

Review Article

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

India

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 during the Green Revolution, which has enabled agriculture to keep up with the increasing demand for food and other agricultural goods. But further 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

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 predominating. Improving the sustainability of smallholder farms necessitates providing them with actionable information that helps them make informed decisions and put those decisions into practice in ways that could boost farm output and sustainability. Sustainable production techniques [5,6] that support production-efficiency-enhancement and better agronomic practices are required in efforts to alter the feeble and frequently inefficient traditional subsistence agriculture practices. 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 agriculture 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 agriculture 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 practices [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.

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.

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.

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.

Crop development and damage assessment

We can assess the amount of land penetration by employing remote sensing technology. a proportion of crops that have progressed and those that have been harmed on farmlands.

Analysis of Cropping Systems and Horticulture

We can examine the planting systems of different crops 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.

Crop Identification

We are able to identify crops with the use 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.

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.

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.

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.

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.

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.

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.

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.

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.

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 pictures 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.

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.

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, *Grapholithamolesta*, 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 (*Agrotisipsilon*) 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 photos, 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.

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 shown 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 GIS can 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 photos 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 photos 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.

Conclusion

In recent years, there has been a significant surge in the application and recognition of Geographic Information System (GIS) in agriculture. 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. GIS is a valuable tool for providing location/spatial intelligence, which is necessary for enhancing the productivity and profitability of farms through precision farming. Its many capabilities and insights, including the latest improvements to collect and analyse data in real time, have further elevated its significance. 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.

References

1. Valin, H.; Sands, R.; Van Der Mensbrughe, D.; Nelson, G.C.; Ahammad, H.; Blanc, E.; Bodirsky, B.L.; Fujimori, S.; Hasegawa, T.; Havlik, P.; et al. The future of food demand: Understanding differences in global economic models. *Agric. Econ.* 2014, 45, 51–67.

2. FAO; IFAD; UNICEF; WFP; WHO. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns; FAO: Rome, Italy, 2019.
3. Elahi, E.; Zhang, Z.; Khalid, Z.; Xu, H. Application of an artificial neural network to optimise energy inputs: An energy- and cost-saving strategy for commercial poultry farms. *Energy* 2022, 244, 123169.
4. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food Security: The Challenge of Feeding 9 Billion People. *Science* 2010, 327, 812–818.
5. Alexandratos, N.; Bruinsma, J. World agriculture towards 2030/2050. *Land Use Policy* 2012, 20, 375.
6. Misselhorn, A.; Aggarwal, P.; Ericksen, P.; Gregory, P.; Horn-Phathanothai, L.; Ingram, J.; Wiebe, K. A vision for attaining food security. *Curr. Opin. Environ. Sustain.* 2012, 4, 7–17.
7. Elahi, E.; Khalid, Z.; Tauni, M.Z.; Zhang, H.; Lirong, X. Extreme weather events risk to crop-production and the adaptation of innovative management strategies to mitigate the risk: A retrospective survey of rural Punjab, Pakistan. *Technovation* 2021, 102255.
8. Lanya, I.; Subadiyasa, N.; Sardiana, K.; Ratna Adi, G.P. Remote sensing and GIS applications for planning of sustainable food agriculture land and agricultural commodity development in Denpasar City. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019.
9. Merchant, J.; Narumalani, S. *Integrating Remote Sensing and Geographic Information Systems*; SAGE Publications: London, UK, 2009.
10. Goodchild, M.F. Spatial thinking and the GIS user interface. *Procedia-Soc. Behav. Sci.* 2011, 21, 3–9.
11. García-Berná, J.A.; Ouhbi, S.; Benmouna, B.; García-Mateos, G.; Fernández-Alemán, J.L.; Molina-Martínez, J.M. Systematic Mapping Study on Remote Sensing in Agriculture. *Appl. Sci.* 2020, 10, 3456.
12. Weiss, M.; Jacob, F.; Duveiller, G. Remote sensing for agricultural applications: A meta-review. *Remote Sens. Environ.* 2020, 236, 111402.
13. Mathenge, M.; Sonneveld, B.G.J.; Broerse, J.E. A Spatially Explicit Approach for Targeting Resource-Poor Smallholders to Improve Their Participation in Agribusiness: A Case of Nyando and Vihiga County in Western Kenya. *ISPRS Int. J. Geo-Inf.* 2020, 9, 612.
14. Li, R.; Wei, C.; Afroz, M.D.; Lyu, J.; Chen, G. A GIS-based framework for local agricultural decision-making and regional crop yield simulation. *Agric. Syst.* 2021, 193, 103213.
15. Brion, J.D.; Balahadia, F.F. Application of remote sensing and GIS for climate change and agriculture in Philippines. In *Proceedings of the 2017 IEEE 15th Student Conference on Research and Development: Inspiring Technology for Humanity (SCORED 2017)*, Putrajaya, Malaysia, 13–14 December 2017; pp. 229–233.

