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GIS for Agri-Resilience

CASE STUDY

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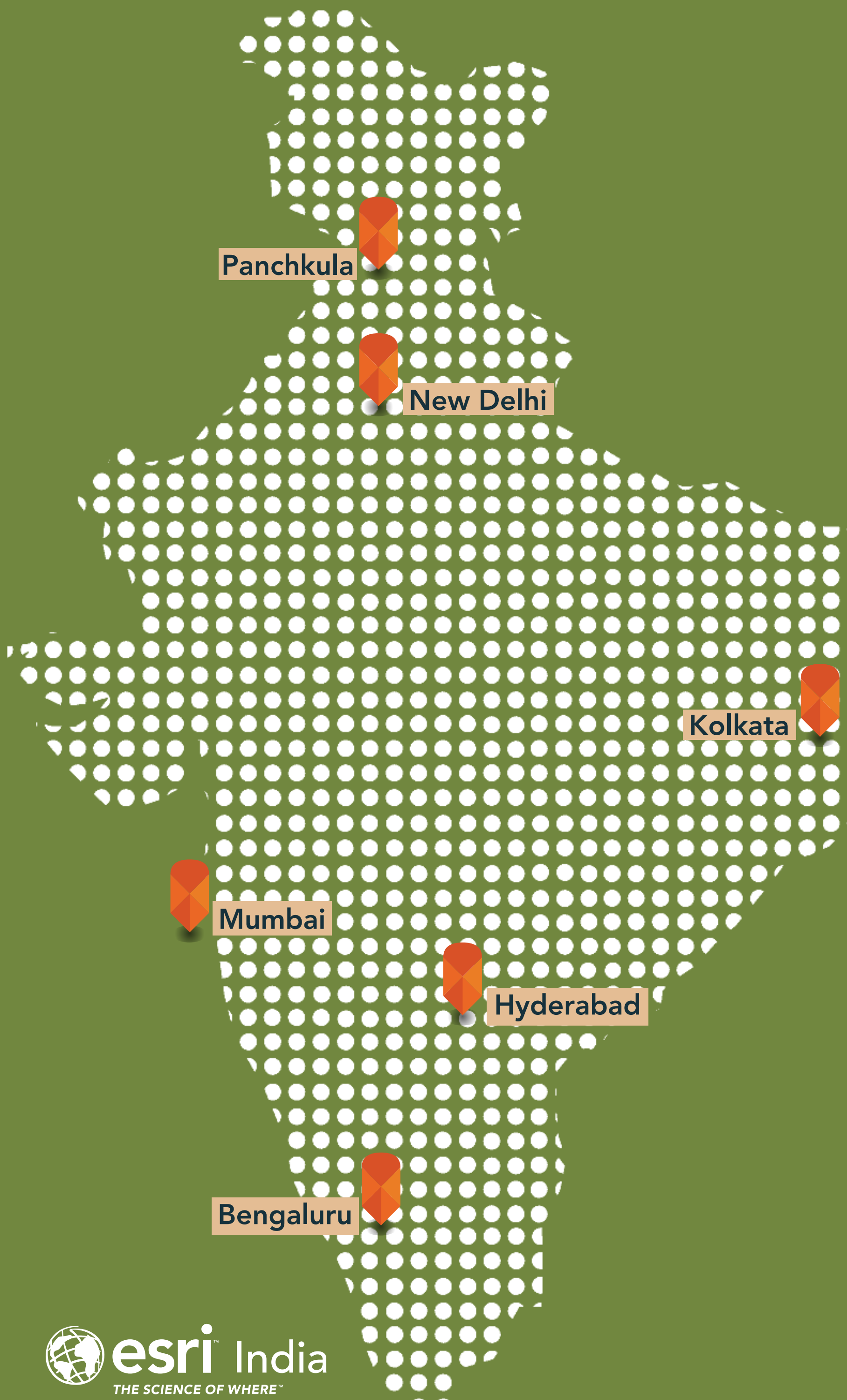
ESRI INDIA LOCATIONS



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CONTENTS

MD'S DESK

Agendra Kumar

Managing Director, Esri India

The agriculture sector plays a very significant role in the country's economy. It contributes around 17 - 19% to India's Gross Domestic Product (GDP) and provides livelihood support to about 42 - 45% of the population. Yet, the agriculture sector faces numerous challenges such as low productivity, water scarcity, soil degradation, land fragmentation, and climate change impacts, which hinder its growth and sustainability.

To overcome these challenges, digital transformation needs to be extended in agriculture. The answer lies in adopting agritech on a larger scale. Agritech innovations such as precision farming, AI-driven tools, IoT sensors, drones, and robotics can significantly enhance productivity and sustainability in agriculture. By providing farmers with real-time data on soil health, weather conditions, water usage, and crop performance, agritech enables them to make informed decisions, optimize resource use, and reduce waste. These technologies help address key challenges such as climate change, water scarcity, and soil degradation, which often hinder agricultural growth. Moreover, agritech promotes efficiency by automating tasks like planting, irrigation, and harvesting, reducing labor costs and minimizing human error. It also enables better pest and disease management through early detection, thus improving crop health and yield.

GIS platforms and mobile apps are becoming increasingly popular and play a crucial role in modernizing farming practices by providing farmers with easy access to vital information and tools that enhance productivity and efficiency. GIS platforms are increasingly being used in agriculture to optimize farming practices, enhance productivity, and promote sustainability. These platforms integrate spatial data from various sources such as satellite imagery, soil sensors, weather stations, and historical crop performance data to create detailed maps and models that support decision-making.

Agricultural mobile apps cover a wide range of functions, including crop management, market price tracking, weather forecasts, pest and disease detection, and financial planning. For instance, apps designed for crop management help farmers track planting schedules, monitor soil conditions, and provide guidance on fertilization and irrigation. Weather apps are particularly useful in predicting weather patterns, allowing farmers to make informed decisions about planting, harvesting, and protecting crops from extreme weather events. Apps focused on pest and disease management use image recognition technology to help farmers identify pests or diseases early, enabling them to take timely action and minimize damage to their crops.

Market price apps provide real-time information on commodity prices, helping farmers get better rates for their produce by connecting them with buyers or markets directly. Some apps also offer financial services, providing information about government schemes, loan options, insurance, and subsidies, thereby supporting farmers in accessing financial resources. Additionally, mobile apps that incorporate machine learning and AI can offer personalized advice, predictions for crop yields, and optimized farm management strategies based on data analysis.

The future of agriculture is in connected, location-aware farms. Rapid advancements in information and communication technology, precision agriculture, and data analytics are paving the way for the development of smart connected farms and a network of interconnected farmers. Smart Connected Farms (SCFs) refer to agricultural systems that leverage advanced technologies, such as the Internet of Things (IoT), sensors, data analytics, and automation, to optimize farm operations. These farms are equipped with smart devices and systems that collect, process, and transmit real-time data, enabling farmers to make informed decisions, improve productivity, and enhance sustainability. SCFs provide unique advantages to farmers to enhance farm production and profitability, while tackling adverse climate events.

Climate change is projected to reduce agricultural productivity by 3 - 16% by 2080, with developing countries experiencing more significant reductions ranging from 10 - 25%; furthermore, crop diseases and other plant stresses will become more widespread with the rise in temperatures and rainfall patterns becoming more variable. Accordingly, we need to focus more on 'climate-smart agriculture' that uses advanced technologies to achieve sustainable farming, which will help us to meet the needs of the present while preserving the environment for future generations.

Celebrating 25 years
of GIS Day

On the occasion of the GIS Day (November 20, 2024), Esri India conducted a Celebrate and Win Contest. As part of the contest, organizations across the country were encouraged to share their achievements in GIS and inspire others to explore and harness the potential of GIS.

70 unique organizations actively participated in the contest.

After thorough rounds of evaluation, the following organizations were selected as the **Winners of this year's GIS Day: Celebrate and Win Contest:**

Indian Institute of Science (IISc), Bengaluru: IISc organized a Geospatial Hackathon, expert-driven sessions on Remote Sensing and GIS, and a hands-on session on GIS (spatial mapping) to celebrate the day. The engaging events saw participation from 200+ students.

KSCSTE-NATPAC, Thiruvanthapuram: The GIS Day event was celebrated with inspiring sessions on the 'evolving landscape of geospatial analytics and its role in shaping a sustainable future' by experts from Digital University, Kerala and Esri India. Marking the 25th anniversary of the GIS Day, the program highlighted the theme "Mapping Minds, Shaping the World: 25 Years of GIS Excellence."

Burns & McDonnell India, Mumbai: Burns & McDonnell India celebrated GIS day by hosting an exclusive event that aimed to promote awareness regarding the ever-evolving industry landscape of the Geographical Information Systems sector. They hosted this event at their regional office based in Mumbai, and also virtually (live event) for the employees in their Bengaluru office. Education Times was the event media partner.

AtkinsRéalis, Bengaluru (Special Recognition): The GIS event featured a variety of engaging presentations, interactive drop-in sessions for poster presentations, and insightful discussions, all focused on the innovative applications of GIS technology. Additionally, attendees enjoyed fun activities such as cake cutting, a GIS quiz, prize announcements, photo booth sessions, and other celebrations. Participants had the opportunity to explore how GIS is being used to address real-world challenges, including engineering infrastructure, transportation, building development, urban planning, and environmental conservation.

MMGEIS

Takes Another Leap Toward Building a Stronger Geospatial Community

The Centre for Knowledge Sovereignty (CKS) and Esri India launched the Pilot program of the Master Mentors Geo-enabling Indian Scholars (MMGEIS) program with 1000 students in August 2024. Upon successful conclusion of the pilot, close to 4000 students have been enrolled in the program, both from schools and colleges. As some of these students transition to the advanced level, they will be mentored by Shri A S Kiran Kumar, former Chairman of ISRO, and a Master Mentor of MMGIS, and other Master Mentors, notably Dr K J Ramesh, former Director General of IMD and Lt. Gen. Girish Kumar, former Surveyor General of India.

To celebrate this accomplishment and the first anniversary of the announcement of the MMGEIS program, a felicitation ceremony, attended by some of the students and distinguished dignitaries, was organized at the India Habitat Centre, New Delhi.

Shri Kiran Kumar's unparalleled expertise and visionary guidance will equip the students with the skills and vision necessary to shape them into future leaders in the field and contribute to India's growing geospatial ecosystem. With this accomplishment, the MMGEIS program is better equipped to work towards building a stronger geospatial community.

Vinit Goenka, Secretary, Centre of Knowledge Sovereignty shared his thoughts on the occasion, "We congratulate all the students for showing exceptional abilities and potential in the field. By graduating to this advanced level, these students have demonstrated their dedication and potential. Under the mentorship of Shri Kiran Kumar, these scholars will not only gain deep expertise but also imbibe the values and vision required to contribute meaningfully to India's geospatial ambitions."

Agendra Kumar, Managing Director, Esri India said, "The MMGEIS program continues to create pathways for students to develop cutting-edge geospatial skills that are crucial for India's growth story. This milestone not only highlights the students' hard work but also reaffirms our commitment to equipping them with mentorship from luminaries like Shri A S Kiran Kumar. We are immensely proud of their achievements and confident that they will contribute significantly to the geospatial community."

The felicitation ceremony also included an interactive session with students, where they shared their aspirations and gained insights from the esteemed mentors and academic council members.

Esri India Launched Maha Kumbh Mela App for the Ease of Pilgrims

The Maha Kumbh Mela 2025 was held from January 13, 2025 to February 26, 2025, in Prayagraj, Uttar Pradesh. Spread across a huge area of over 4,000 hectares along the riverbank, the Mela witnessed over 40 crore visitors from across the globe.

To help the pilgrims navigate easily at the Mela and have an enriching experience, Esri India launched a Webapp, https://kumbhlocator.esri.in/. Available in Hindi and English, the GIS-based Webapp provided information about **mela accommodations, snan ghats, parking, roads (with live traffic), weather updates, entry and exit points, lost and found centres, e-rikshaw stands, police stations, fire stations, hospitals, etc.**

Users could also mark the locations of **events, programs, and other activities** through the app. It also displayed ArcGIS Story Maps to show important temples and other tourist places in Prayagraj.

Agendra Kumar, Managing Director, Esri India shares, *"With an intent to enhance the experience of lakhs of pilgrims at the Kumbh Mela, we launched a Webapp. Through this app, we could provide all the useful information at one place. The app was available in Hindi and English and didn't require any login or download. The app empowered the pilgrims to easily navigate the Mela, access key locations, and stay updated about the facilities, ensuring safety and improving their overall journey."*

The app saw about 6000 visitors on the day of the launch, indicating its real-time impact and usefulness. Through the Kumbh Mela Webapp, Esri India aimed to provide all the vital information about the Mela to the pilgrims at a single location, allowing them to focus on their spiritual journey with peace of mind.

GIS Ushering in NextGen Agriculture

India is one of the major players in the agriculture sector worldwide, and it is the primary source of livelihood for ~45% of the country's population. The sector plays a major role in supporting livelihoods and ensuring food security for millions. In addition to providing food, feed, fuel, and fiber to meet the growing needs of the burgeoning population, it supplies raw materials to the country's agri-based industry. Climate change and depleting natural resources are seriously threatening agricultural productivity and incomes. To enhance agricultural production and farmers' incomes, remove poverty, and ensure food and nutritional security on a sustainable basis, suitable location-specific climate-smart agriculture technologies must be identified, created, and adopted at field levels. Integrated farming systems must also be promoted. Modern tools and technologies such as GIS, remote sensing, AI, drone technology, crop modelling, site specific nutrient management, and mobile applications must be adopted for farmers to make informed decisions about better nutrient management, reducing wastage, and minimizing environmental footprints. These tools can also significantly aid in improving farm productivity and farmer's income.

GIS is pivotal in modern agriculture as it allows farmers to optimize resource utilization, reduce environmental impact, and tailor farming practices to the unique conditions of each field. The result is a more efficient, productive, and sustainable approach to agriculture, particularly through precision agriculture. Esri's ArcGIS is making agronomic understanding more accessible and empowering those responsible for feeding the planet.

Precision Farming

One of the major benefits of GIS is its role in increasing agricultural productivity, which is vital to global food security. By using spatial data to optimize planting patterns and resource allocation, farmers can achieve higher yields without expanding agricultural land. This technology enables precision farming, where each aspect of farm management is tailored to the specific needs of individual crops, resulting in better yields and more efficient resource use.

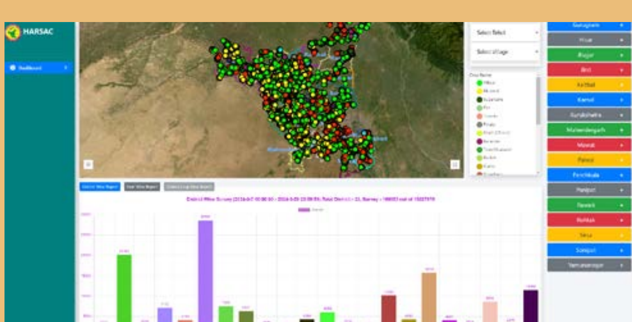
Precision agriculture is a modern farm management approach that focuses on observing, measuring, and responding to variability within and between fields. It aims to optimize farm inputs by targeting the inherent differences in the land through Variable Rate Application (VRA). To implement VRA effectively, detailed spatial data must be gathered across fields using tools like GIS and remote sensing. Some of the major precision farming technologies include precision irrigation systems, yield mapping and monitoring tools, and information management systems. By utilizing advanced descriptive, predictive, and prescriptive analytics, precision agriculture enables farmers to make data-driven decisions that promote cost-effective, environmentally friendly, and sustainable farming practices. According to the World Economic Forum, adopting precision agriculture technologies on 15-25% of farms could increase global food production by 10-15% by 2030, while reducing greenhouse gas emissions and water consumption by 10-20%, respectively.

