International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 2597-2608, 2023; Article no.IJECC.109153
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

A Comprehensive Review of Application of RS, GIS and GPS in Agriculture India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i113428

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/109153

Review Article

Received: 29/08/2023
Accepted: 06/11/2023
Published: 09/11/2023

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ABSTRACT

Food and fibre, two of humanity's most fundamental requirements, are met by agriculture. In the last century, new farming methods have been introduced, such as the Green Revolution, which has enabled agriculture to keep up with the increasing demand for food and other agricultural goods. But population growth, rising income levels, and increased food demand will probably put more stress on the planet's natural resources. As the detrimental effects of agriculture on the environment become more widely acknowledged, new methods and strategies need to be able to meet future food needs while preserving or lessening the environmental footprint of agriculture. Informed management decisions aiming at increasing crop production could be made with the help of emerging technologies like artificial intelligence (AI), Internet of Things (IoT), big data analysis, and geospatial technology. Many scientists, engineers, agronomists, and researchers use a variety of technologies each year to boost agricultural output while minimising pollution, yet these efforts have a negative environmental impact. Precision agriculture examines how technology might be applied to enhance agricultural practises relative to traditional methods while minimising negative environmental effects. Precision agriculture greatly benefits from the deployment of remote sensing technologies, which also presents new chances to enhance agricultural practises. Geographically, latitude and longitude data can be recorded for field data (slope, aspect, nutrients, and yield) using the global positioning system (GPS). Because of its ability to continuously determine and record the right position, it can build a larger database for the user. Geographic Information Systems (GIS), which can handle and store these data, are needed for the additional analysis. This review will offer you an overview of Remote Sensing technology, GPS, and GIS, and how it might be used for precision agriculture.

Keywords: Big data analysis; disease and pest management; nutrient management; satellite remote sensing; UAV; vegetation indices; water management.

1. INTRODUCTION

Global food consumption has increased dramatically and is predicted to reach 59–98% by 2050 [1]. But there are rising worries that the agricultural food production systems cannot meet the increased demand, particularly in developing countries, which would lead to a rise in food insecurity [2]. Food insecurity is also caused in part by the inefficiencies of the food production systems [3]. It is a monumental effort for government and policymakers to figure out how to best support expanded food production without endangering energy, the environment, or land and water resources [4].

The majority of food production in many low- and middle-income countries (LMICs) is centred on rural areas, with smallholder and subsistence farmers predominate. Improving the sustainability of smallholder farms necessitates providing them with actionable information that helps them make informed decisions and put those decisions into practise in ways that could boost farm output and sustainability. Sustainable production techniques [5,6] that support production-efficiency-enhancement and better agronomic practises are required in efforts to alter the feeble and frequently inefficient traditional subsistence agriculture practises. These include incorporating biodiversity solutions into sustainable food production systems, planting climate-resilient crops, high-yielding crop types, crop yield forecasts, and integrated pest control [7,8]. In the end, the implementation of these cutting-edge treatments would necessitate the adoption of extensive, current geographical and non-spatial datasets as well as sophisticated GIS technology capable of combining and synthesising social, spatial, economic, demographic, and environmental data in agriculture. Evidence-based geographic information that enhances our comprehension of agriculture sustainability and helps to promote improved policies and decision-making processes will be the result of this synthesis.

High-resolution satellite images and digital spatial data can be obtained and operationalized thanks to recent advancements in Geographic Information Systems (GIS), Remote Sensing (RS), and Geographic Positioning Systems (GPS) technology [9].

These geographical data have facilitated research into the spatial relationships between environmental, social, physical, and agroecological complexity and how they impact agricultural sustainability in the field of agriculture. A variety of geospatial information management tools and techniques are available to users of GIS technology, enabling them to gather, store, integrate, query, display, and analyse geospatial data at different sizes [10]. Remote sensing technology uses sensors installed on various platforms, such as satellites, unmanned aerial vehicles (UAVs) and manned drones, to gather data about crops and soil. Computers then process this data to support agricultural decision-making systems [11,12].

From the standpoint of farmers' varying access to local resources, infrastructure, and services, as well as to the vital services and infrastructure already present in a community, the spatial context of agriculture can be understood. The data comprising all of these elements can be broken down into nested spatial layers in a GIS system, each with a geographic coordinate derived from GPS data that roots it in the local geography [13]. Then, these spatial layers can be processed and analysed in a GIS system in a variety of ways to forecast agricultural trends, expose crop and soil conditions and spatial interconnections, monitor pests, track changes in land use, and aid in the conservation of biodiversity [14–17]. They can be used to map agricultural production barriers and identify their spatial locations, as well as to uncover new data that could enhance agricultural sustainability.

