging the environment

Precision farming : Precision farming is the adoption of highly precise set of practices that uses technology to cater to the needs of individual plots and crops. Precision agriculture helps farmers live a debt free life, as production cost and losses are reduced and overall environmental impact is also minimized. GIS is used in precision agriculture to manage spatial information and help farmers make decisions by comparing multiple variables (for example, soils, yield and elevation) to create management zones. Factors such as previous crop yields, terrain specifics, organic matter content, pH, moisture, and soil nutrient levels aid in proper preparation for precise farming. Combine harvesters equipped with GPS tracking units can measure crop yields along with crop quality values like plant water content and chlorophyll levels in real time and at the exact location in the field from which they are harvested.

Variable rate technology (VRT), the component of precision agriculture, enables the data to be put directly to use. It combines farm machinery, control systems, and application equipment to apply precise amounts of growing inputs at exact times or locations. Precision farming with VRT has both economic and environmental advantages. Applying seed, fertilizer, nutrients, or pesticides only where and when they are needed can have a substantial cost savings for the farmer and boost revenues. Additionally, negative environmental impacts from over-application of some chemicals are alleviated, and the use of certain chemicals could potentially be eliminated entirely based on data analysis.

The use of GPS devices by farmers has become an essential tool in the agriculture industry leading to actual mapping of the fields and farmers can actually get site specific and more precise solutions for their problems. For example in fertilizing crops, where machine sensors gather information about the crops, and the GPS records the exact position it is applied on the field. The technology then aids the application of fertilizer only to the areas where it is needed, and can vary the rate of application to target nutrient-deficient sites

(GIS Geography, 2018). This saves money on expensive fertilizers as well as trace elements and the environment from over-application and runoff into local streams and rivers.

Real-time mapping: Geospatial technology in agriculture relies on various tools such as satellites, aircraft, drones, and sensors. These tools are used to construct images and connect them with maps and non-visualized data, resulting in getting a map displaying crop position and health status, topography, soil type, fertilization and other related information. Sensors mounted on satellites, tractors and in fields are constantly collecting data. GIS and other technologies shape this data into information that is accessible and interpretable by farmers and land managers to make efficient and informed decisions for maximum yields (Geospatial World, 2018). GIS tools and online web resources are helping farmers to conduct crop forecasting and manage their agriculture production by utilizing multispectral imagery collected by satellites. Hence, satellites and drones can be used by farmers to make real-time actionable decisions. Monitoring yields, applying nitrogen, using precision water sensors and identifying critical areas for intervention are all valuable uses that this technology can provide (GIS Geography, 2018).

With one of the key farming challenges being the availability and management of water for agricultural purposes, **satellite technology** can collect real-time data from the Earth's surface to assess and monitor the condition of the land. Soil moisture ocean salinity (SMOS), vegetation growth using Landsat imagery, and applying the normalised difference vegetation index (NDVI), as well as a variety of other factors, can all be used to help estimate crop productivity and monitor drought and flooding on a global scale (GIS Geography, 2018). An observation satellite, **Landsat 8**, captures the visible light as well as thermal infrared radiation (TIR) spectrum which can be used to evaluate plant disease, nutrient deficiencies, insect infestation, crop moisture excess as well as shortage, and the maturity of fruits. The recorded data is converted to visible digital imagery and can be applied to general objectives like managing water for irrigation consumption or plant disease detection. One of the greatest benefits of remote sensing is that it is non-invasive and does not negatively impact the area under observation.

Drone technology is useful in collecting more local field data such as plant height and biomass, flora counts, disease and weed presence, nutrient values, elevation and volume calculations. Drones can replace time-consuming tasks, normally performed by scouring fields on foot, to assess qualities of the flora and vegetation. Farmers are thus able to cover more ground, inspecting the health of the crops using aerial imagery and other data that the drone can record.

Uses of GIS & Remote Sensing Techniques in Agricultural Sector:

1. **Crop sown / crop average area estimation**

   Crop sown area estimation is one of the major sections in agriculture Remote Sensing activities. Remote Sensing plays a crucial role in mapping and monitoring various crops sown area estimation. Satellite data such as Sentinel-1, 2, Landsat-8, World View-3, LISS-IV provide precise level crop sown area and helps in crop loss assessment due to various catastrophic disasters.

2. **Normalized difference vegetation index (NDVI)**

   This is primarily used for the assessment of vegetation dynamics, particularly in determining the crop health status. With NDVI, the possibility of understanding the crop phenology escalates, as it explains the crop chronology and their relationship with weather and climate (season). NDVI is measured using mathematical calculation of spectral bands within the satellite image which measures the health of vegetation, as it has a robust correlation with green biomass indicating healthy vegetation or crop.

3. **Crop diseases identification**

Remote Sensing technology provides information of spatial distribution of diseases and pests over a large area with relatively low cost. With the help of satellite imagery and spatial analysis techniques, areas having crops infected with Mealybug, Plant Hopper, and White Fly are identified to get an overview for evaluating the potentially infected areas.