Tools like ArcGIS play a crucial role in precision agriculture by providing farmers with detailed data about soil types, crop health, moisture levels, and other relevant factors. This information helps them monitor field variability, identify areas that need attention, and apply inputs like water, fertilizers, and pesticides more accurately.

HARSAC Brings Groundbreaking Agri Reforms with ArcGIS

Haryana Space Applications Centre (HARSAC) has developed and deployed a Geospatial Technology-based Crop Management Solution to address challenges in agricultural management. This solution empowers farmers, enhances transparency, and strengthens agricultural reforms in Haryana. The solution, which is part of HARSAC's OneMap Gurugram Portal, enables the authority to capture real-time, ground-truth intelligence on the total crop produced in Haryana. It allows the government to precisely record, measure, and analyze agricultural produce, leading to more effective governance in yield management and agricultural income generation. By bringing transparency to the lifecycle from seed to market, farmers feel more empowered. The system has led to significant improvements in yield management, cost reduction, and resource optimization, resulting in substantial financial savings for the state.

The Crop Management Solution, built using Esri's Geospatial Technology, enables complete data collection of crop types and conditions across Haryana. It performs precise measurements of farmland size in each district, helping HARSAC manage farmlands and crops more effectively, reduce labor costs, and minimize resource waste. The accurate, up-to-date data allows for the formulation of feasible funding and agricultural development plans. The system encourages farmers to register on a common portal, promoting transparency. Currently, about 1.2 million farmers are registered. This registration facilitates complete knowledge of farmland, easing crop monitoring and management. Farmers receive updated market rates and can schedule appointments to sell produce at government-approved centers, saving time and effort.



Crop Health Monitoring

Instead of manual inspections, GIS enables remote monitoring of crop health using satellite imagery, providing insights about humidity, temperature, and overall growth. This helps in identifying areas needing attention. By monitoring changes in crop health indicators over time, GIS enables early detection of stress factors such as nutrient deficiencies, water scarcity, diseases, and pest outbreaks. Early identification allows farmers to take timely corrective actions, preventing potential yield losses and reducing the need for extensive interventions later in the season.

GIS also helps to monitor terrain slope and runoff patterns, enabling the stakeholders to track changes in soil health over time. This data can predict areas at risk of degradation, ensuring that timely interventions are made to prevent soil erosion and maintain long-term soil health.

Crop Yield Prediction

Accurate yield predictions are vital for food security and financial planning. Crop yield prediction using GIS involves combining spatial data with advanced analytics to forecast agricultural output. GIS integrates a variety of data types, including soil quality, topography, weather patterns, and satellite imagery, to provide a comprehensive view of the factors influencing crop growth. By mapping climate data such as temperature, precipitation, and growing-degree days (GDD), GIS helps farmers determine the optimal times for planting and harvesting to maximize yield. Soil analysis, through GIS-generated maps, identifies the nutrient levels, pH, and texture of the soil, guiding decisions on which crops are most suited for specific field areas. Remote sensing technologies, including satellite imagery and drones, provide real-time data on crop health, enabling early detection of stress factors like pests or nutrient deficiencies that could affect yield. Additionally, GIS incorporates historical yield data to predict future crop production trends, enhancing the accuracy of forecasts. With the integration of machine learning, GIS can analyze large datasets to create predictive models, allowing farmers to forecast crop yields with higher precision. Precision agriculture techniques, supported by GIS, enable farmers to optimize field inputs based on location-specific data, increasing efficiency and yield. Overall, GIS serves as a powerful tool for making informed decisions, improving crop management, and enhancing yield prediction accuracy.

Farmers in Odisha Improve Crop Choices, Boost Income Using Spatial Analytics

Farmers in South Odisha have achieved significant improvement in crop choices and income through the Agri-GIS app, built using ArcGIS by the Centre for Spatial Analytics and Advanced GIS (C-SAG).

The app delivers personalized advisories via text messages, phone calls, or smartphone notifications, offering weather forecasts, crop recommendations, market analysis, and alerts for events like cyclones. Agri-GIS integrates spatial data from satellites, weather services, and GIS systems, along with social, economic, and family data, to provide tailored advice for individual farms.

The app uses advanced GIS tools like ArcGIS and AI to generate insights based on factors such as soil, climate, and family circumstances. It provides real-time updates every crop season, with a focus on personalized, hyperlocal advisories. Farmers who followed the app's advice have seen their income increase by almost 60%, with an estimated total income boost for 150,000 farmers in the region.

Source: *https://www.esri.com/about/newsroom/arcnews/farmers-in-india-improve-crop-choices-boost-income-using-spatial-analytics/*

Insect and Pest Control

GIS provides farmers and agricultural specialists with a powerful way to map, analyze, and manage pest populations, improving the efficiency of pest control efforts while minimizing the use of pesticides. By integrating spatial data with environmental factors such as temperature, rainfall, soil type, and crop distribution, GIS enables precise monitoring of pest outbreaks. It helps in identifying areas of high pest density, allowing for targeted interventions rather than broad-spectrum pesticide applications, which not only saves costs but also reduces environmental harm. GIS tools can also support the creation of predictive models, assessing how pest populations might spread based on climatic conditions, land use, and crop types. This predictive capability aids in early detection and intervention, preventing widespread infestations and crop damage. Furthermore, GIS plays a crucial role in Integrated Pest Management (IPM) strategies, where it assists in combining various pest control methods, such as biological controls, habitat manipulation, and chemical treatments, tailored to specific regions. By tracking pest populations over time, GIS also facilitates the evaluation of control measures, ensuring that pest management strategies are both effective and sustainable. Overall, GIS empowers agricultural professionals to make informed decisions, optimize pest control resources, and protect crops, thereby enhancing productivity and reducing environmental and economic risks associated with pest infestations.

New Zealand's Largest Fertilizer Manufacturer helps Farmers Achieve Soil Sustainability using Geospatial Technology

Today more than ever, farmers rely on inputs to increase the quality of the produce they grow. These inputs vary from seed, fertilizer, and pesticides to machinery parts and monitoring equipment. In past generations, farmers tended to spread fertilizer evenly over the entire field. Now, thanks to geospatial technology, spreading methods can be more exact by type, quantity, and location of application. Outfitting the spray rig with computerized controllers and GPS navigation systems is an approach to farming that is both friendly to the environment and profitable for the farmer. Ravensdown, New Zealand's largest manufacturer and distributor of fertilizers, is using geospatial technology to improve the way New Zealand farmers manage their inputs. By using GIS and GPS to guide the application of fertilizers, farmers are decreasing the amount of wasted resources that can potentially cause harmful runoff into streams and waterways. At the same time, they are reducing their total fertilizer expenditure by up to 10 percent per year. Ravensdown worked with Eagle Technology Group to design the solution that is built on Esri's ArcGIS software. The system accurately records where and how much fertilizer has been applied to a certain area. This information is merged with digital orthophotos and the farm's relational databases to create a vivid picture of the farm's overall soil sustainability.

Once the raw spatial and attribute data is captured from GPS transceivers on the trucks, it is transmitted wirelessly to Ravensdown's facility where it is loaded into the GIS and processed in near real time. The onboard GIS creates a map-based display that shows fertilizer application data as a series of color-coded "snail trails" that are overlaid on the map, giving a very good representation of the process. An additional benefit is that the system can be used as evidence to verify "proof of placement." With geospatial technology, it is easy to demonstrate that the fertilizer has been spread in a manner consistent with best environmental practices. Eagle used the development capabilities available in ArcGIS Server to embed the map interface in Ravensdown's customer relationship management (CRM) system. Ravensdown wanted seamless access to the spatial and attribute data, so Eagle developers used the .NET framework to build an interactive map viewer that the call center staff can access with a click of the mouse. Staff members can query the database, manipulate the display, and print or fax hard-copy maps.

Irrigation Control

GIS facilitates the development of irrigation schedules tailored to specific field conditions and crop water needs. By analyzing spatial data on soil moisture, rainfall patterns, and evapotranspiration rates, GIS helps farmers and water managers optimize the timing, duration, and frequency of irrigation events to minimize water waste and maximize crop yields.

GIS can assist in monitoring water quality parameters such as salinity levels and contamination risks. By analyzing spatial data on soil types, land use practices, and proximity to sources of pollutants, GIS helps in identifying areas vulnerable to water quality degradation and implementing measures to protect irrigation water sources. As much as 70% of good water is used in agriculture, saving on this water use can help in addressing water stress. Wise usage of water can be made possible by adopting precision technology.

Crop Loss Adjustments and Payouts

In periods of catastrophic events like floods, heavy rainfall, drought, etc., GIS can be used to determine exactly how much of a given crop has been damaged and the progress of the remaining crop on the farm. GIS can generate crop condition and distribution analytics, leading to faster loss adjustment and payout to the farmers. In the crop insurance business, high-resolution imagery plays a key role in speeding up the claim process. Using ArcGIS and image processing software like ENVI, farmers and insurance providers can achieve the benefits of faster claim processes and payouts, visibility on in-season crop conditions at different time intervals fostering risk analysis and decision making, crop classification and crop risk analysis, acreage estimation of different crops, identification of inundation area and exposure monitoring, reduced operational and data processing cost, and more.

Reliance General Insurance Leverages GIS Technology for Crop Insurance

In line with the Pradhan Mantri Fasal Bima Yojana (PMFBY), Reliance General Insurance (RGI) provides crop insurance schemes protecting farmers against financial losses due to unforeseen crop losses. The level of risks involved in agriculture insurance made it necessary for RGI to ensure its crop insurance solution not only covers farmers' production and financial risks but also the ability to first analyze and assess the potential risk to farmland and accordingly charge a premium. RGI invested in satellite-based analysis, which helped in addressing risks in crop health during the ongoing season, sowing patterns, area sown, localized calamity, and yield estimates.

ArcGIS-based analysis helped RGI gain visibility on crop classification and acreage estimation; crop health monitoring; loss event monitoring, and yield estimation. The GIS technology intervention helped RGI eliminate the on-field physical visits to every gram panchayat/ village/ to monitor crop health and identify risks and also reduced the operational and administrative costs involved.

ArcGIS ensured rapid data collection and real-time analysis. ENVI assisted in processing satellite images and revealed the below insights:

- Total count of the crops in an agricultural field
- Location and sizes of the agricultural field
- Different crop rows in the field and also gaps within a row
- Damage to the field, crops, and plants

Sustainable Farming

Providing the current population and future generations with an indefinite food supply is an economic, environmental, and social concern. Geographic information system (GIS) technology enables community planners, economists, agronomists, and farmers to research and devise practices that will enable the sustainability of food production to ensure the survival of the human race. Whether implementing organic farming methods, finding the most profitable and healthy places to plant new crops, or allotting farmland for preservation to secure future food production, GIS has the capabilities to collect, manage, analyze, report, and share vast amounts of agricultural data to aid in discovering and establishing sustainable agriculture practices.

Farmers can make well-informed decisions based on precise spatial data, such as soil variability, moisture levels, and pest distribution. These insights allow farmers to treat specific areas of their land according to their exact needs, thus reducing waste and minimizing environmental harm. Recent studies indicate that over 70% of farms use some form of geoinformatics, making it a growing trend in agriculture. By integrating geospatial data, farmers are not only enhancing their productivity but also improving environmental sustainability.

GIS aids in sustainable farming practices by:

- **Reducing carbon footprints:** Optimizing farming practices to minimize the use of fertilizers, pesticides, and water.
- **Preserving biodiversity:** Identifying and preserving natural habitats and ensuring that farming practices do not damage the environment.

Esri and Microsoft Collaborate on Sustainable Agriculture Development in Africa

Extreme weather events linked to climate change are increasingly threatening the security of food and water supply across the globe. Africa, already struggling with low agricultural production and heavily degraded soils, is disproportionally affected. To help support government and nonprofit organizations on the continent to address these challenges, Esri has collaborated with Microsoft on a sustainable agriculture development initiative in Africa.

Across the African continent, there is an urgent need to improve agricultural productivity. Deeper understanding of the current agricultural landscape, close monitoring of crop conditions throughout the growing season, and mitigation of climate change impacts will all contribute to better production and food security. Crop patterns and health can be identified, extracted, and monitored seasonally by combining Esri's geospatial artificial intelligence (GeoAI) capabilities, satellite imagery, as well as Microsoft's infrastructure and AI devices.

Having data related to water, fertilizer, and seed use accessible at the right time helps enable more sustainable agricultural practices and improve crop yield forecasts. Key stakeholders can derive insights from the data through intuitive visualizations, applications, and dashboards to make better-informed business and policy decisions.

Source: *https://www.esri.com/about/newsroom/announcements/esri-and-microsoft-collaborate-on-sustainable-agriculture-development-in-africa*

The Future of Agriculture

The future of agriculture lies in connected farms that are location-aware, with seed selection being an excellent starting point. Major seed companies invest in research on hybrid seeds, and with the advent of advanced technologies like IoT sensors, drone-based imagery, automated field equipment, and AI, they can capture more performance data than ever before. This wealth of information helps them understand which seed will perform best in specific locations, and more importantly, when to plant it to optimize growing-degree days for the best yield.

AI-based robots that can navigate fields to pick produce are another promising development in the agriculture sector. Significant investment is going into making this a reality, as these robots can be spatially aware, enhancing efficiency in harvesting. Additionally, the combination of drones and AI is transforming the way crop health and damage are monitored. Farmers can fly drones over their fields, and AI technology can analyze the images to identify potential problems, eliminating the need for field workers to manually scout crops. This capability allows farmers to quickly pinpoint issues in their crops.