Recently, the growing complexity of agricultural production systems has piqued the interest of policymakers in learning more about how to use advanced GIS, RS, and GPS technologies to exploit the spatial aspect or "dimension" of agriculture in order to increase agricultural productivity and improve production practises [18,19]. Better spatial explicit frameworks that facilitate the construction of dynamic agricultural databases and interactive systems are now more likely to be developed as a result of the integration of GIS technology in agriculture [20]. These database systems provide exact positioning data and real-time interaction with spatially referenced agriculture data, hence improving decision-making frameworks. This has led to the emergence of new agricultural GIS fields. These comprise climate change detection, automated farm systems, agricultural yield forecasts, precision agriculture, and real-time crop output monitoring [11,12,21]. Food security and agricultural productivity could both be enhanced by these.

Several recent comprehensive literature reviews have been carried out with the aim of bringing to light and compiling the different applications of GIS, RS, and GPS technology in the agriculture sector. García-Berná et al. [11] focused on the existing trend and the new potential in agriculture that come with remote sensing technology through a thorough mapping research. Their research revealed a rise in the use of RS technologies for the collection and extraction of georeferenced data from unmanned aerial vehicles and satellite imagery.

Numerous fields have benefited from the application of spatial data from these technologies, such as the monitoring of water and nutrients in plants, the extraction of farmland parameters, the calculation of crop growth and yield, and the identification of weeds and diseases. The authors did not go into detail on how this application might be used to enhance spatially-based agriculture policymaking. The review by Al-Ismaili [22] emphasised the combined use of RS and GIS methods in precision farming as well as in the mapping, identification, and categorization of greenhouses using satellite data and aerial photos. It was not explained how a method like this may be applied to improve policymaking. Weiss et al. [12] conducted a meta-review in which they emphasised the recent advancements in RS that can be used to improve crop breeding, agricultural land use monitoring, crop yield forecasts, and biodiversity loss. Sharma, Kamble, and Gunasekaran's study [23] concentrated on the ways that precision agriculture has benefited from the usage of GIS data applications. To help with the application of big GIS data in the agriculture supply chain, the authors presented the "Big GIS Analytic" framework. Additionally, their methodology establishes a theoretical framework for enhancing the quality of GIS data application in agriculture in order to boost productivity. These studies aid in our comprehension of the advancements in GIS and RS applications in agricultural production systems. Nevertheless, it doesn't appear that the current systematic studies explain specifically how GIS and RS technologies could improve how the spatial aspect of agriculture is included into frameworks and actions for policy.

2. GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information System (GIS) is regarded as the brains behind precision agriculture because of its ability to facilitate feature and location data collection, storage, retrieval, and analysis. It also plays a vital part in data-driven solutions, such site-specific management [32]. Several layers of information are stored on digital GIS maps, which set them apart from conventional maps. Each layer contains a map or information about a specific attribute, such as yield, insect infestation, nutrient status, precipitation, soil survey, etc. Furthermore, GIS offers analytical power by utilising statistical instruments and geospatial analytics to enable the extraction of connections between features. The insights obtained in this way are useful for making decisions regarding management strategies.

3. GLOBAL POSITIONING SYSTEM (GPS)

With the help of this satellite-based positioning and navigation system, positional information may be ascertained by obtaining a location's latitude, longitude, and elevation. With the use of GPS receiver location data, farmers and researchers can accurately identify fields, map field boundaries, water features, infested or problematic areas, and comprehend the relationship between various other attributes both inside and outside the boundaries of a given field. Precision agriculture's key components of increased production and lower input costs are made possible by the site-specific application of water, fertilisers, herbicides, and pesticides made possible by such high-fidelity field mapping.

4. REMOTE SENSING (RS)

The field of agriculture has witnessed a revolution in crop monitoring and productivity-boosting interventions through the numerous methodologies and applications of remote sensing [33,34]. For precision agriculture to be implemented, RS is essential in conjunction with GPS, GIS, and other tools. This combination plays a key role in enabling a number of applications that serve as the foundation for managing fields according to specific sites. These applications include soil mapping, crop growth monitoring, estimation of soil moisture and fertility, detection of biotic (drought and flood) and abiotic (pests and diseases) stresses, and yield estimation.

5. CROP DEVELOPMENT AND DAMAGE ASSESSMENT

The amount of land penetration can be assessed by employing Remote Sensing technology. A proportion of crops that have progressed and those that have been harmed on farmlands.