16. Wang, Y.; Chen, Y.; Peng, S. A GIS Framework for Changing Cropping Pattern Under Different Climate Conditions and Irrigation Availability Scenarios. *Water Resour. Manag.* 2011, 25, 3073–3090.
17. Markoski, M.; Arsov, S.; Mitkova, T.; Janeska-Stamenkovska, I. The benefit GIS technologies and precision agriculture principles in soil nutrient management for agricultural crop production. *Bulg. J. Agric. Sci.* 2015, 21, 554–559.
18. Clay, D.E.; Shanahan, J.F. *GIS Applications in Agriculture: Volume Two: Nutrient Management for Energy Efficiency*; CRC Press: Boca Raton, FL, USA, 2011; pp. 1–445.
19. Thakur, J.K.; Singh, S.K.; Ekanthalu, V.S. Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. *Appl. Water Sci.* 2017, 7, 1595–1608.
20. Nie, P.; Di, W.; Yang, Y.; He, Y. Hybrid combination of GIS,GPS,WSN and GPRS technology in modern digital agriculture application. *Adv. Mater. Res.* 2010, 108, 1158–1163.
21. Dunaieva, I.; Mirschel, W.; Popovych, V.; Pashtetsky, V.; Golovastova, E.; Veчерkov, V.; Melnichuk, A.; Terleev, V.; Nikonorov, A.; Ginevsky, R. GIS Services for Agriculture Monitoring and Forecasting: Development Concept BT. In *Proceedings of the International Scientific Conference Energy Management of Municipal Facilities and Sustainable Energy Technologies EMMFT*, Samara, Russia, 10–13 December 2018; Murgul, V., Pasetti, M., Eds.; Springer: Cham, Switzerland, 2019; pp. 236–246.
22. Al-Ismaili, A.M. GIS and remote sensing techniques in Controlled Environment Agriculture: A review. *J. Agric. Mar. Sci. JAMS.* 2021, 26, 10–23.
23. Sharma, R.; Kamble, S.S.; Gunasekaran, A. Big GIS analytics framework for agriculture supply chains: A literature review identifying the current trends and future perspectives. *Comput. Electron. Agric.* 2018, 155, 103–120.
24. Pardossi, A.; Incrocci, L.; Incrocci, G.; Malorgio, F.; Battista, P.; Bacci, L.; Rapi, B.; Marzialetti, P.; Hemming, J.; Balendonck, J. Root zone sensors for irrigation management in intensive agriculture. *Sensors* 2009, 9, 2809–2835.
25. Boland, A.; Bewsell, D.; Kaine, G. Adoption of sustainable irrigation management practices by stone and pome fruit growers in the Goulburn/Murray Valleys. *Aust. Irrig. Sci.* 2006, 24, 137–145.
26. Thompson, R.B.; Gallardo, M.; Valdez, L.C.; Fernandez, M.D. Using plant water status to define threshold values for irrigation management of vegetable crops using moisture sensors. *Agric. Water Manag.* 2007, 88, 147–158.
27. Holt, N.; Sishodia, R.P.; Shukla, S.; Hansen, K.M. Improved water and economic sustainability with low-input compact bed plasticulture and precision irrigation. *J. Irrig. Drain. Eng.* 2019, 145, 04019013.
28. Eching, S. Role of technology in irrigation advisory services: The CIMIS experience. In *Proceedings of the 18th Congress and 53rd IEC meeting of the International Commission on Irrigation and Drainage (ICID), FAO/ICID International Workshop on Irrigation Advisory Services and Participatory Extension Management*, Montreal, QC, Canada, 24 July 2002; Volume 24.