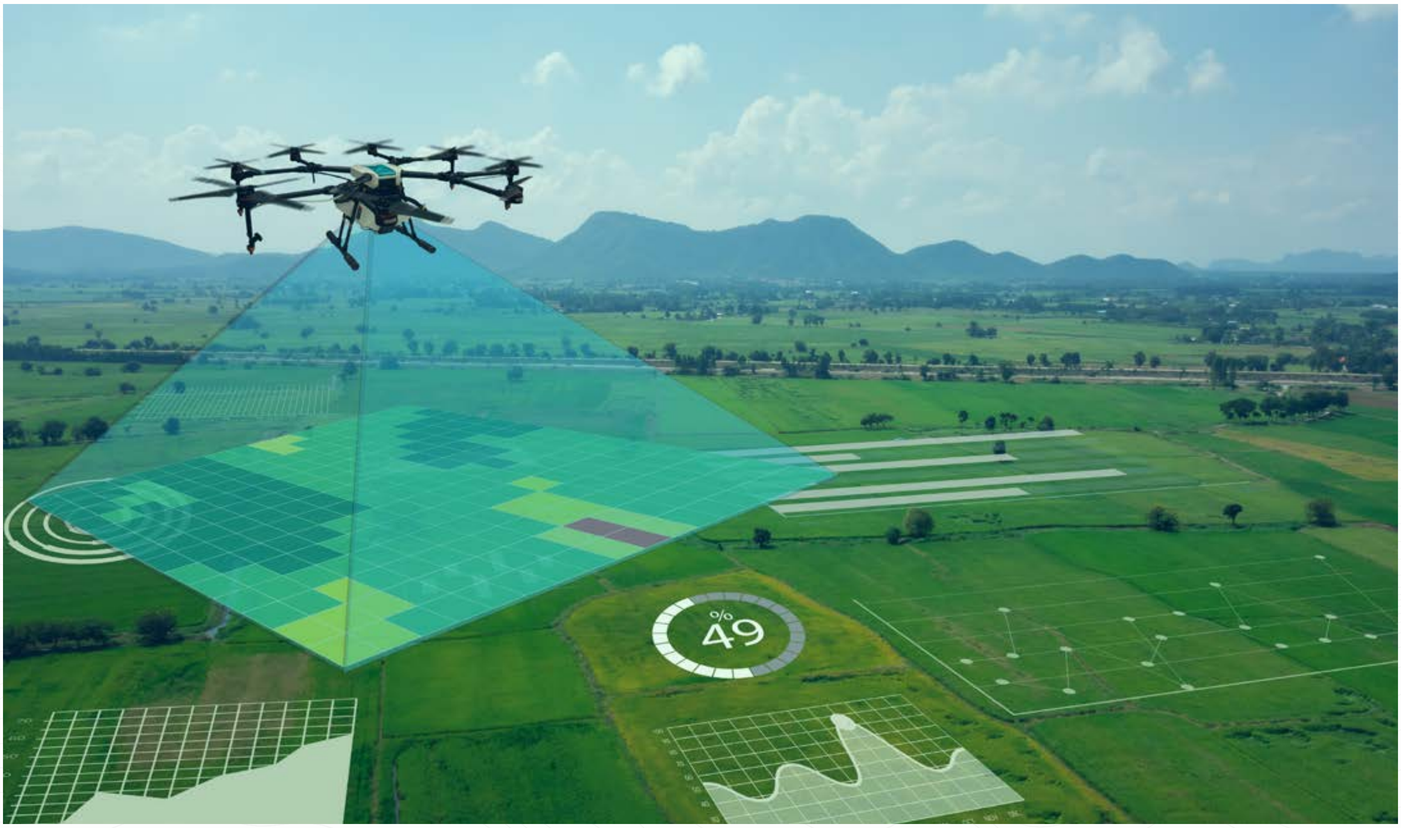
Insurance companies are also using drones to conduct damage assessments and expedite claims processing. By deploying drones equipped with AI, they can distinguish between crops damaged by hail and those that remain unaffected, enabling a swift response that helps farmers recover more efficiently. Furthermore, machine learning models are being used to crunch vast amounts of data to support planning decisions. Farmers and seed companies are using historical weather data, past yield performance, and other relevant information to feed into location-intelligent systems. These systems continuously work to determine the optimal placement of seeds, while GIS technology provides the smart maps necessary to interpret the results.

Conclusion

GIS helps land use planners and managers select the best sites for agricultural projects. It can be used to map the location of resources such as water, soil, and transportation, as well as the location of potential hazards such as flooding and pollution. This information can be used to identify sites suitable for the proposed agricultural project and unlikely to be affected by hazards. By collecting data from field samples or sensors measuring soil characteristics such as texture (sand, silt, clay), organic matter, pH, electrical conductivity, and nutrient levels (nitrogen, phosphorus, potassium), stakeholders can generate detailed soil maps. These maps aid in visualizing spatial variability in soil properties, allowing for targeted application of fertilizers and soil amendments (e.g., lime, organic matter) at varying rates based on the specific needs of different areas within the field. Also, suitability analyses, facilitated by GIS, help the stakeholders to determine the optimal crops for each plot of land, based on its soil, climate, and social conditions, and conceptualize the best practices at all stages of the farming season. This understanding helps in improving farm productivity and farmer's income.

By utilizing GIS, agriculture becomes more efficient, sustainable, and cost-effective. Farmers can make better-informed decisions, leading to increased productivity, reduced environmental impact, and improved food security. GIS in agriculture offers a powerful approach to optimizing the management of resources, crops, and land, which is essential for meeting the growing global demand for food. GIS supports crop health monitoring through multispectral and hyperspectral imagery, which can detect early signs of plant stress or disease. This proactive approach allows farmers to address issues before they escalate, further enhancing resource management.

As the technology continues to evolve, its role in precision agriculture will only grow, contributing to higher productivity, improved environmental sustainability, and a more resilient agricultural sector. Using GIS, predictive models can be developed to forecast crop yields based on historical data and current environmental conditions. By embracing GIS and other advanced technologies like AI, and IoT, the agricultural community can move towards a future where farming practices are both efficient and sustainable, ensuring food security for generations to come.



CASE STUDY

HARSAC Harvests Success: Groundbreaking Agri Reforms Mapped with ArcGIS

Client
Haryana Space Applications Centre (HARSAC)

Industry
Agriculture

Organization Profile
Haryana Space Applications Centre (HARSAC) is responsible for implementing GIS, Remote Sensing, UAV, and GPS technologies across Haryana State, covering a total of 42,212 sq. km. HARSAC harnesses geospatial technology to benefit the state's citizens and prepares plans, policies, and proposals to guide decision-making authorities in the government of Haryana.

Website
www.hsac.org.in/harsac

Project
Crop Management Solution

Highlights

- Facilitates capture of real-time, ground-truth intelligence on the total crop produced in Haryana.
- Ensures more effective governance in yield management and agricultural income generation.
- Brings more transparency to the lifecycle from seed to market; empowering farmers.
- Leads to substantial financial savings for the state.

Project Summary

Haryana Space Applications Centre (HARSAC) has developed and deployed a Geospatial Technology-based Crop Management Solution to address challenges in agricultural management. This solution empowers farmers, enhances transparency, and strengthens agricultural reforms in Haryana. The solution, which is part of HARSAC's OneMap Gurugram Portal, enables the authority to capture real-time, ground-truth intelligence on the total crop produced in Haryana. It allows the government to precisely record, measure, and analyze agricultural produce, leading to more effective governance in yield management and agricultural income generation. By bringing transparency to the lifecycle from seed to market, farmers feel more empowered. The system has led to significant improvements in yield management, cost reduction, and resource optimization, resulting in substantial financial savings for the state.

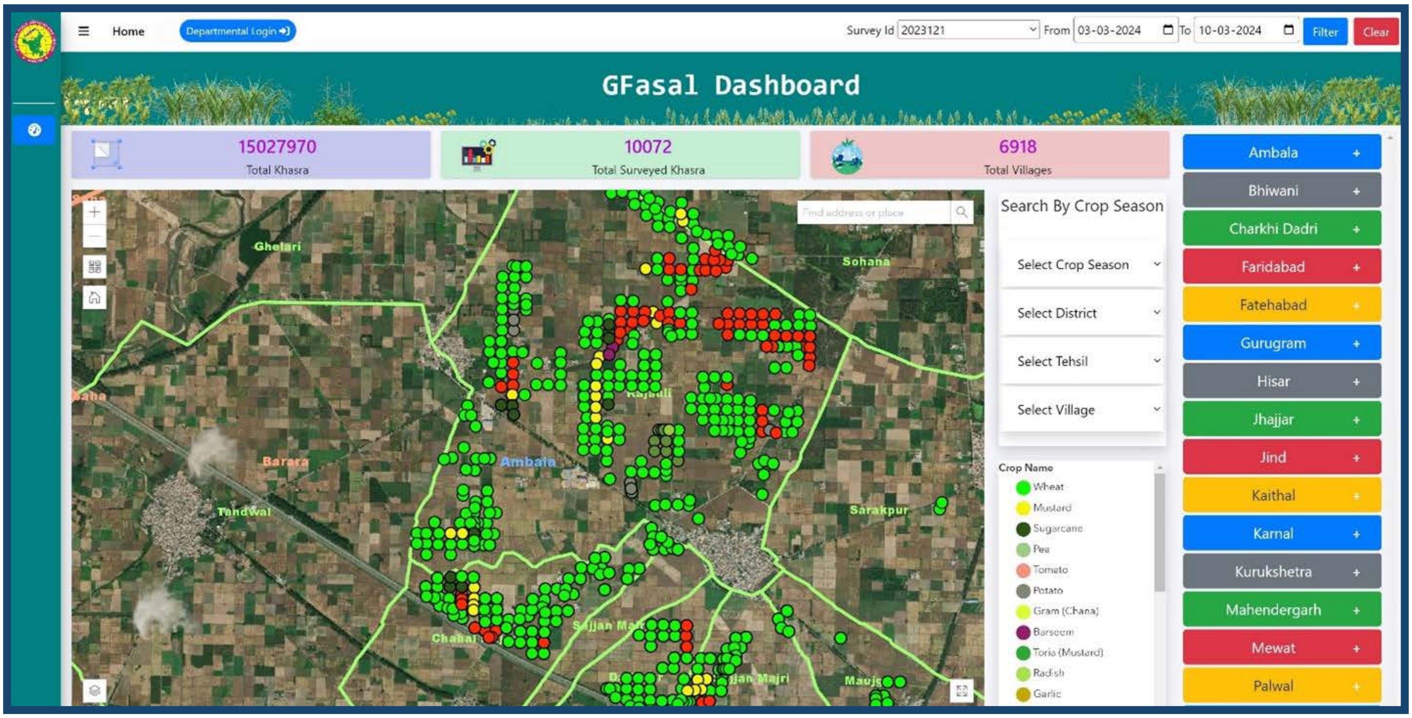
Challenges

Traditional paper-and-pencil surveys in agriculture are prone to errors in measuring farmlands and yields, leading to mismatches in records. Without a digital system, government benefits like subsidies and insurance often do not reach farmers. Additionally, traditional systems struggle with collaboration among different departments.

Solution

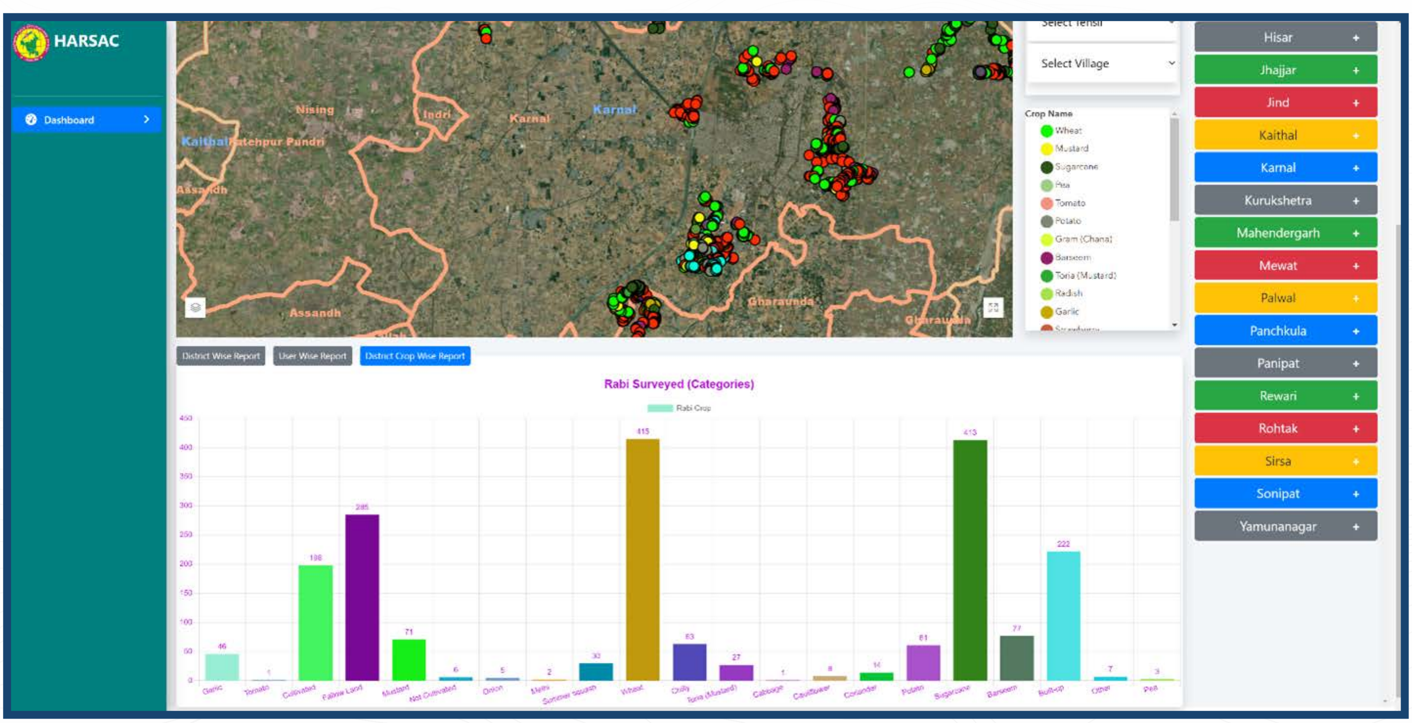
The Crop Management Solution, built using Esri's Geospatial Technology, enables complete data collection of crop types and conditions across Haryana. It performs precise measurements of farmland size in each district, helping HARSAC manage farmlands and crops more effectively, reduce labor costs, and minimize resource waste. The accurate, up-to-date data allows for the formulation of feasible funding and agricultural development plans.

The system encourages farmers to register on a common portal, promoting transparency. **Currently, about 1.2 million farmers are registered.** This registration facilitates complete knowledge of farmland, easing crop monitoring and management. Farmers receive updated market rates and can schedule appointments to sell produce at government-approved centers, saving time and effort.



Overview of the GFasal Dashboard

GFASAL: Geospatial Governance revolutionizing Farming Activities through Spatial Analysis and Learning, The GIS system allows HARSAC to visualize and analyze field data easily, ensuring integrated agricultural data can be updated and managed through an enterprise geodatabase. The system also serves as a platform for data synchronization, management, and sharing, enhancing collaboration among departments and leading to informed decision-making.