4. **Soil properties**

Soil properties are crucial in farm management practices as it has a direct impact on the yield output. Soil is a very important aspect of agriculture with characteristics like soil pH, soil organic matter, soil texture, soil moisture among many others. These characteristics infer information about soil moisture mapping as well as soil condition by observing what happens on the surface in terms of vegetation growth. Change in farming system and land management results in soil change which compromises the current and future capacity for primary production and provision of crops by micro-nutrition mapping.

5. **Flood impact**

Every year in the Kharif season in India, the majority of the agricultural area is damaged due to flash floods or excessive rainfall. Satellite Remote Sensing provides significant information through the use of satellite imagery along with ground-based data collected from ground surveying teams, to compute precise damage assessment. In case of flood due to rainfall, the excess amount of water caused by the precipitation affects the agricultural area where the water drainage system is absent causing inundation. Flood due to overflow ultimately forms small tributaries and joins the river, creating a situation of flood in the vicinity of river banks and river plains. The damage assessment of floods can significantly improve the role of land use planning in managing flood risk.

6. **NATCAT modelling**

Natural Catastrophe modelling is a system to estimate the real-time or possible forecast of risk assessment, using the probabilistic approach to predict the outcome and behaviour of natural hazards. This includes risk mapping and measuring hazards through computer-simulated catastrophe models where scientific studies and historical occurrences are linked with advanced information technology and geographic information system (using Remote Sensing & GIS). Flood risk maps are prepared depending on the estimated depth of inundation of flood. The estimation is commonly derived from various hydrological and remotely sensed data where the process ensures that areas having a higher depth of inundation will be assigned a high 'hazard denomination'.

7. **Drone image analysis for crop damage assessment**

Drone image analysis is very useful in micro-level crop assessment for crop loss due to hailstorm, horticulture tree counting, diseases, and many more. The accuracy of drone image data is directly related to the spatial resolution of the input imagery as the spatial resolution is very high ranging from 50 cm and can be increased as per requirement.

8. **Crop yield prediction**

Using GIS technique, the farmers can very well assess about the tentative yield they are going to get, keeping in view the health of the crop using the colour image of high resolution satellite data (HR). As per the normal opinion of the users, the prediction was found to be about 90% correct.

Strategic Uses for GIS in Agriculture

❖ **Strategic planning**

GIS can present combinations of map layers to address different agricultural problems. For example, depending on the size of their farm and presence of factors that are important to the type of farm, a farmer might view and analyse GIS maps of soil properties, average rainfall, elevation, and more, all in one map. Using these detailed maps, they can plan the most efficient and cost-effective way to use their land.

❖ **Water management**

Another important use for GIS in agriculture is water management. Using GIS, the farmer can determine where rain water is draining too quickly or too slowly so that either engineering steps can be taken to reroute its flow or chemicals can be applied to improve the internal drainage of the soil. In areas where water flows too quickly, the result can be crop loss and soil erosion. In areas where flows too slowly, crop growth could be hampered, sometimes referred to as plants having 'wet feet'.

❖ **Crop suitability mapping**

Soil characteristic maps can help with crop planning. A map of soil themes such as salinity, internal drainage, pH and various aspect of soil chemistry that are important to the crop a farmer is planning on planting, can provide an important information backdrop for understanding whether or not a crop will grow successfully in an area.
AABSyS IT uses GIS application in agriculture sector such as GIS agriculture for improving present method of acquiring and generating agricultural and resources data.

Meeting the Future Demand for Food

One of the most important functions of GIS and mapping is to be used to raise awareness of such issues as food scarcity, and locating areas that are in need of assistance. Web mapping tools like the Institute of the Environment and the University of Minnesota's Feeding the World map, and the Food and Agriculture organisation of the United Nations (FAO)'s World Hunger Map provide a unique view of global food production. Through establishing the underlying causes of food insecurity, GIS data and technology are helping to safeguard the areas and communities affected by food scarcity.

For today's governing agencies, the need to secure the necessary food sources to support the continuous rise in population has been a growing concern. It has been estimated that the current production of crops will need to double by 2050 in order to meet future needs for food (GIS Geography, 2018). For such purposes, GIS is not only being used for real-time analyses, but also to compare historical data. Landsat satellite imagery can be used to assess historical trends of agricultural land use over time. This can help to predict and plan for the amount of arable land needed to supply food to the future populations.

In the United States of America, the National Agricultural Statistics Services (NASS) have developed an online mapping application called **CropScape**. This application can provide area estimates of crops, estimate the type of crop growing and how large the size of its yield could be. Not just for privatised use, government agencies have used CropScape data to assess national issues such as food security, pesticide control and changes to land-use (NASS, 2018). By using land-use and primary food crop statistics, along with data collected by satellites and mobile devices to identify areas in need and underlying causes of food insecurity, GIS is also instrumental in the efforts to end global hunger.