6. ANALYSIS OF CROPPING SYSTEMS AND HORTICULTURE

Planting systems of different crops can be examined by employing Remote Sensing technology. The horticultural sector can also use these technology for flower growth through which, with the aid of numerous analyses, we may forecast and examine the pattern of flower growth.

7. CROP IDENTIFICATION

Variety of crops can be identified with the aid of Remote Sensing technology. We must keep an eye on our crops if they exhibit any odd traits. Additionally, the data that was gathered was brought to labs to examine various facets of crops and crop culture.

8. CROP ACREAGE ESTIMATION

Using remote sensing technologies, we may calculate the amount of agricultural area on which to grow our crop. Whenever we estimate agricultural lands manually, the process is usually quite large because of the enormous acreages involved.

9. EVALUATION OF CROP HEALTH AND STRESS DETECTION

With the use of remote sensing technologies, we are able to evaluate both the health and stress of crops. Moreover, the crop's quality can be determined using these statistics.

10. DATES FOR PLANTING AND HARVESTING

Farmers can now forecast the seasons or dates for planting and harvesting each crop by employing remote sensing technology to observe a wide range of factors, such as soil types and weather patterns.

11. CROP YIELD ESTIMATION AND MODELLING

Experts and farmers can use remote sensing technologies to estimate the projected crop yield for a given piece of land by analysing the crop's quality and size.

12. DISEASE AND PEST IDENTIFICATION

We can identify agricultural pests and provide information on effective pest management techniques by employing remote sensing technologies. in order to eradicate the pests and this disease from the land.

13. ESTIMATION OF SOIL MOISTURE

We can estimate the moisture content of the soil by utilising remote sensing technologies. These technologies enable us to obtain data on soil moisture, which is useful in estimating the amount of moisture present in the soil and the kind of crop that may be planted there.

14. APPLICATIONS OF GIS

With the advent of digital agriculture, which is regarded as the fourth agricultural revolution, farming has completely changed as a result of advancements in robotics, sensors, artificial intelligence, geospatial technology, and other tools and technologies. Image and non-image data, as well as spatial context, are needed to accurately identify the trouble spots in crops and to monitor and manage every stage of the complete agriculture value chain. With the use of its partner technologies, such as GPS and remote sensing, and its component tools and analytical modules, GIS offers clear and easy-to-understand information visualisation for data-driven decision making aimed at enhancing crop productivity. Although GIS has been utilised for agricultural purposes for a while, the number of uses has increased significantly in recent years as a result of advancements in technology. The most popular and recently developed applications are listed and discussed below.

15. MANAGEMENT OF IRRIGATION WATER

In order to minimise crop water stress and achieve the best possible crop development and production, irrigation application timing and rate are crucial. Depending on a number of variables, such as the availability of water, the farm's current infrastructure for managing it (such as the type and storage of irrigation systems), local and regional water regulations, the size and economic standing of the farm, the farmer's level of expertise, and others, farmers employ a variety of irrigation management techniques [24,25].

Based on their past knowledge or experience of farming, soils, and climate at the location, many farmers apply consistent irrigation at regular intervals [26]. Based on the observed soil moisture data and crop/plant water requirements, large commercial farmers use soil moisture monitoring systems (wired or wireless moisture sensors) to irrigate (automatically or manually operated mode) [26,27]. According to the observed climate and weather in the area, local and regional agricultural authorities may offer irrigation advise services [28,29].

Virtually all of these traditional farming methods use a fixed irrigation rate across the field, not accounting for any fluctuation within the field. When using variable rate irrigation with widely used irrigation systems like a centre pivot, remote sensing data can assist in identifying the variations within the field. Applying fertiliser at a variable rate can assist reduce water and nutrient losses while achieving consistently high yields across the field in the face of extreme wet and dry conditions [30,31]. A variety of crop water demand indicators, including ET, soil moisture, and crop water stress, are determined using remote sensing photos that are taken several times over a growing season. These indicators help with accurate irrigation scheduling and crop water requirement estimation.

16. PLANNING FOR LAND USE AND EVALUATING LAND SUITABILITY

Currently, there is a shortage of arable land and a problem to feed billions of people. As a result, we must maximise the advantages of our usage of natural resources. GIS offers a great platform for evaluating a piece of land's suitability for a certain use. Researchers most often choose the multi-criteria decision-making (MCDM) technique based on GIS for land use planning. The distribution of soil types, soil textures, buried deep underground water levels, soil fertility, soil pollution, slopes, hydraulic conductivity of soil (Ks), soil texture (ST), depth to water-table (DTW), electrical conductivity of groundwater (ECw), topography, climate, and satellite data are just a few of the features that researchers can use to identify the various interactions, dependencies, and effects of these interacting factors on sustainable land use.