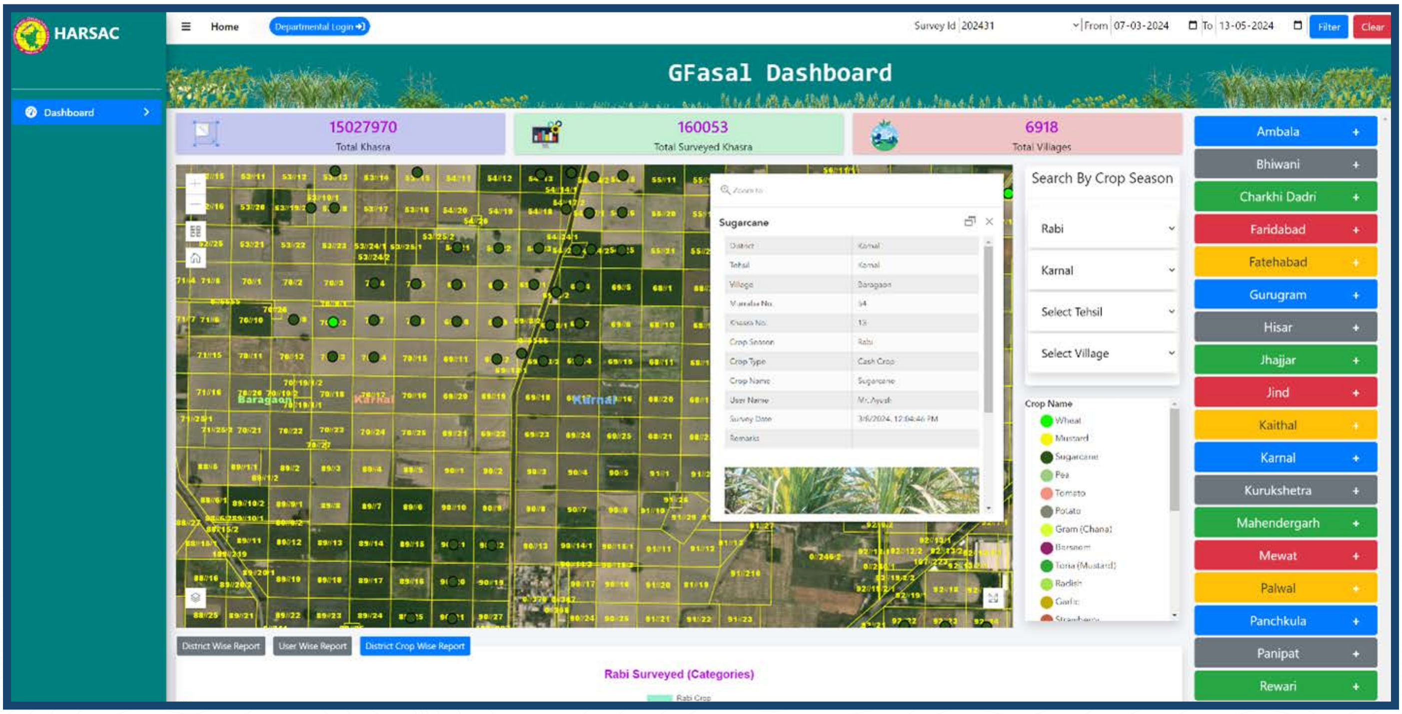
Major Crop Classification in Karnal District

A mobile application enables surveyors to measure farmland areas, add attributes, and take pictures of crops using integrated GIS and GPS technologies, ensuring real-time data upload.

The GFasal Dashboard provides district-wise crop details, allowing users to see information on crops surveyed, crop types, and village-level data, promoting transparency from seed to market.

This robust GIS-facilitated system ensures genuine farmers are identified, bogus beneficiaries are excluded, and registration anomalies are reduced. The state's income from agricultural produce is optimized, and government benefits reach the real farmers.

Field surveys, carried out by students, involve using the mobile app. This experience imparts geospatial data knowledge and GIS skills, contributing to future capacity building and making students more employment-ready.



Area 54//13 in Karnal: Sugarcane, Sown on 8th March 2024, with Geotagged Photo Attached

Methodology

The Crop Management Solution employs the following GIS tools and techniques:

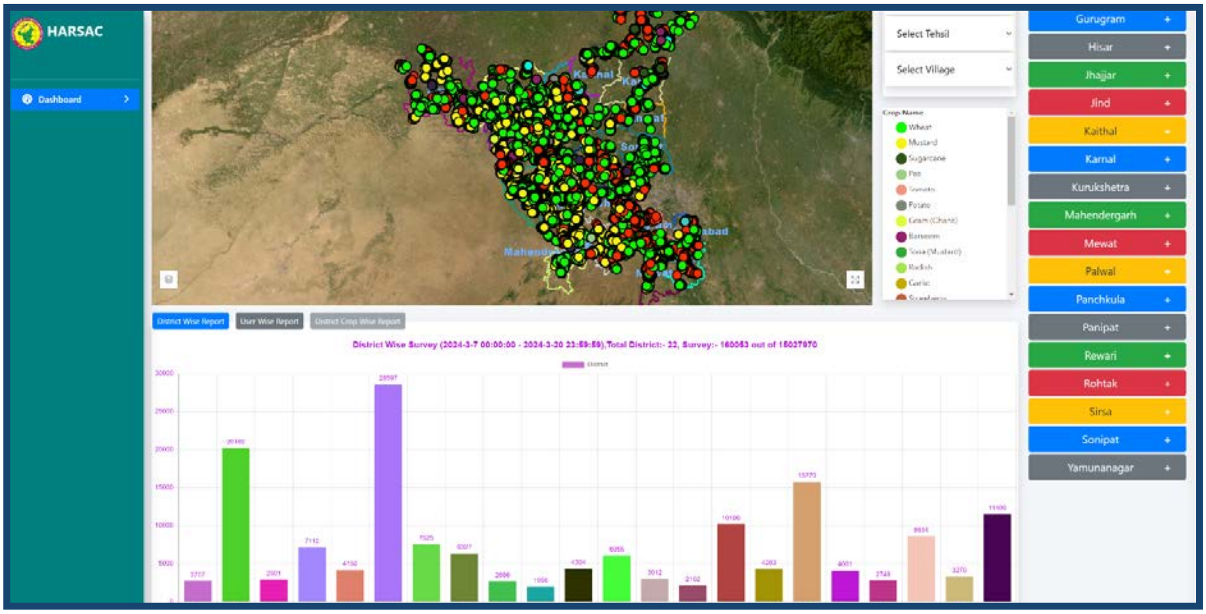
1. **Data Collection:** Using mobile applications integrated with GIS and GPS, surveyors collect data on crop types, farmland size, and conditions.

2. **Real-time Data Upload:** Collected data is uploaded in real time to an enterprise geodatabase, ensuring accuracy and timeliness.

3. **Data Visualization:** The GFasal Dashboard provides a visual representation of crop data, enabling easy analysis and decision-making.

4. **Collaboration:** The system facilitates data sharing and synchronization across departments, enhancing collaboration and informed decision-making.

5. **Farmer Portal:** Farmers register on a common portal, where they can access information on market rates, selling outlets, and schedule appointments for selling produce.



District-wise Crop Survey Count across Haryana: Mapping Agricultural Abundance for Sustainable Growth

Benefits

The implementation of the Crop Management Solution has led to significant improvements:

1. **Yield Management:** Accurate measurement and analysis of farmlands and yields.
2. **Cost Reduction:** Reduced labor costs and minimized resource waste.
3. **Transparency:** Enhanced transparency in the agricultural supply chain.
4. **Financial Savings:** The state has saved approximately 300-400 crores.
5. **Farmer Empowerment:** Farmers receive support throughout the crop lifecycle, from production to market.
6. **Social Enforcement/Assessment Impact:** Strengthened social enforcement mechanisms and enhanced assessment capabilities, fostering greater accountability and compliance within the agricultural sector.

The integration of Geographic Information Systems (GIS) in agriculture is transforming traditional farming practices. GIS technology enables precise data collection, a nalysis, and visualization, which are crucial for effective decision-making and resource management. Agriculture plays a vital role in the economy, and efficient crop management is essential to support the livelihoods of millions of farmers. HARSAC, recognizing the need for modernizing agricultural practices, implemented a Geospatial Technology-based Crop Management Solution to overcome the limitations of traditional methods and enhance agricultural productivity and governance. The Crop Management Solution by HARSAC is a pioneering step towards modernizing agriculture in Haryana. By leveraging Geospatial Technology, the state has achieved significant improvements in yield management, transparency, and financial savings.

> “The Crop Management Solution developed using Esri's Geospatial Technology is enabling HARSAC to effectively govern the full lifecycle of agricultural production in the State of Haryana. By removing demand-supply gaps and minimizing errors in yield estimations and procurement predictions, it fosters a culture of sustainable agriculture, bringing about 300-400 crores worth of savings to the State.”
>
> **- Dr. Sultan Singh, Head (GIS), HARSAC**

Esri India Building Sustainable Forest Management Solutions with ideaForge

In conversation with Abhilash Damodaran, Forest Officer, Himachal Pradesh Forest Department

The key priorities of the Himachal Pradesh Forest Department are to ensure the ecological stability of the state, enhance the forest cover, improve the quality of the forest, and ensure the sustainability of livelihoods of the forest-dependent population in the state. The long-term goal is to protect against the climate change vulnerabilities that are predicted to happen across the globe.

Boosting Performance with Drone and GIS Technologies

Drones are helping the Forest Department to get higher-resolution imagery. The images can be captured at suitable frequencies and multiple operations can be undertaken. The array of operations can be effectively planned based on the planning requirements and the demand from the field units. The topography of Himachal Pradesh is quite undulating, mountainous, and inaccessible, so the endurance of the drones matters a lot.

By combining drone technology with GIS, the Forest Department is transforming forest mapping and management. The integrated solution provides a complete, end-to-end workflow to capture high-resolution imagery and diverse data in real-time, process it, and generate useful insights that empower forest managers to make informed decisions in resource allocation, plantation management, wildlife management, forest fire detection & damage assessment, and more.

The integrated Drone-GIS solution is providing the Himachal Pradesh Forest Department unparalleled insights into forest resource/ inventory, health, security, and operations.

In the future, using the deep learning capabilities of ArcGIS, the department aims to achieve more effective outcomes in vegetation mapping, biomass estimation, habitat characterization, forest protection, tracing out man-animal conflicts, etc. The video motion feature of ArcGIS Pro can be used to detect forest offenses or the areas where forest offenses have occurred. The routes and the various paths taken by people in the forest can also be detected.

Additionally, while managing a forest area, it is important to take care of the local communities. It is important to consider their livelihoods and the other activities that are happening there because all these are interrelated and they ultimately affect the quality of the forest and wildlife in that particular area. GIS and drone technologies aid in mapping these effectively and taking the best course of action. The combination of GIS and drone technologies widens the scope of decision-making in forest and wildlife management. The integrated solution is boosting the Himachal Pradesh Forest Department's performance.

"It has been a great working experience with ideaForge and Esri India. Due to the support provided by them, our personnel quickly learned the diverse applications. By combining our forest and wildlife management skills with Esri India's skills in digital mapping using modern tools and technology, we look forward to continuously achieving excellent outcomes in our forest and wildlife management efforts."

- Abhilash Damodaran, Forest Officer, Himachal Pradesh Forest Department

Gaining Better Produce with GIS: Higher Accuracy in Soil Health and Crop Yield Management

Geographic Information System (GIS) has significantly transformed agricultural practices, particularly in soil health and crop yield management. By integrating GIS technology with farming practices, farmers are able to achieve more efficient and precise management, ultimately improving both the quality and quantity of their produce.

In a conversation with **Dr. Jaya N. Surya, Principal Scientist and Head, ICAR – NBSS & LUP, Regional Centre, Delhi,** we explored how digital soil mapping using GIS is benefitting planners, farmers, stakeholders, and developmental agencies.

What are the core functions of ICAR and the National Bureau of Soil Survey & Land Use Planning?

ICAR's main mandate is to maintain land resource inventories and to take care of soil health and its management, and the National Bureau of Soil Survey & Land Use Planning's mandate is to undertake soil survey and mapping, its classification, and correlation for the identification of constraints and potential. On the basis of this identification, we can manage and monitor soils and inform farmers how to utilize the land resources in a sustainable manner.

For what purposes are you using GIS?

We use GIS for digital soil mapping. For digital soil mapping, we analyze the terrain parameters, and on these attributes/ parameters, we prepare the base maps for soil surveys. Geospatial techniques are very useful for soil surveys, especially for large areas. They are cost and time effective. Using geospatial techniques, we can generate detailed site-specific information and identify constraints and potentials, which prove very useful for creating detailed soil and other thematic maps.

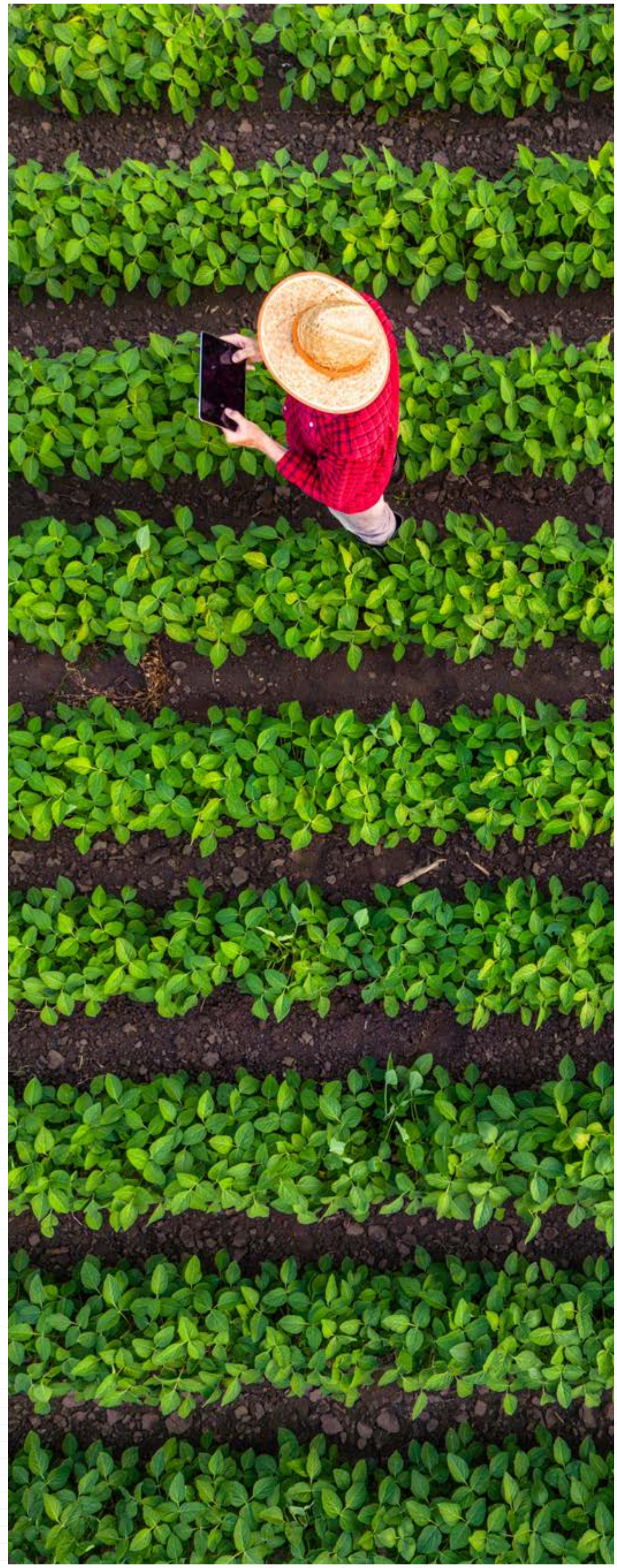
What are the benefits of using GIS?

The National Bureau of Soil Survey's main mandate is soil survey and mapping. In digital soil mapping, we interpret all the digital terrain parameters. On the basis of these parameters, we characterize the soil properties and create soil maps. As part of our land resource inventory program, we create regional maps as well as various thematic maps. These region-specific maps are very useful for planners, farmers, stakeholders, and developmental agencies.

How do farmers benefit from the use of GIS?

We are generating datasets for different regions. The farm-level data benefits farmers. We run many projects for sustainable land use planning, and land evaluations for crop suitability for particular regions including cash crops that are beneficial for farmers. We in the Bureau, are also working on watershed development programs such as reward and LRI-PMKSY-2.0 In these programs, soil and watershed development plans are generated and soil and water conservation measures for every farm in a particular region are suggested. This is beneficial for farmers and stakeholders.

We also develop detailed soil information maps. We are distributing land resource inventory cards. In those cards, we provide information about 12 important parameters of soil along with other soil characteristics and morphological features and give a range of that (low, medium, high). According to those low, medium, high parameters, we suggest the nutrient requirement of particular farms. This is very important information for the farmers as it helps them manage and monitor the fertilizer dosage and maintain soil health and crop yield. All these data are interpreted on the GIS platform in a short period of time and with utmost accuracy.