Since the World GIS day has already been celebrated on November 2021, it is a great time to appreciate just how much this technology has influenced the productivity of farmers, agriculture specialists and environmentalists alike. Therefore, GIS has become indispensable for mapping agricultural activities.The Agricultural Geographic Information System Laboratory (AGIS) developed at the University of California, Davis, is deeply involved in the advancement of the agriculture/GIS relationship. This AGIS lab researches the effects a watershed area has on soil nutrients, the use and movement of pesticides on crops, mapping water use and availability in rural agricultural areas as well as cities, tracking potential plant diseases, and expanding the GIS capabilities to cover the entire state. In addition to expanding the potential uses of GIS, the AGIS Laboratory is dedicated to disseminating the information they gather to local farmers, wineries, and city officials to help promote healthy change in behaviours that affect the agricultural outputs of California.

With the permeation of technology in the global culture, it is possible that in a few years GIS could be available to rural farmers in the developing world to help them grow better crops, feed their families, and produce enough food to ship to neighbouring areas. Farmers in severe-weather prone areas (like flood plains or drought zones) would be able to predict what this weather could do to crops, could move fields to better geographic locations, and know how to irrigate based on local water resources and weather patterns. The world food crisis could be alleviated by the use of GIS.

Advantages and Limitations of GIS

Advantages: The use of GIS data has a profound impact on business and industry, as well as on the general public. It allows people to see the world in a different way by mapping the position and quantity of things, mapping the density of people and objects, and mapping any changes that occur.

- Geographic Information System (GIS) combines layers of information about a place to give a better understanding of that place.
- GIS allows us to find out what is happening inside a specific area or nearby to a specific area.
- GIS links maps to databases and creates a visualization of data, and hence, allows interactivity between the map and the data in a database.
- Persons with GIS degree can opt for multiple career options (Fig 3).

Limitations: GIS technology might be considered as expensive software. It requires enormous data inputs that are needed to be practical for some other tasks.

- Lack of awareness about the robustness of the technology.
- Computer capacity and speed and the user's knowledge of using the software
- Learning curve on GIS software can be long.
- It shows spatial relationships but does not provide absolute solutions.
- Integration with traditional map is difficult.
- Since the earth is round and so there would be geographic error that will increase as one gets in a larger scale.

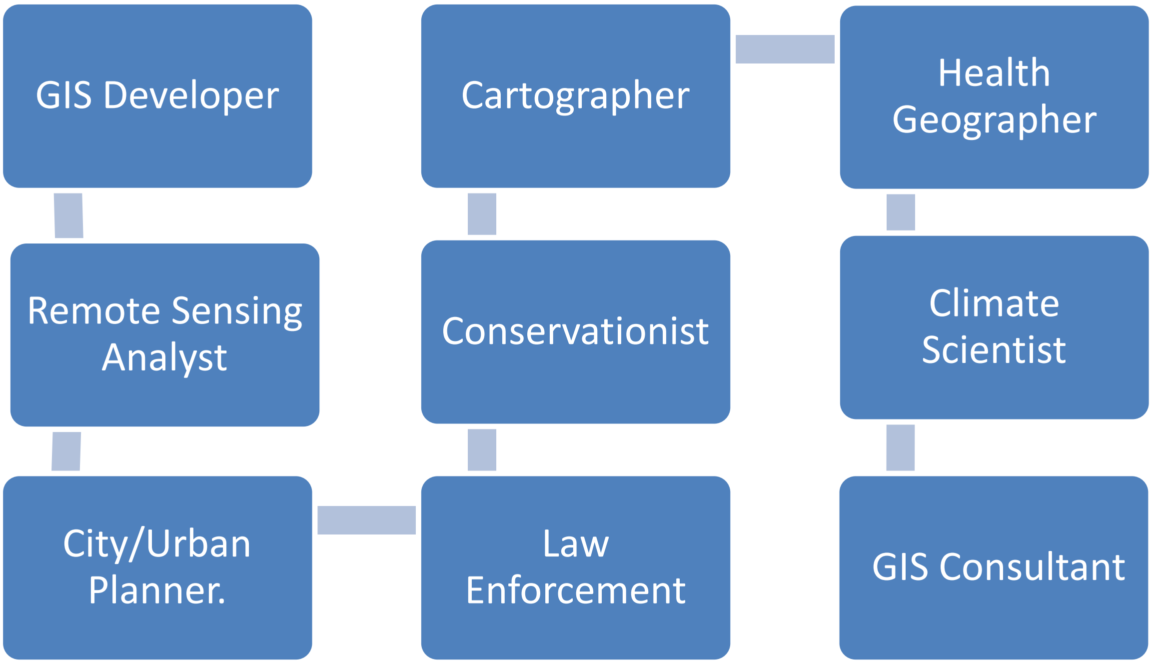

Fig 3: Multiple Career Options with GIS Degree

In fact, GIS & remote sensing is playing a very vital role specifically in the field of agriculture. Farmers rely on integrated data monitoring and technological improvements for smart and sensitive agriculture. GIS can be used by agricultural agencies to support pesticide and food safety regulations, show economic impacts of policy, reveal environmental health issues, depict animal health and welfare issues, record data about an area, and arbitrate land use conflicts. Map my India has introduced the MAPPLS app (Maps + technologies) for a better future for India, and now for the world. The Indian Prime Minister, Narendra Modi, on 1st anniversary of the release of the Government of India's Geospatial Guidelines emphasized the role of Geospatial technology in transformation of agriculture industry.

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