29. Smith, M.; Munoz, G. Irrigation advisory services for effective water use: A review of experiences. In Proceedings of the Irrigation Advisory Services and Participatory Extension in Irrigation Management Workshop Organized by FAO-ICID, Montreal, QC, Canada, 24 July 2002.
30. Evans, R.G.; LaRue, J.; Stone, K.C.; King, B.A. Adoption of site-specific variable rate sprinkler irrigation systems. *Irrig. Sci.* 2013, 31, 871–887.
31. McDowell, R.W. Does variable rate irrigation decrease nutrient leaching losses from grazed dairy farming? *Soil Use Manag.* 2017, 33, 530–537.
32. Kumar S, Karaliya SK, Chaudhary S. Precision farming technologies towards enhancing productivity and sustainability of rice-wheat cropping system. *International Journal of Current Microbiology and Applied Sciences.* 2017;6(3):142-151.
33. Sishodia RP, Ray RL, Singh SK. Applications of remote sensing in precision agriculture: A review. *Remote Sensing.* 2020;12(19):3136.
34. Weiss M, Jacob F, Duveiller G. Remote sensing for agricultural applications: A meta-review. *Remote Sensing of Environment.* 2020;263:111402
35. Chen Y, Yu J, Khan S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental Modelling and Software.* 2010;25(12):1582-1591
36. Zolekar RB, Bhagat VS. Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. *Computers and Electronics in Agriculture.* 2015;118:300-321
37. Pan G, Pan J. Research in crop land suitability analysis based on GIS. In: *International Conference on Computer and Computing Technologies in Agriculture.* Berlin, Heidelberg: Springer; 2011. pp. 314-325
38. El Baroudy AA. Mapping and evaluating land suitability using a GIS-based model. *Catena.* 2016;140:96-104
39. Zabihi H, Ahmad A, Vogeler I, Said MN, Golmohammadi M, Golein B, et al. Land suitability procedure for sustainable citrus planning using the application of the analytical network process approach and GIS. *Computers and Electronics in Agriculture.* 2015;117:114-126
40. Tashayo B, Honarbakhsh A, Akbari M, Eftekhari M. Land suitability assessment for maize farming using a GIS-AHP method for a semi-arid region. *Iran. Journal of the Saudi Society of Agricultural Sciences.* 2020;19(5):332-338
41. Parnes R. *Soil Fertility. A Guide to Organic and Inorganic Soil Amendments.* 2013
42. Marschner H. *Mineral Nutrition of Higher Plants.* London-UK: Academic Press; 2008. p. 889
43. Velayutham M, Bhattacharyya T. Soil resource management. In *natural resource management for agricultural production in India*. Special publication during International Conference on Management of Natural Resources for Sustainable Agricultural Production in the 21st Century. 2000 Feb 14. pp. 14-18
44. Wang G, Cao F. Integrated evaluation of soil fertility in Ginkgo (*Ginkgo biloba* L.) agroforestry systems in Jiangsu, China. *Agroforestry systems.* 2011 Sep;83(1):89-100