ARTICLE

Transforming Farming Decisions with GIS

The agriculture sector is one of the most important threads in the socio-economic fabric of the Indian economy. The sector's role extends beyond economic contributions, not only ensuring food security and stability for the nation but also posing as the primary source of livelihood for around 55% of India's population. This being acknowledged, it is only wise to strengthen this crucial pillar of support, and the answer lies in using technologies like Geographic Information Systems (GIS) to bring digital transformation in agriculture.

Indo ArcGIS facilitates stakeholders to collect, maintain, analyze, and share agriculture data and make more informed decisions at all stages of the agricultural lifecycle. Indo ArcGIS allows the analysis of all field data in one centralized system. It enables integration of Earth observations, imagery, field data, and real-time data streams to improve efficiency, profitability, and sustainability.

A Crop Management Solution developed using Indo ArcGIS, implemented by the Haryana Space Applications Centre (HARSAC), is enabling the organization to effectively govern the full lifecycle of agricultural production in the State of Haryana. By removing demand-supply gaps and minimizing errors in yield estimations and procurement predictions, the Solution is fostering a culture of sustainable agriculture along with bringing substantial savings to the State.

From soil and nutrient analysis to sustainable farming, GIS has a vital role to play in every facet of agriculture.

Agricultural Mapping

Accurate mapping of geographic and geologic features of farmlands enables scientists and farmers to create more effective and efficient farming techniques. Suitability analyses, facilitated by GIS, help the farmers determine the optimal crops for each plot of land, based on its soil, climate, and social conditions and conceptualize the best practices at all stages of the farming season. GIS offers vital insights related to crop health, soil conditions, and weather patterns in real-time. GIS allows the stakeholders to develop a holistic approach to precision farming. It helps in creating maps and dashboards that integrate important variables such as soils, irrigation, yield, production costs, profit, and compliance data.

Crop Yield Prediction

Accurate yield predictions are vital for food security and financial planning. Using GIS, predictive models can be developed to forecast crop yields based on historical data and current environmental conditions. Machine learning algorithms and statistical techniques are often applied to analyze spatial relationships and make accurate predictions.

Crop Health Monitoring

Instead of manual inspections, GIS enables remote monitoring of crop health using satellite imagery, providing insights about humidity, temperature, and overall growth. This helps identify areas needing attention. GIS allows farmers and agronomists to create detailed maps of fields, depicting variations in crop health indicators such as vegetation indices, chlorophyll content, and thermal imagery. These maps help visualize spatial patterns of crop health across large agricultural areas.

Insect and Pest Control

By monitoring changes in crop health indicators over time, GIS enables early detection of stress factors such as nutrient deficiencies, water scarcity, diseases, and pest outbreaks. Early identification allows farmers to take timely corrective actions, preventing potential yield losses and reducing the need for extensive interventions later in the season.

Irrigation Control

GIS facilitates the development of irrigation schedules tailored to specific field conditions and crop water needs. By analyzing spatial data on soil moisture, rainfall patterns, and evapotranspiration rates, GIS helps farmers and water managers optimize the timing, duration, and frequency of irrigation events to minimize water waste and maximize crop yields.

Water Quality Management

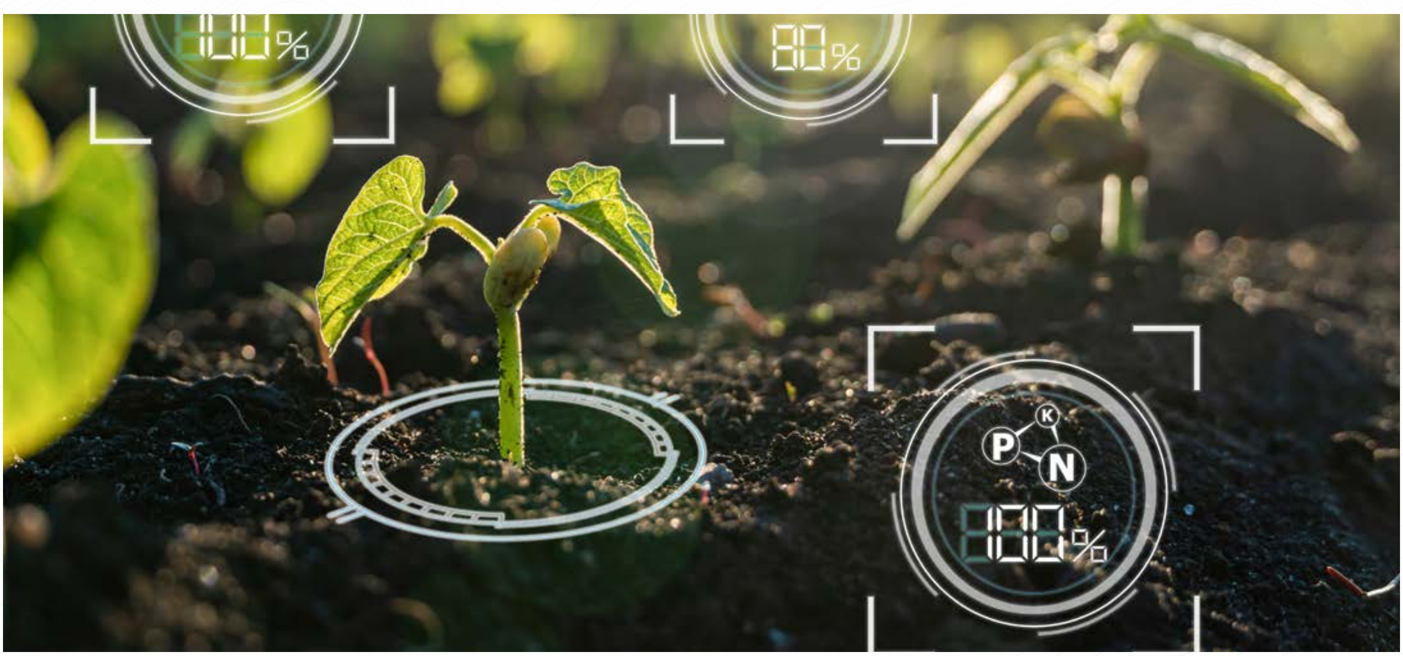
GIS assists in monitoring water quality parameters such as salinity levels and contamination risks. By analyzing spatial data on soil types, land use practices, and proximity to sources of pollutants, GIS helps in identifying areas vulnerable to water quality degradation and implementing measures to protect irrigation water sources. As much as 70% of good water is used in agriculture, saving on this water use can help in addressing water stress. Wise usage of water can be made possible by adopting precision technology.

Crop Insurance and Loss Assessment

In periods of catastrophic events like floods, heavy rainfall, drought, etc., GIS can be used to determine exactly how much of a given crop has been damaged and the progress of the remaining crop on the farm. GIS can generate crop condition and distribution analytics, leading to faster loss adjustment and payout to the farmers. In the crop insurance business, high-resolution imagery plays a key role in speeding up the claim process. Using Indo ArcGIS and image processing software like ENVI, farmers and insurance providers can achieve the benefits of faster claim processes and payouts, visibility on in-season crop conditions at different time intervals fostering risk analysis and decision making, crop classification and crop risk analysis, acreage estimation of different crops, identification of inundation area and exposure monitoring, reduced operational and data processing cost, and more.

Conclusion

The list is endless when it comes to the benefits of using GIS in agriculture. Indo ArcGIS analytics for agriculture empowers farmers to optimize workflows, enhance resource management, and boost profitability. As the need to increase food production to meet global demands persists, incorporating GIS in farming is imperative. The value of GIS software in the agriculture market is projected to be approximately USD 2.61 billion by 2029. With advanced mapping, high-resolution imagery, and AI, GIS solutions are set to revolutionize farming practices, helping to feed the world sustainably. Integrating GIS with IoT sensors and drones will provide rapid and improved real-time information. This information combined with historical data, and emerging technologies such as AI will drive informed decision-making to leverage best-in-class farming practices, thereby creating a highly productive environment for both the producers and consumers.



Site Scan for ArcGIS

Site Scan for ArcGIS, part of the ArcGIS Reality suite of products, is the end-to-end, cloud-based drone mapping software that revolutionizes drone imagery data collection, processing, and analysis.

Using Site Scan for ArcGIS, you can securely process imagery in a scalable cloud environment to create high-quality 2D and 3D imagery products that can be quickly shared throughout your organization, on any device. You save time using the measurement and analysis tools to get the answers you need from your data. You can directly publish your drone data to your ArcGIS organization to perform advanced drone analytics such as object detection and the application of artificial intelligence (AI).

How it Works

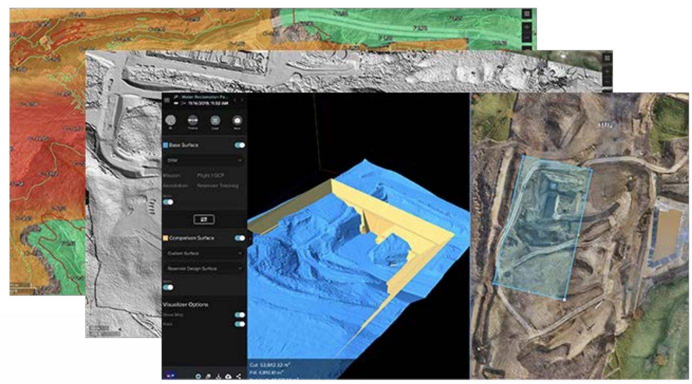
1. **Plan the optimal flight path**
   For enhanced safety and planning accuracy, import layers and 3D models from previous flights or ArcGIS Online.

2. **Execute an autonomous flight**
   Complete your preflight checklist and execute an autonomous drone flight.

3. **Upload & process the data in the cloud**
   After the flight is complete, upload your data for cloud processing and mark ground control points manually or automatically using computer vision.

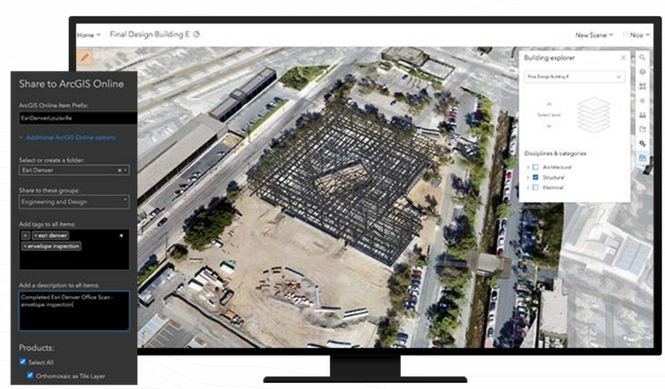
Processing data in cloud

4. **Visualize, analyze & share your outputs**
   View 2D and 3D outputs on the web. Make measurements, track changes, and perform other analyses. Invite your team to view project data and results.

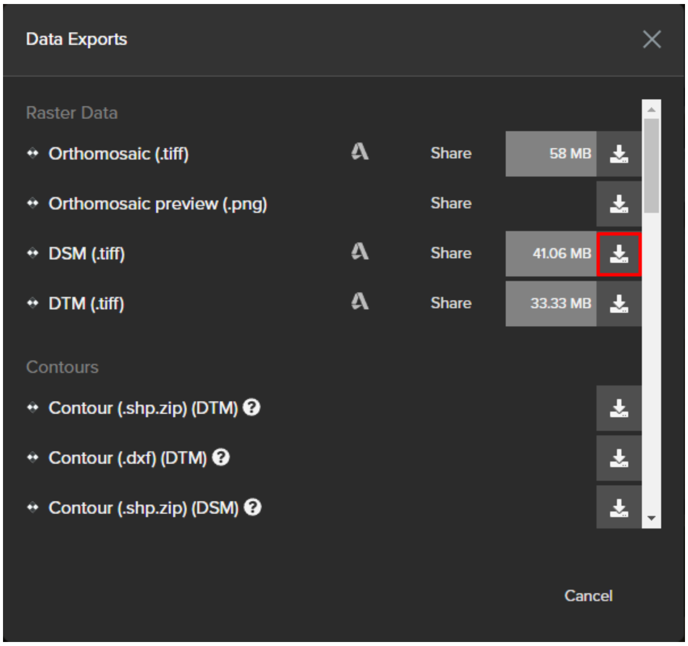


Visualization of analyzed imagery

5. **Publish content & perform advanced analysis**
   Export in formats you need, publish to your ArcGIS organization for advanced analysis such as deep learning workflows.



Share outputs across organization



Data export formats

Drone Derived Products

1. Digital Surface Model
2. Orthomosaic
3. 3D Point Cloud
4. 3D Reality Mesh etc.

Supported Flight Modes

Site Scan supports several types of flight modes:

1. Large area scan
    - Area Survey
    - Crosshatch Survey
2. Inspection and visualization
    - Inspection
    - Panorama

Site Scan for ArcGIS is a powerful tool for agricultural resilience, enabling crop health monitoring, precision agriculture, soil analysis, disaster management, yield prediction, and field planning. It captures high-resolution imagery, enables early identification of pests, diseases, and water stress, and integrates with other GIS data for better yields and reduced costs. It also aids in disaster management, predicting crop yields, and planning infrastructure for increased efficiency and productivity.

Site Scan for ArcGIS is a drone mapping software that provides an end-to-end workflow for acquiring and processing drone imagery, working with the resultant data products, and managing the construction assets.

ArcGIS Dashboards

ArcGIS Dashboards enable users to convey information by presenting location-based analytics using intuitive and interactive data visualizations on a single screen. Every organization using the ArcGIS system can take advantage of ArcGIS Dashboards to help make decisions, visualize trends, monitor status in real-time, and inform their communities. You can tailor dashboards to your audiences, giving them the ability to slice the data to get the answers they need. Dashboards are essential information products, like maps and apps, providing a critical component to your geospatial infrastructure.

A good dashboard starts with a good map, and configuring your map to take advantage of the latest mapping functionality will enhance its effectiveness. **There are two areas where following good practices can help the effectiveness of your dashboards: the map layers and the map design.**

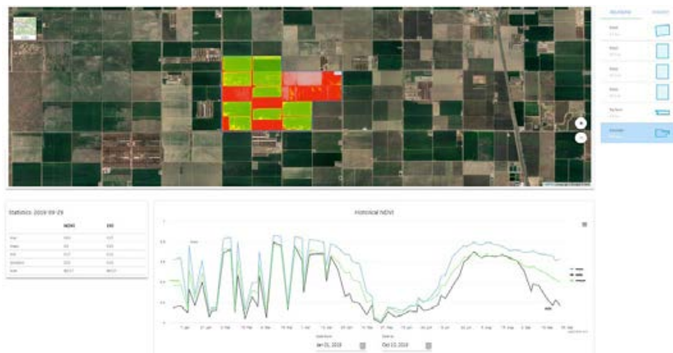
Best Practices for Map Layers

The following are recommendations for configuring map layers in web maps used in dashboards:

- **Set appropriate refresh intervals:** Refresh intervals determine how often the operational layer updates and how often elements in your dashboard that use the map as their data source update. Set a refresh value that reflects how often your data updates. You can also set a refresh interval for the media in your pop-ups, which can appear in elements such as the details element. Refresh intervals are not supported in mobile view.

- **Exclude irrelevant data from operational layers:** Apply filters on operational layers so that only the information that is needed is shown.