The weight sensitivity of the MCDM model for assessing land suitability for irrigated agriculture was assessed by Chen et al. [35]. Their goal was to investigate how altering the input feature weights might affect the model's output. The findings indicated that sensitivity had a significant impact, and as a result, it was advised to place extra focus on this requirement. To assess agricultural practises in mountainous areas, Zolekar and Bhagat [36] used IRS P6 LISS-IV satellite imagery as input for a GIS-based MCDM model. Correlation analysis and recommendations from scientific literature were used to determine the ranking of influential criteria. The evaluation of land suitability benefited from the combined use of GIS and remote sensing. Three scales and two-step analytic hierarchy processes (AHP) were used by Pan & Pan [37] for GIS-based crop suitability assessment. They have underlined how crucial it is to choose relevant evaluation elements, recommended taking into account characteristics that significantly differ, managing land use, and avoiding causation. After using this feature selection method, the AHP output showed spatial distinctness. On the basis of land suitability maps, the authors have suggested suitable land use. In a different study, [38] chose the characteristics according to growth requirements in order to assess the appropriateness of the ground for growing wheat. Citrus crop site suitability was evaluated by evaluating the interdependence of strategic input variables using the Analytic Network Process (ANP) model [39]. Important variables for optimising yield and reducing production loss were found using the ANP in conjunction with the GIS-MCDM. In calcareous and saline-sodic soils, AHP combined with geostatistics has demonstrated its value in mapping the suitability of land for maize cultivation [40]. Planning for land reclamation with appropriate conservation practises is made possible by these potent GIS tools.

17. MANAGEMENT OF FERTILITY AND SOIL HEALTH

Productivity is directly correlated with soil fertility. It regulates the crop's access to water and nutrients. Numerous problems, including pollution, sealing, overgrazing, waterlogging, excessive use of agricultural pesticides, and erosion, have contributed to the degradation of soil fertility. For the purpose of organising efficient site-specific management or precision farming techniques, it is important to ascertain the fertility and health of the soil [41,42,43]. In order to measure the soil fertility state, a variety of features are commonly utilised, including soil macronutrients (N, P, and K), micronutrients (Zn, Mn, and Fe), pH, soil organic carbon (SOC), water holding capacity, erosion status, and moisture content [44,45,46,47]. The most widely used geospatial analysis approaches that give decision-makers access to the spatiotemporal variability of soil health and fertility status are spatial interpolation, Multi-Criteria Decision Analysis (MCDA) [48,49,50,51], and Ordered Weighted Averaging (OWA) [52,53,54,55].

The state of soil erosion is a crucial factor in evaluating the quality of the soil, and the geographical variation in erosion provides a clear picture for agricultural planning [56]. It was shown that the Inverse Distance Weighted (IDW) method's geospatial maps of soil erodibility are an excellent tool for supporting land use planning at the sub-watershed level. In order to evaluate the state of soil fertility, AbdelRahman et al. [57] integrated remote sensing and GIS technologies. In order to determine the geographical variance of soil erosion and nutrient availability, they gathered soil nutrient field data, employed a geostatistical model, and classified land uses using LISS III and IV images using the RUSLE approach. In a different study, [58,79] generated soil nutrient maps using the IDW model, homogenised the maps using the OWA approach, and then utilised the homogenised maps as input for a fuzzy inference system to map soil fertility. SOC, total N, total P, total K, available N, available P, available K, pH value, and cation exchange capacity were all used as fuzzy mathematics indicators in ArcGIS to show that the soil fertility of mid- and low-yielding fields was low and directly correlated with the configuration of the soil profile [59,80]. Crop productivity and soil fertility are well correlated, and field-specific crop suitability can be predicted in advance using GIS-based soil mapping and fertility status.