45. Viscarra Rossel RA, Webster R. Predicting soil properties from the Australian soil visible-near infrared spectroscopic database. *European Journal of Soil Science*. 2012;63:848-860
46. Shen W, Ni Y, Gao N, Bian B, Zheng S, Lin X, et al. Bacterial community composition is shaped by soil secondary salinization and acidification brought on by high nitrogen fertilization rates. *Applied Soil Ecology*. 2016;108:76-83
47. Yang MH, Mouazen AM, Zhao XM, Guo X. Assessment of a soil fertility index using visible and near-infrared spectroscopy in the rice paddy region of southern China. *European Journal of Soil Science*. 2019
48. Malczewski J. *GIS and Multicriteria Decision Analysis*. New York: John Wiley & Sons Inc.; 1999
49. Shumilov OI, Kasatkina EA, Mielikainen K, Timonen M, Kanatjev AG. Palaeovolcanos, solar activity and pine tree-rings from the Kola Peninsula (northwestern Russia) over the last 560 years. *International Journal of Environmental Research*. 2011;5(4):855-864
50. Salehi E, Zebardast L, Yavri AR. Detecting forest fragmentation with morphological image processing in golestan national park in northeast of Iran. *International Journal of Environmental Research*. 2012;6(2):531-536
51. Feng XY, Luo GP, Li CF, Dai L, Lu L. Dynamics of ecosystem service value caused by land use changes in ManasRiver of Xinjiang, China. *International Journal of Environmental Research*. 2012;6(2):499-508
52. Asproth V, Holmberg SC, Håkansson A. Decision support for spatial planning and management of human settlements. In: Lasker GE, editor. *Advances in Support Systems Research*. Vol. 5. Ontario, Canada: Windsor; 1999. pp. 30-39
53. Jiang H, Eastman JR. Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information System*. 2000;14:173-184
54. Malczewski J, Chapman T, Flegel C, Walters D, Shrubsole D, Healy MA. GIS-multicriteria evaluation with ordered weighted averaging (OWA): Case study of developing watershed management strategies. *Environment & Planning A*. 2003;35(10):1769-1784
55. Malczewski J, Rinner C. Exploring multicriteria decision strategies in GIS with linguistic quantifiers: A case study of residential quality evaluation. *Journal of Geography System*. 2005;7(2):249-268
56. Kusre BC, Ghosh P, Nath K. Prioritization of soil conservation measures using erodibility indices as criteria in Sikkim (India). *Journal of Earth System Science*. 2018;127(6):1-3
57. AbdelRahman MA, Natarajan A, Srinivasamurthy CA, Hegde R. Estimating soil fertility status in physically degraded land using GIS and remote sensing techniques in Chamarajanagar district, Karnataka, India. *The Egyptian Journal of Remote Sensing and Space Science*. 2016;19(1):95-108
58. Mokarram M, Hojati M. Using ordered weight averaging (OWA) aggregation for multi-criteria soil fertility evaluation by GIS (case study: Southeast Iran). *Computers and Electronics in Agriculture*. 2017;132:1-3