- **Manage operational layer visibility:** Too many operational layers in a map can be a distraction. You can turn off the visibility of operational layers on your map. Even if an operational layer is not visible on the map, it can still be used as a data source for other elements in a dashboard.



Best Practices for Map Design

The following are recommendations for designing and styling web maps used in dashboards:

- **Set visible range:** Multiscale maps enable you to view certain data at specific scales or zoom levels. When you set the visible range for a map, it can keep your maps from getting too crowded.

- **Adjust pop-up fields:** The fields specified in feature pop-ups determine the information displayed in many dashboard elements. Configure your pop-ups to only show the information you need.

- **Bookmark areas of interest:** You can bookmark areas of importance or relevance on a map. Dashboard users can use bookmarks you create to quickly jump to the areas of importance.

- **Style your data:** A map is powerful because of its ability to show data in a variety of ways. However, due to its complex nature, it's sometimes hard to get your data to tell the right story when displayed on a map. Using one of the many styling options, you can style your map to display your data in a meaningful way.

- **Include labels for map layers:** Labels are short pieces of text that can provide clarity to a map.

- **Choose appropriate colors:** When choosing the basemap and colors for layers in your map, consider the type of environment where the dashboard will be used.

The best dashboards are informative and clear. Effective dashboards should be designed to support real-time situation awareness by expressing performance measures clearly, precisely, and without distraction. Dashboards should get the attention of your audience, make it easy to identify what's most important on the screen, and help users understand what's happening and respond immediately.

The best practices for creating effective dashboards are described below.

- Determining your audience
- Avoiding information overload
- Providing context
- Making good design choices

When a dashboard is shared using the Everyone (public) option, it may experience high demand and generate a large amount of traffic. High-demand activity can occur when a dashboard is picked up by social media, a news feed, or other outlets.

The best practices described below ensure that the traffic generated by a dashboard uses the scalable infrastructure of ArcGIS Online, and scales effectively in high-demand situations.

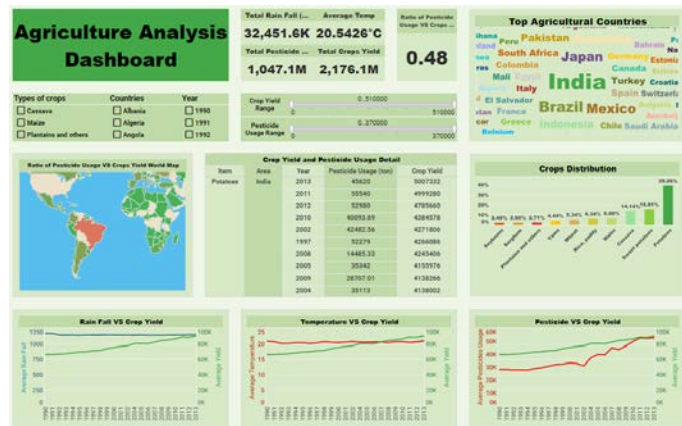
Data sources are the web maps and web layers stored in your ArcGIS Online organization. Use the following guidelines to optimize the layers in dashboards:

- Ensure that the dashboard and all referenced web maps and layers are shared with everyone.

- Ensure that all layers used in the dashboard are a hosted feature layer, feature layer view, or hosted tile layer.

- Ensure that editing, sync, and ownership-based access control are all disabled.

Ownership-based access control may still be enabled even after sync is disabled.



If the data requires editing, don't share it with the public. If sharing is required, create a feature layer view and ensure that it follows the best practices described here.

- Attribute updating is not recommended for public dashboards.

- For hosted feature layers and feature layer views, set their cache control duration to a value that reflects how often the data is actually updated (the default is 30 seconds).

- For hosted feature layers with a large number of features, create attribute indexes on any fields that are queried often.

- For layer filters and view definitions, do not include relative date conditions. These are the 'in the last' or 'not in the last' operators.

ArcGIS Field Maps

ArcGIS Field Maps is a powerful and versatile mobile app solution used to complete a variety of field workflows. Leveraging the power of a map, Field Maps enhances situational awareness, enables simple and advanced capture capabilities, and can record and share where mobile workers have gone, all within a single location-aware mobile app.

When it comes to agriculture resilience, ArcGIS Field Maps can play a crucial role in enhancing efficiency, productivity, and sustainability in the agricultural sector. By leveraging the features of ArcGIS Field Maps in agriculture resilience initiatives, stakeholders can streamline field operations, improve data accuracy, and adapt to changing conditions more effectively, ultimately enhancing the resilience and sustainability of agricultural practices.

What's New

Several key usability improvements have been introduced in Field Maps Designer. Some stability and performance enhancements have also been incorporated in both iOS and Android mobile apps.

Web app–ArcGIS Online

The latest version of the Field Maps Designer web app on ArcGIS Online was released in November 2024. It includes the following:

- Use predefined map templates to create new maps and layers.
- Determine if mobile workers can create new offline map areas and if they can access the online version of the map.
- Various bug fixes and improvements.

Web app–ArcGIS Enterprise 11.4

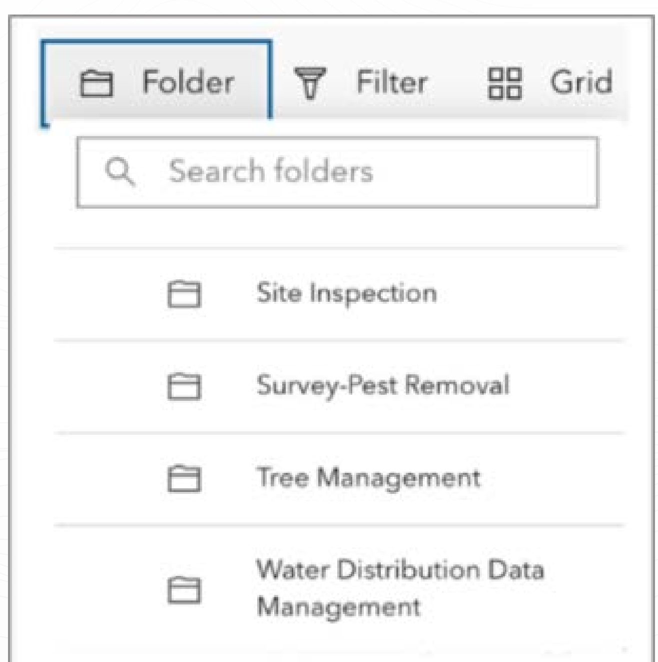
The Field Maps web app on ArcGIS Enterprise 11.4 was released in November 2024. It includes the following:

- Filter maps by folder on the Maps page.
- Mobile map packages (MMPKs) now appear on the Maps page. You can modify their item details and sharing settings.
- Make edits to the map by opening Map Viewer from the Open button.
- Understand why content is preventing a map from being taken offline with improved messaging.
- Various bug fixes and improvements.

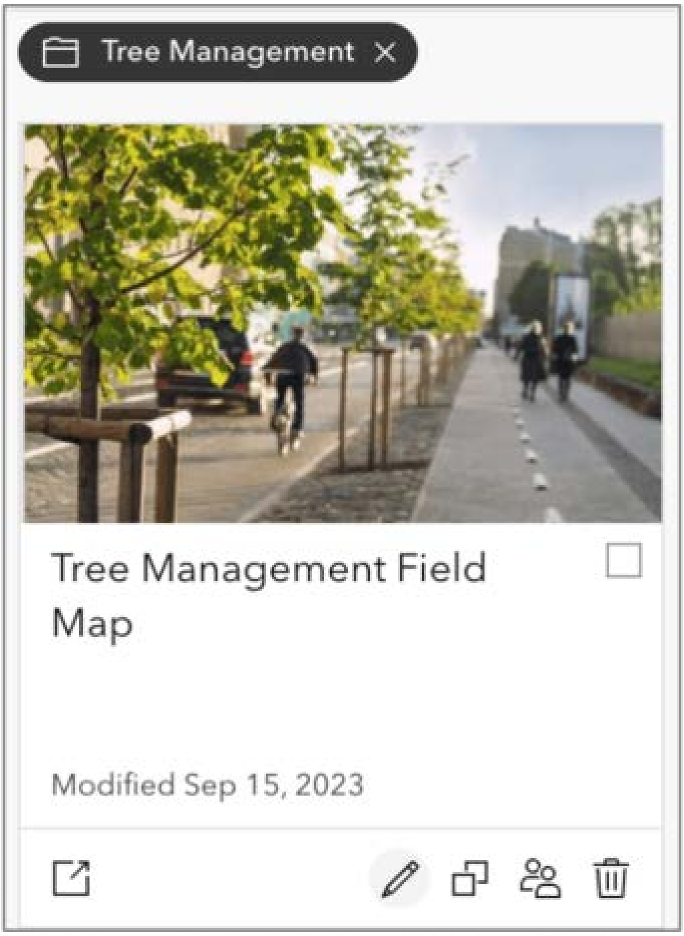
View Maps by Folder

Folders are the drawers in your map cabinet. They're used to organize maps and group related content in your ArcGIS organization.

Within Field Maps Designer, the Maps page provides a list of all available maps you can configure. Now you can view those maps by the folder you placed them in.



When a folder is chosen, an ornament will appear indicating that the list of maps has been filtered by folder. Clicking the x will remove the filter and return the author to their My maps list.

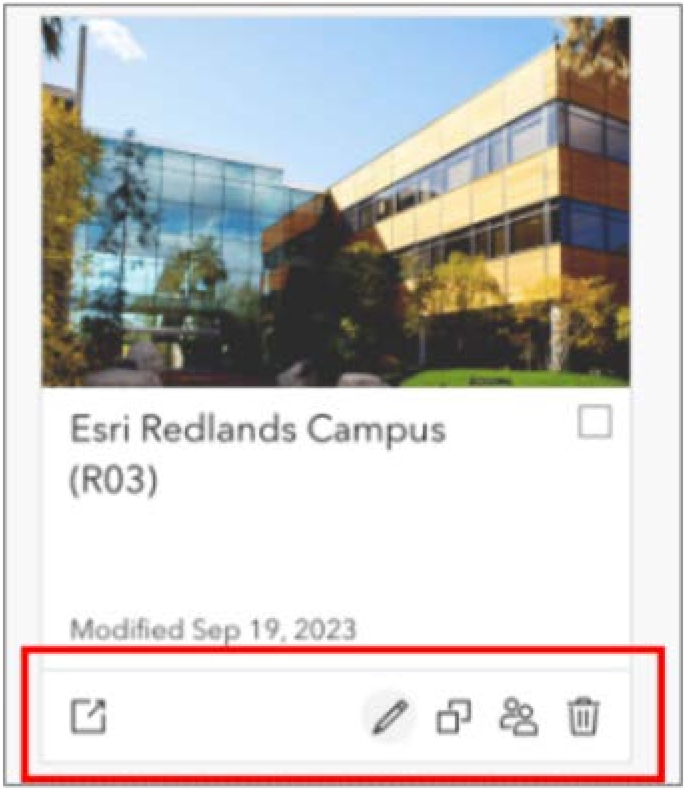


Map Card Indicators

From the Maps page, each map is displayed as a card in grid view or a row in table view and there are a set of actions and capabilities shown:

- Actions include Configure, Duplicate, Edit Sharing, and Delete.
- At a glance, indicators represent the map's capabilities (Editing or Read-only, Mobile Map Packages).

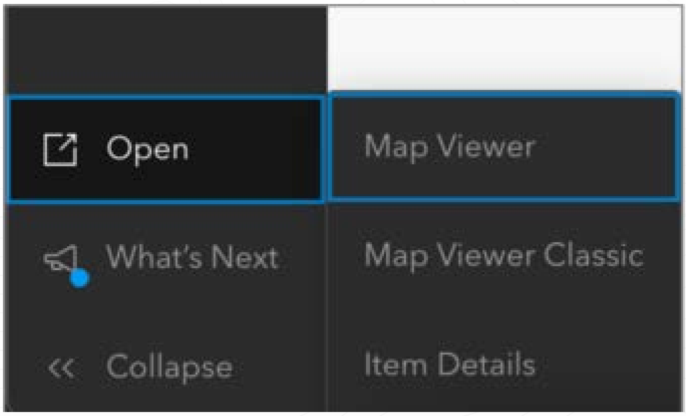
You can use these new indicators to quickly discover the capabilities of a map.



Open Map Viewer

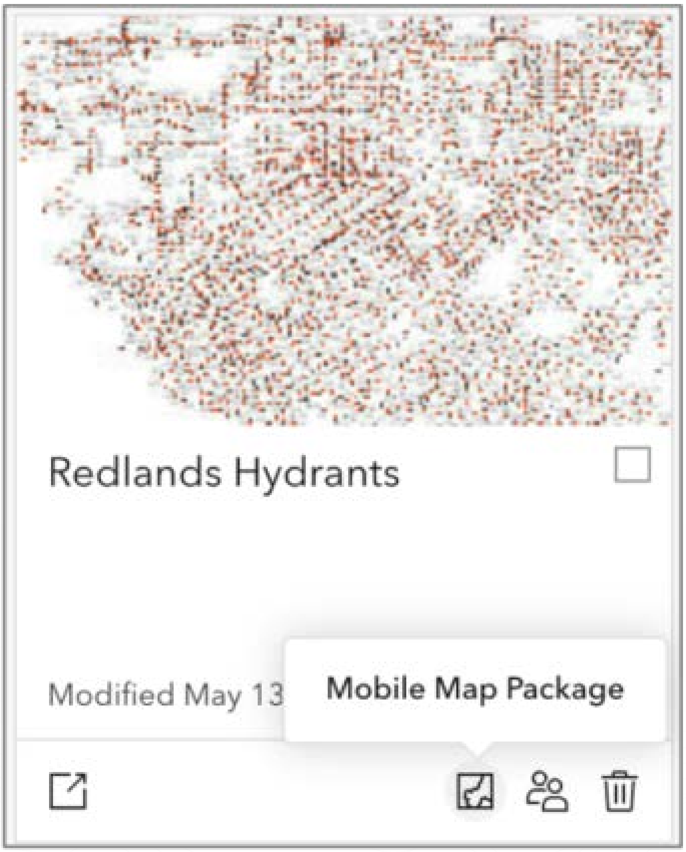
When configuring a map for field use, you may need to open the Map Viewer and make changes beyond what is available within Designer itself. Opening the Map Viewer directly from Designer ensures edits made to a map never get out of sync – a common occurrence if multiple tabs or browser windows are used.

Access to the Map Viewer is now available from the action bar. Previously it was only accessible from the Overview page.



Mobile Map Package Support

Field Maps Designer now supports viewing as well as limited configuration of mobile map packages.