18. EVALUATION AND MITIGATION OF BIOTIC AND ABIOTIC DAMAGE

According to studies, biotic crop damage brought on by fungus, insects, and other pests can result in a yield loss of 15–70% [60,61,62]. This scenario has an effect on farmers' economies as well as the supply and demand chains. The crops are vulnerable to pests and diseases because to the fluctuating weather patterns. While the availability of crop protection techniques is helpful in addressing crop health, the harm caused by pests and diseases is uncontrollable due to a lack of timely information. The use of GIS technology in site-specific pest and disease management has enormous promise. Farmers can stop crop declines and financial losses with the help of remote sensing and GIS-based forewarning systems. Forecasting systems for pests and diseases, according to Ranjan and Vinayak [63], should enable farmers to deploy control measures ahead of time in order to save production costs. In addition to serving as a warning system, the pest population density map is essential for pinpointing hotspots and providing farmers with advice. By using regionally appropriate management techniques, information regarding the geospatial density of the oriental fruit moth, Grapholita molesta, has the potential to reduce crop damage and pest population, according to [64]. Two polyphagous and invasive Icerya species have different geographic distributions now than they did in the past, which amply demonstrated how climate change affects pest assault patterns [65]. Farmers, agricultural specialists, and policymakers may create management plans to fend off pest attacks in the future with the help of these maps showing the location of pests. Given the cases of abrupt outbreaks of autumn armyworm (Spodoptera frugiperda) and cutworm (Agrotis ipsilon) on continents other than their usual geographical locations, tracking the migratory patterns of pests is crucial [66,67,68]. In order to monitor the habitats of pest species like Lygus hesperus, the western tarnished plant bug, and migratory and Australian plague locusts, remote sensing and geographic information systems (GIS) are crucial tools [69,70]. When determining the degree of crop damage caused by pests and diseases, remote sensing and GIS are quick and affordable technologies to use [71]. Researchers have shown that using remote sensing imageries, it is possible to map the severity and identify different pest and disease types [72,73,74]. Important spatial data regarding the damaged agricultural acreage and its trend over several years and across various geographic units is contained in these damage assessment maps. These maps could be useful for farmers seeking insurance settlements as well as for those requesting government perks and subsidies.

19. CROP OBSERVATION AND YIELD FORECASTING

In order to estimate economic return and evaluate food production, which aids in managing food security, it is essential to monitor crop growth, health, and yield prediction accuracy or near accuracy. Numerous research shows that using conventional techniques to estimate agricultural production could result in erroneous crop area evaluation and unsatisfactory assessment [75,76]. Moreover, gathering crop and yield data using these approaches is costly, time-consuming, and labor-intensive. The ability to evaluate the temporal and spatial variability of crop dynamics and yield output is where technologies such as remote sensing (RS), GPS, and GIS come in very handy [77,81]. With the necessary assistance from other technologies, the two main partner technologies RS and GIScan be used to effectively monitor crop health and create models that forecast agricultural yields at various spatial scales. While crop health may be monitored and yield predictions can be made with remotely sensed imageries and related analytics, geographic information system (GIS) technology makes it possible to gather, store, retrieve, and visualise data that is connected spatially. Crop health evaluation is made possible by the use of remotely sensed geospatial data collected by satellites, aeroplanes, or unmanned aerial vehicles (UAVs). This data can be used to learn more about the traits of the soils that promote crop growth as well as various crop aspects. The collected data can be utilised to evaluate overall health, disease or insect infestations, or growth anomalies brought on by abiotic stressors like drought. Predictions of expected yields based on crop growth and health are provided by geospatial data gathered in a spatiotemporal way and the related analysis tools, which aid in evaluating changes in crop health and allowing management interventions. Determining vegetation indices, which are based on surface reflectance from crop canopies at two or more wavelengths, is a widely used technique for evaluating crop health. There are additional examples where damage to some high-value crops was assessed using RS and GIS together. One crop in particular, cranberries, shows drastic fluctuations in crop production because of the properties of the soil, which in turn affect the availability of nutrients and water. [78] have produced a spatial variation map for the crop using GIS, GPS, and RS, allowing for the investigation of crop losses within fields or across the entire field.

20. CONCLUSION

In recent years, there has been a significant surge in the application and recognition of RS, GPS and GIS in agriculture. This can be attributed to the development of digital technologies that have made RS and GIS as tools for problem solving and decision making. These tools has been used for evaluating crops, soils, and their surroundings. This can be attributed to the development of digital technologies, which have made GIS a vital tool for evaluating crops, soils, and their surroundings. This chapter covers the usage of GIS throughout the entire agricultural value chain. Apart from its traditional and widespread applications in planning land suitability and use, managing water, soil, and biotic and abiotic stresses, and high fidelity crop monitoring, yield prediction, precision farming, and supply chain management for primary produce and biomass utilisation for energy production, the introduction of digital agricultural tools and technologies has further enhanced the potential of GIS. These valuable geospatial tools provides location/spatial intelligence that is necessary for enhancing the productivity and profitability of farms through precision farming. They provide accurate, inexpensive geo-referenced data within a short period of time and also, possess the ability to collect, store, analyse and present data/information in real time. These attributes have further elevated the relevance of these tools. RS and GIS is essential to achieving sustainable agricultural productivity because of its many applications, both current and emerging, and its ability to work with both older and newer partner technologies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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