59. Li M, Zhang XL. GIS-based evaluation of farmland soil fertility and its relationships with soil profile configuration pattern. *Ying Yong Sheng tai xue bao= The Journal of Applied Ecology*. 2011;22(1):129-136
60. Jackai LE, Daoust RA. Insect pests of cowpeas. *Annual Review of Entomology*. 1986;31(1):95-119
61. Haile FJ, Higley LG, Specht JE. Soybean cultivars and insect defoliation: Yield loss and economic injury levels. *Agronomy Journal*. 1998;90(3):344-352
62. Cerda R, Avelino J, Gary C, Tixier P, Lechevallier E, Allinne C. Primary and secondary yield losses caused by pests and diseases: Assessment and modeling in coffee. *PloS One*. 2017 Jan 3;12(1):e0169133
63. Ranjan R, Vinayak S. Application of remote sensing and GIS in plant disease management. *TTPP*. 2020;509
64. Duarte F, Calvo MV, Borges A, Scatoni IB. Geostatistics applied to the study of the spatial distribution of insects and its use in integrated pest management. *Revista Agronómica del Noroeste Argentino*. 2015;35(2):9-20
65. Liu Y, Shi J. Predicting the potential global geographical distribution of two *Icerya* species under climate change. *Forests*. 2020;11(6):684
66. Bale J, Walters KF. Overwintering biology as a guide to the establishment potential of non-native arthropods in the UK. In: Atkinson DA, Thorndyke M. *Temperature and Development*. 2001 Jan 1
67. Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HC, et al. Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*. 2018;1(8):441-446
68. Zeng J, Liu Y, Zhang H, Liu J, Jiang Y, Wyckhuys KA, et al. Global warming modifies long-distance migration of an agricultural insect pest. *Journal of Pesticide Science*. 2020;93(2):569-581
69. Carrière Y, Ellsworth PC, Dutilleul P, Ellers-Kirk C, Barkley V, Antilla L. A GIS-based approach for areawide pest management: The scales of *Lygus hesperus* movements to cotton from alfalfa, weeds, and cotton. *Entomologia Experimentalis et Applicata*. 2006;118(3):203-210
70. Latchininsky AV, Sivanpillai R. Locust habitat monitoring and risk assessment using remote sensing and GIS technologies. In: *Integrated Management of Arthropod Pests and Insect Borne Diseases*. Dordrecht: Springer; 2010. pp. 163-188
71. Mahlein AK. Plant disease detection by imaging sensors—parallels and specific demands for precision agriculture and plant phenotyping. *Plant Disease*. 2016;100(2):241-251
72. Franke J, Menz G. Multi-temporal wheat disease detection by multi-spectral remote sensing. *Precision Agriculture*. 2007;8(3):161-172
73. Mahlein AK, Rumpf T, Welke P, Dehne HW, Plümer L, Steiner U, et al. Development of spectral indices for detecting and identifying plant diseases. *Remote Sensing of Environment*. 2013;128:21-30
74. Zhang J, Huang Y, Yuan L, Yang G, Chen L, Zhao C. Using satellite multispectral imagery for damage mapping of armyworm (*Spodoptera frugiperda*) in maize at a regional scale. *Pest Management Science*. 2016;72(2):335-348

75. Reynolds CA, Yitayew M, Slack DC, Hutchinson CF, Huete A, Petersen MS. Estimating crop yields and production by integrating the FAO Crop Specific Water Balance model with real-time satellite data and ground-based ancillary data. *International Journal of Remote Sensing*. 2000;21(18):3487-3508
76. Dadhwal VK, Ray SS. Crop assessment using remote sensing-Part II: Crop condition and yield assessment. *Indian Journal of Agricultural Economics*. 2000;55:55-67
77. Taylor JC, Wood GA, Thomas G. Mapping yield potential with remote sensing. *Precision Agriculture*. 1997;1:713-720
78. Oudemans PV, Pozdnyakova L, Hughes MG, Rahman F. GIS and remote sensing for detecting yield loss in cranberry culture. *Journal of Nematology*. 2002;34(3):207
79. Katkani D, Babbar A, Mishra VK, Trivedi A, Tiwari S and Kumawat RK. 2021. A Review on Applications and Utility of Remote Sensing and Geographic Information Systems in Agriculture and Natural Resource Management. *International Journal of Environment and Climate Change* 12 (4): 1-18.
80. Trivedi A, Rao KVR, Rajwade Y, Yadav D and Verma NS. 2022. Remote Sensing and Geographic Information System Applications for Precision Farming and Natural Resource Management. *Indian Journal of Ecology* 49(5): 1624-1633.
81. Trivedi A and Gautam VK. 2022. Decadal analysis of water level fluctuation using GIS in Jabalpur district of Madhya Pradesh. *Journal of Soil and Water Conservation* 21(3) : 250-259.

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