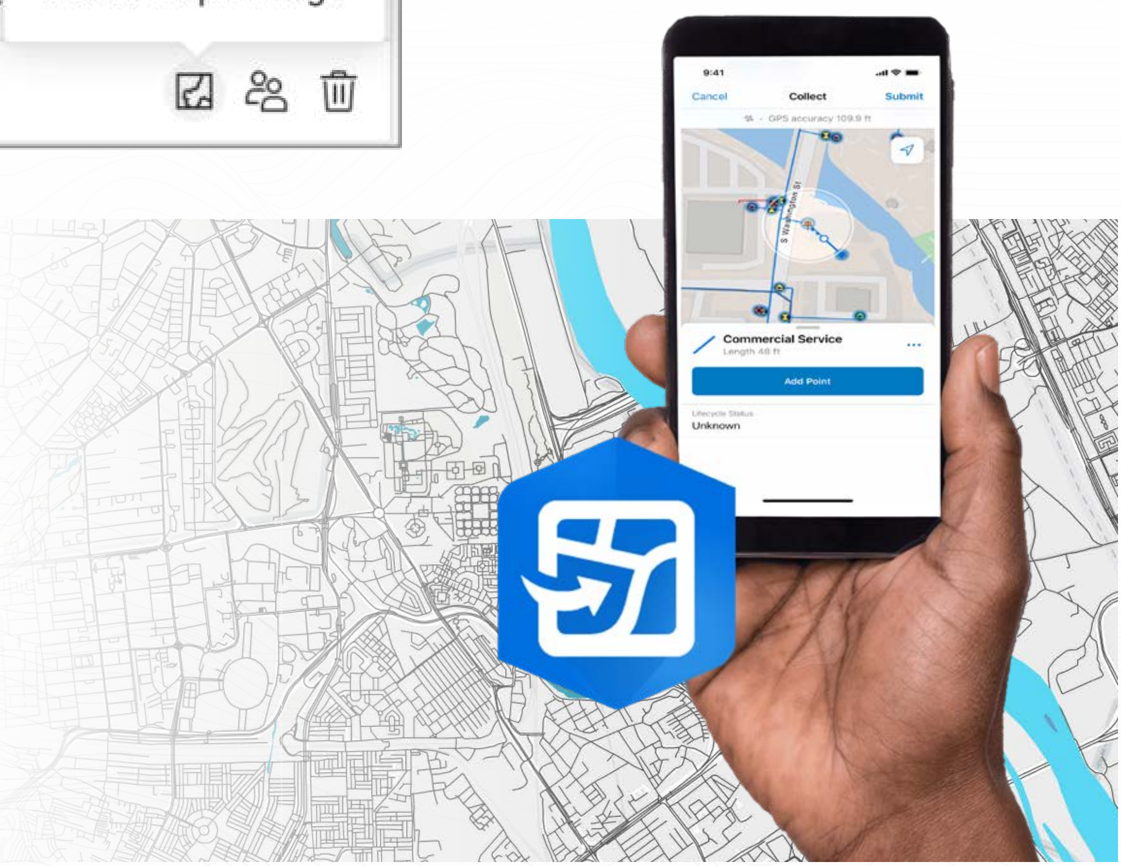


Offline Improvements

For the past 3 releases, Field Maps Designer has included validation checks that highlight error and warning issues in your map so you can understand why content is preventing your map from being taken offline. New checks have also been added and all checks are now available from the web map item details page as well as in Designer.

What's Coming Next

The Field Maps team has been busy building new and enhancing existing capabilities in the mobile apps for release in 2025. This includes support for planning and coordinating field tasks, offline viewing and tracing of utility networks, a new and improved personal markup experience, forms support for Edit Multiple, a refreshed user experience, and much more.



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Eos Positioning Systems® Introduces
The Skadi Series™
High-Accuracy GNSS Receivers for ArcGIS® Apps
NEW
Skadi Tilt Compensation™
No more bubbling up!
Increase your productivity,
by reducing your time on each point.
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Putting RTK In Your Hand™
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Scaling up Technology-enabled Agriculture Education: The University of Agricultural Sciences, Raichur

The mission of the University of Agricultural Sciences (UAS), Raichur is to generate quality human resources in the area of agriculture and allied disciplines, generate cutting-edge competitive technologies, and evolve efficient disseminating mechanisms so as to serve the farming community of the State and the country.

Through a conversation with **Dr. Rajesh N L, Assistant Professor, UAS Raichur, Head, Geospatial Technological Applications Centre, UAS Campus, Raichur, and Director, KRSAC (Additional Charge),** let's explore how UAS is taking concrete steps towards building a strong, technology-savvy agricultural workforce for the country.

How does GIS aid in addressing challenges in agriculture management?

Geographic Information Systems (GIS) play a crucial role in addressing challenges in agriculture management by enabling farmers and agricultural experts to analyze, manage, and visualize spatial data effectively. GIS allows for collecting and integrating various types of data, such as soil properties, crop health, weather patterns, and land use, which can be analyzed to make informed decisions. For instance, precision maps help identify areas within a field that require specific inputs like water, fertilizer, or pesticides, thus optimizing resource usage and reducing waste. Prediction maps help to detect early signs of diseases or pests, which can lead to timely interventions. Furthermore, GIS aids in land use planning and crop rotation using detailed maps of soil types, topography, and climate conditions, enabling better decision-making for sustainable land management.

Overall, GIS enhances productivity, reduces costs, and promotes sustainability in agriculture by providing insights that improve decision-making and resource management. Further, geospatial technologies help to develop and adopt market-driven agriculture through the convergence of location-specific farmer's information, government schemes, supply & demand chains, best management practices, and resource availability, for sustainable food production and security.

What's your take on the availability of enough skilled workforce to use various geospatial technologies in agriculture?

The availability of a skilled workforce to effectively use geospatial technologies in agriculture remains a significant challenge. While geospatial technologies like GIS and remote sensing are increasingly adopted in agricultural practices, there is often a gap in the number of professionals who are adequately trained to use these advanced tools for spatial analysis.

Additionally, there is a shortage of GIS hands-on specialized education programs and training opportunities that focus on geospatial applications in agriculture. However, this gap is gradually being addressed through initiatives by universities like ours and technology companies offering specialized courses and certifications. Despite these efforts, more investment in education and training is essential to ensure that the workforce is equipped with the necessary skills to maximize the benefits of geospatial technologies. Bridging this skills gap is key to ensuring the continued growth and efficiency of modern agricultural practices.

What role is your university playing in minimizing this workforce availability gap?

Our university is actively working to minimize the workforce availability gap by offering a range of programs and initiatives designed to align GIS education with industry needs. Our UG & PG courses in various streams viz., Soil Science, Agronomy, Soil Water Engineering are specially designed to equip students with the latest GIS knowledge and skills. Through the development of specialized degree programs, internships, and partnerships with the industry, the university ensures that students gain the necessary skills and practical experience to meet the demands of the industry.

By fostering a collaborative environment between academia and industry, the university is helping to bridge the gap between the skills students acquire and the specific needs of the GIS industry, ensuring that graduates are well-prepared to contribute to the workforce.

What are the futuristic technologies for agriculture in India?

Futuristic technologies for agriculture in India are poised to revolutionize the sector, enhancing productivity, sustainability, and efficiency. Spatial analytics driven by Internet of Things (IoT) sensors, drones, and satellite imagery, enables farmers to monitor soil health, moisture levels, and crop conditions in real-time, allowing for data-driven decision-making. Artificial Intelligence (AI) and machine learning are being used to predict weather patterns, optimize irrigation schedules, and detect crop diseases early, minimizing losses. Additionally, automation technologies, including robotic harvesters and automated irrigation systems, are reducing labor costs and improving operational efficiency. These technologies, when integrated, promise to boost agricultural productivity, improve sustainability, and help India address the challenges of food security and climate change in the coming decades.

How is Esri India helping you to impart GIS/geospatial skills to your students?

The University of Agricultural Sciences is a renowned institution dedicated to advancing education in agriculture management. We have established a 'Geospatial Technological Applications Centre for Agricultural Input and Land Health Management' to strengthen capacity building in this field and to carry out relevant projects. **Esri India, which is a leader in GIS technology, through their training programs, is equipping our students with the latest methodologies, tools, and techniques. Given the rapid evolution of GIS technology, such initiatives are critical to meet the growing demand for up-to-date knowledge and skills.** Additionally, a collaborative effort to establish a Center for Excellence could serve as a hub for research, knowledge creation, workshops, faculty development programs, conferences, and disseminating valuable insights, further enhancing the connection between academia and industry.

What's the way forward for the University of Agricultural Sciences?

The University of Agricultural Sciences is committed to upgrading its curriculum and providing students with the latest skills and knowledge in agriculture management, and for this purpose aims to incorporate emerging trends and technologies in the curriculum that are shaping the industry. One key approach is to introduce courses that focus on modern agricultural technologies, such as precision farming, data analytics, AI, drones, remote sensing, and the Internet of Things (IoT). These tools are transforming farming practices and should be integrated into practical learning experiences to ensure students can apply them effectively. Strong industry partnerships and internship opportunities are crucial in ensuring that academic learning aligns with real-world needs. These partnerships provide students with exposure to agricultural operations, agribusinesses, and policy development, allowing them to apply classroom knowledge in practical settings.

RESEARCH PAPER

Remote Sensing and GIS based Groundwater Resources and Demand Estimation in Ayad River Basin, Udaipur (Rajasthan)

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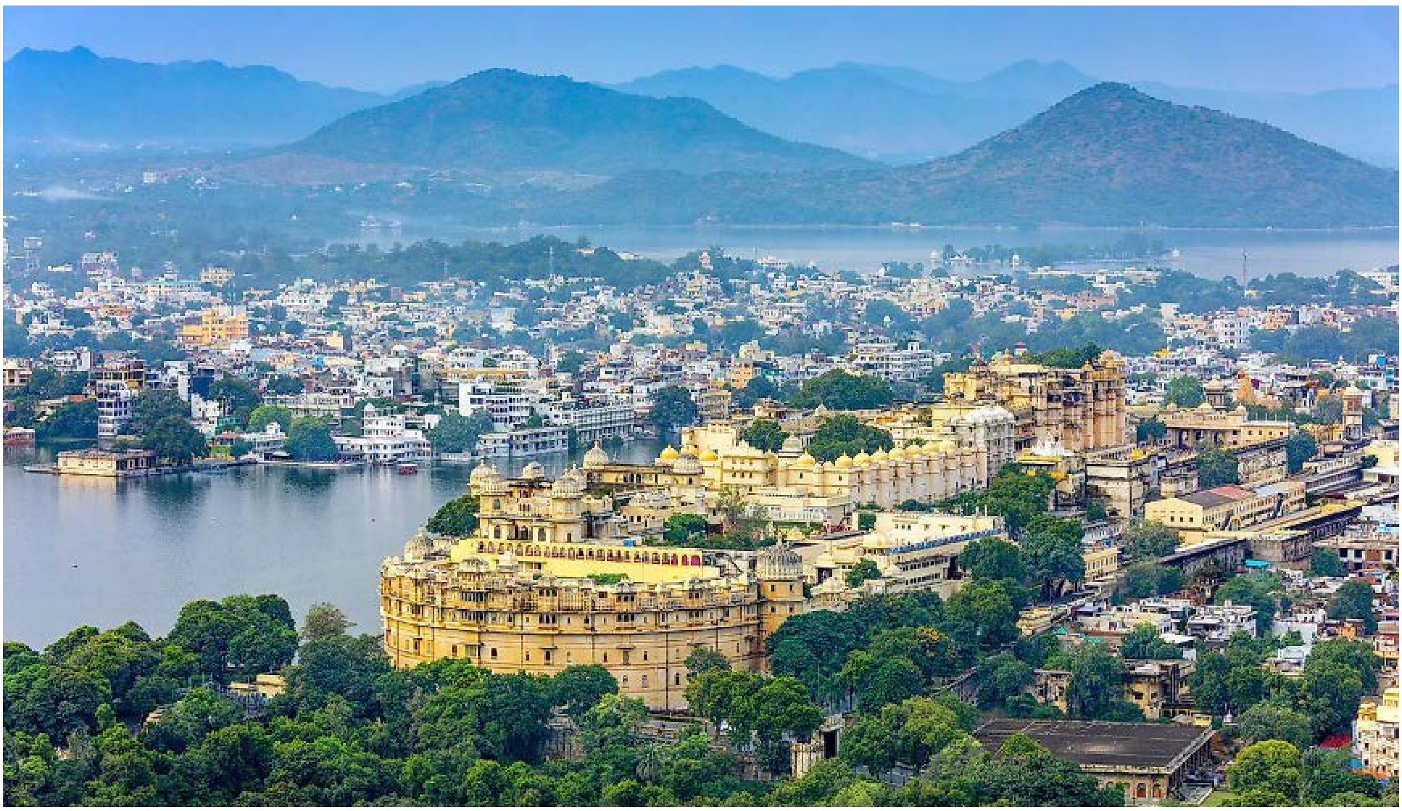

Abstract

The hydrological dynamics of the Ayad River Basin are significantly influenced by climatic changes and demographic trends. Analysis from 1901 to 2022 indicates a mean annual rainfall of 641 mm with notable variations, including dry spells in 1901-1920, 1931-1940, and 1971-2010, with the longest drought from 1971 to 2010. Since 2010, a trend toward wetter conditions has been observed, increasing water resources. However, this does not consistently boost groundwater recharge due to factors like topography and aquifer properties. Groundwater level observations from 1984 to 2022 show increases near natural water sources and vegetation, while agricultural and urban areas saw less change. Land use changes during this period revealed an inverse correlation between groundwater level changes and irrigated agriculture, urbanization, and natural vegetation. Groundwater abstraction trends from 2009 to 2022 showed an upward trend, causing increased fluctuations in groundwater levels. Future population projections and water demand estimations highlight the need for sustainable management practices. The Rainfall Infiltration Factor (RIF) method, validated against empirical approaches, estimated an average annual groundwater recharge of 62.9 MCM from 1984-2022. Projections under RCP4.5 and RCP8.5 scenarios indicate a growing disparity between groundwater demand and availability, with a projected deficit of 2% by 2026, 27% by 2056, and 39% by 2091. This study emphasizes the

importance of adaptive management strategies to ensure water security in the Ayad River Basin amidst changing climatic and demographic conditions.

Introduction

Groundwater plays a critical role in meeting the water demands for domestic and agricultural purposes in Rajasthan, India. As a semi-arid region with limited surface water resources, the state heavily relies on groundwater to fulfill its water needs (Chinnasamy et al., 2015). Groundwater abstraction has increased significantly over the years to support the growing population, agricultural activities, and industrial development in the state. Groundwater in Rajasthan is primarily sourced from wells, tube wells, and hand pumps for both rural and urban communities. Due to the lack of perennial rivers and adequate rainfall, groundwater is the primary source of irrigation for agriculture in the region, making it a crucial resource for sustaining agricultural practices and urban-rural livelihoods (Dangar et al., 2021). Approximately 90% of the drinking water supply and 60% of irrigation needs are fulfilled by groundwater resources. During the 1970s and 1980s the epoch of the Green Revolution occurred in India, during which extensive groundwater extraction was practiced in Rajasthan (Mukherji, 2020). The demand for groundwater is continuously increasing due to the growing population, the establishment of additional industries and the intensification of irrigation. This escalating demand has accentuated the pressure on groundwater reserves. Alarmingly, around 80% of the state's territories have witnessed a decline in groundwater levels due to overexploitation and excessive pumping of groundwater leading to declining water levels and aquifer depletion in various parts of the state, particularly in areas with intensive agricultural activities (Parimita et al., 2020). Moreover, numerous towns and villages are suffering from water scarcity, particularly in the summer months, highlighting the urgency of sustainable groundwater management strategies. The overexploitation has raised concerns about the long-term sustainability of groundwater resources and potential adverse impacts on the local environment and communities.

About the Study Area

The Ayad river basin extends from 24° 50′ 16″ N to 24° 27′ 46″ N and 73° 31′ 44″ E to 73° 59′ 44″ E covering an area of 1206.75 Km2. Administratively, the Ayad river basin falls into 4 tehsils (Girwa - 58.48%, Mavli - 19.85%, Vallabh Nagar - 6.97%, Gogunda - 5.94%) of Udaipur district and 1 tehsil (Nathdwara - 8.76%) of Rajsamand district. The Ayad river originates from the hills of Gogunda in the north-west of Udaipur and travels through for 68.45 Km before joining the Vallabh Nagar lake in the eastern part of Udaipur. The Ayad river is the major river flowing through Udaipur, it is seasonal, and discharge is peaking during Monsoons (Pareta et al., 2022). The Ayad river is a tributary of the Berach river, which is itself a tributary of Chambal River of Yamuna basin.

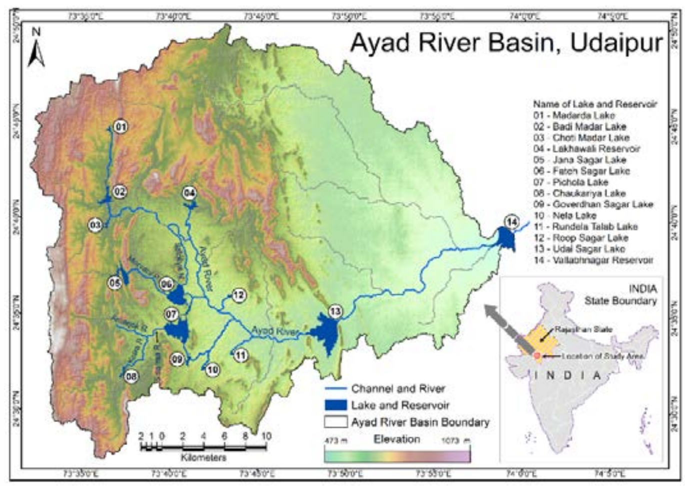

Figure 1. Ayad River Basin, Udaipur

Data Used and their Sources

S. No.	Data type	Period	Sources
1	Survey of India (SoI) Toposheet at 1:50,000 Scale	2006	Toposheet No.: 45H/09, 10, 11, 13, and 14 Source: http://www.soinakshe.uk.gov.in
2	Landsat-9 OLI-2 Satellite Imagery with 30 m Spatial Resolution	2023	USGS Earth Explorer Source: http://earthexplorer.usgs.gov
3	Topography / Digital Elevation Data (DEM) Data	2014	Shuttle Radar Topography Mission (SRTM), USGS Earth Explorer. Source: http://earthexplorer.usgs.gov
4	Geological Data at 1:50,000 Scale	2011	Geological Survey of India (GSI) Source: http://www.portal.gsi.gov.in
5	Monthly Precipitation Data at College of Technology and Engineering (CTAE) rain-gauge station	1901-2022	Water Resource Department, Govt. of Rajasthan Source: https://water.rajasthan.gov.in/wr/#/department-order/142/23/2776/30900
6	Groundwater Level Data of Monitoring Wells	1984-2022	Ground Water Department, Rajasthan Source: https://phedwater.rajasthan.gov.in
7	Groundwater Resource Assessment (Annual Groundwater Extraction Data)	2004-2022	Ground Water Department, Rajasthan Source: https://phedwater.rajasthan.gov.in/content/raj/water/ground-water/en/ground-water-resource-assessment.html
8	Projections of Climate Change	1951-2100	Coordinated Regional Climate Downscaling Experiment (CORDEX) Source: https://esg-dn1.nsc.liu.se/search/cordex/ or https://www.flooddroughtmonitor.com/DataApp/
9	Human Population	1901-2011	Census of India. Rajasthan - Series 09 - Part XII B - District Census Handbook, Udaipur Source: https://censusindia.gov.in/nada/index.php/catalog/1033
10	Tourists Population	2000-2022	Udaipur Municipal Corporation (UMC) Source: https://udaipurtimes.com/travel-and-tourism/Udaipur-tourist-footfall-2022/cid9640906.htm

Table 1. Collected data used and their sources

Methodology

Groundwater recharge

Annual groundwater recharge of Ayad river basin has been carried out using the rainfall infiltration factor method, which is a well-established method and has been widely used in hydrological studies to estimate groundwater recharge in various regions (UNDP, 1985; Pareta et a., 2015; CGWB, 2022; and Pareta, 2023). The method is based on a rainfall infiltration factor RIF, which is multiplied by the annual rainfall P and upscaled to the area of the considered hydrogeological unit area AHU leading to the following equation for estimation of the volumetric groundwater recharge. $R_{GW}=A_{HU}R_{IF}P$.

Central Groundwater Board (CGWB) (GEC 1997) has recommended the rainfall infiltration factors RIF for different hydrogeological units given in Table 2. In the table are also listed the areas of the different units.

No.	Hydrogeological units	A_{HU} (km^2)	(R_{IF}) %
1	Clayey Alluvium, Alluvial Plain	75.7	21
2	Granite, Schist, Gneiss, Limestone	120.3	9
3	Marble, Phyllite, Quartzite	489.3	6.5
4	Migmatite Complex, and Meta-Basics	462.3	5.5
5	Valley Fill	59.1	22
	Total	1,206.8	

Table 2. Hydrogeological unit area AHU and rainfall infiltration factor RIF for Ayad river basin

Projections of climate change

Projections of rainfall were carried out for the Ayad River Basin for medium-range future (2029-2060) and far future (2071-2100) under the two representative concentration pathways emission scenarios RCP4.5 and RCP8.5 (IPCC, 2014). The RCP scenarios are widely used to project future greenhouse gas emissions and their potential impacts on the climate.

The GCMs were dynamically downscaled by the same RCM model to obtain a spatial resolution more appropriate for hydrological applications.

GCM	RCM	Period	Resolution (time, spatial)
ECEARTH	RCA4	1951-2100	Daily, 50 km
NorESM	RCA4	1951-2100	Daily, 50 km
IPSL-CM5A	RCA4	1951-2100	Daily, 50 km

Table 3. GCMs and RCM from the CORDEX project

ECEARTH = European community earth system model, NorESM = Norwegian earth system model, IPSL-CM5A = Institute Pierre-Simon Laplace - climate model 5A, RCA4 = Rossby Centre Regional Atmospheric Climate Model.

These models were selected based on their ability to accurately represent regional climate conditions and their reliability in simulating historical climate patterns in the study area (DHI, 2023. https://www.flooddroughtmonitor.com/DataApp/). Based on the projections from the three climate model combinations mean monthly and annual values were computed to understand the potential changes in rainfall patterns in the Ayad River Basin for the near 2016-2035, medium-range 2046-2065 and far future 2081-2100.

Historical rainfall data spanning from 1984 to 2022, covering a total of 39 years, was used as the reference period. Monthly average rainfall data was extracted from the historical records and for projecting future rainfall for the three periods, the monthly average rainfall data was multiplied by the climate change factor expressed as the fraction between the projected future monthly rainfall and the simulated monthly rainfall for the reference period, Table 4. The calculations for the projected monthly rainfall for the three periods are also presented in Table 4.

Month	-	Climate change factor (%) for future periods					
		RCP4.5 2016-2035	RCP4.5 2046-2065	RCP4.5 2081-2100	RCP8.5 2016-2035	RCP8.5 2046-2065	RCP8.5 2081-2100
Jan		0.66	0.21	2.78	1.06	0.78	1.39
Feb		2.62	3.64	0.41	3.51	4.98	0.81
Mar		0.25	0.03	1.49	0.20	0.52	0.81
Apr		1.51	2.07	1.07	0.52	0.00	1.35
May		0.74	1.70	0.68	1.23	1.41	1.43
Jun		0.76	0.62	1.08	0.69	1.07	0.86
Jul		1.44	1.31	1.35	1.04	1.45	1.65
Aug		0.76	1.02	1.44	0.80	0.89	1.30
Sep		1.06	0.86	1.00	0.96	0.89	1.39
Oct		1.19	1.24	1.14	1.17	1.03	1.74
Nov		1.25	0.50	1.09	1.26	1.77	1.36
Dec		0.72	1.07	0.85	0.65	0.56	1.23
Month	Average rainfall (mm) for 1984-2022	Predicted rainfall data (mm) for future periods					
		RCP4.5 2016-2035	RCP4.5 2046-2065	RCP4.5 2081-2100	RCP8.5 2016-2035	RCP8.5 2046-2065	RCP8.5 2081-2100
Jan	2.7	1.7	0.6	7.4	2.8	2.1	3.7
Feb	2.8	7.4	10.2	1.2	9.9	14.0	2.3
Mar	1.5	0.4	0.1	2.3	0.3	0.8	1.2
Apr	6.1	9.3	12.7	6.6	3.2	0.0	8.3
May	12.3	9.2	21.0	8.4	15.2	17.4	17.6
Jun	69.2	52.3	43.0	74.5	48.0	74.0	59.4
Jul	207.6	299.1	272.7	280.0	216.2	301.4	342.4
Aug	209.5	159.0	213.4	301.7	167.3	186.8	271.7
Sep	107.7	114.0	92.2	108.1	103.3	96.1	150.0
Oct	20.5	24.3	25.4	23.3	23.9	21.1	35.7
Nov	6.8	8.5	3.4	7.4	8.5	12.0	9.2
Dec	1.7	1.2	1.8	1.5	1.1	1.0	2.1
Annual Rainfall	648.5	686.2	696.3	822.2	599.7	726.6	903.7

Table 4. Climate change factors for the future periods 2016-2035, 2046-2065 and 2081-2100 and for RCP4.5 and RCP8.5

Projections of future population

The projection of the future population in the Ayad river basin involves a systematic approach that considers various demographic factors and trends. Historical demographic data from 1901 to 2011 has been collected from Census of India (2011). Using this data, population growth rates and patterns have been analyzed to identify the factors driving changes in population over time. Projection has been carried out for the next 80 years using various methods e.g., arithmetical increase, geometrical increase, incremental increase, and state urban increase method (Stillwell et al., 2011). For estimating the population for the next 80 years, three factors were considered of significance for future developments: (i) past growth trends of population and its patterns (1901-2011), and (ii) growth of various economic activities such as industrial development, agriculture, and tourism related activities, and (iii) urbanization of surrounding villages (CDP, 2014).

Projections of future water demand

Future water demand refers to the projected quantity of water required to meet the needs of a growing population, intensification of irrigation for food production, expanding industries, and changing patterns of water use over time (Boretti et al., 2019). It is essential to estimate future water demand accurately to ensure sustainable water management and allocation. Factors such as population growth and water use patterns, urbanization, industrial development, agricultural expansion and cultivation practices, and climate change can influence water demand patterns (Kirby et al., 2022). Among the diverse techniques available for water demand projection, this study adopts simple methods based on projected increase in population and demand for industrial and agricultural uses.

Results and Discussion

Estimation of groundwater recharge

Pareta (2023) validated groundwater recharge estimation by rainfall infiltration factor (RIF) method by comparing the results against estimates obtained by the water fluctuation method, which is the most widely used method for recharge estimation. As reported in Pareta (2023) and listed in Table 5 the results obtained by the various methods compared favorably suggesting that the rainfall infiltration method is a valid method and thus will be used in this study.

Years	Methods / Empirical formula → / Rainfall (mm) ↓	RIF (2022) RIF = (A_HU) * (R_IF) * (R_N)	Chaturvedi (1936) Rg = 2.0 * (Pin - 15)^0.4	UPIRI (1954)[1] Rg = 1.35 * (Pin - 14)^0.5	Bhattacharya (1954) Rg = 3.47 * (Pcm - 38)^0.4	Krishna (1970) Rg = K * (Pmm - X)	Sehgal (1973) Rg = 2.5 * (Pin-16)^0.5	Kumar (2002) Rg = 0.63 * (Pin - 15.28)^0.76	NGRI (2003) Rg = 0.174*(Pmm) - 62	Pareta (2023) WTF. ΔS = h * Sy * A
1984	547.0	53.0	107.6	94.1	107.0	36.8	119.5	64.5	33.2	
1985	588.3	57.0	117.6	103.8	116.9	47.1	135.9	76.8	40.4	
1986	383.9	37.2	105.8	92.4	105.2	35.0	116.5	62.3	32.0	
1987	393.7	37.1	105.8	92.4	105.2	35.0	116.5	62.3	32.0	
1988	467.0	45.3	82.7	71.8	82.4	16.8	78.5	37.9	19.3	
1989	895.2	86.8	169.2	158.0	167.9	123.8	222.8	155.7	93.8	
1990	666.4	64.6	133.7	119.9	132.8	66.6	162.5	98.7	54.0	
1991	615.3	59.7	123.5	109.6	122.7	53.8	145.7	84.6	45.1	
1992	727.3	70.5	144.4	131.2	143.4	81.8	180.6	114.7	64.6	
1993	353.1	34.2	105.8	92.4	105.2	35.0	116.5	62.3	32.0	
1994	778.9	75.5	152.7	140.0	151.6	94.7	194.5	127.8	73.5	
1995	333.7	32.4	105.8	92.4	105.2	35.0	116.5	62.3	32.0	
1996	636.4	61.7	127.9	114.0	127.0	59.1	152.9	90.5	48.7	
1997	673.9	65.3	135.1	121.4	134.2	68.5	164.9	100.7	55.3	
1998	669.2	64.9	134.2	120.5	133.3	67.3	163.4	99.5	54.4	
1999	412.9	40.0	55.6	51.5	55.9	3.2	25.7	15.7	9.8	
2000	439.7	42.6	71.0	62.4	70.9	9.9	58.2	27.4	14.5	
2001	531.2	51.5	103.4	90.2	102.8	32.8	112.6	59.5	30.4	
2002	365.3	35.4	105.8	92.4	105.2	35.0	116.5	62.3	32.0	
2003	497.4	48.2	93.4	81.0	92.9	24.4	96.2	48.5	24.5	
2004	601.0	58.3	120.5	106.6	119.7	50.3	140.6	80.5	42.6	
2005	885.2	85.8	167.9	156.6	166.6	121.3	220.6	153.4	92.0	
2006	984.3	95.4	180.4	170.6	179.0	146.1	242.3	176.1	109.3	
2007	476.3	46.2	86.2	74.7	85.9	19.1	84.3	41.2	20.9	
2008	572.2	55.5	113.9	100.1	113.2	43.1	129.8	72.1	37.6	
2009	456.1	44.2	78.4	68.2	78.1	14.0	71.1	33.8	17.4	
2010	790.4	76.6	154.5	141.9	153.3	97.6	197.5	130.6	75.5	
2011	1100.4	106.7	193.5	185.7	192.0	175.1	265.5	201.6	129.5	152.6
2012	730.7	70.9	145.0	131.8	144.0	82.7	181.5	115.6	65.1	117.9
2013	663.5	64.3	133.1	119.4	132.2	65.9	161.6	97.9	53.4	103.8

Table 5. Calculation of annual groundwater resource (1984-2022) by rainfall infiltration factor (RIF) and empirical formulas in Ayad river basin

[1]This formula was later modified by further work at U.P. Irrigation Research Institute, Roorkee (Chaturvedi, 1973)

Years	Methods	RIF (2022)	Chaturvedi (1936)	UPIRI (1954)1	Bhattacharya (1954)	Krishna (1970)	Sehgal (1973)	Kumar (2002)	NGRI (2003)	Pareta (2023)
	Empirical formula →	RIF = (A_{HU}) * (R_{IF}) * (R_N)	Rg = 2.0 * (Pin - 15)^0.4	Rg = 1.35 * (Pin - 14)^0.5	Rg = 3.47 * (Pcm - 38)^0.4	Rg = K * (Pmm - X)	Rg = 2.5 * (Pin-16)^0.5	Rg = 0.63 * (Pin - 15.28)^0.76	Rg = 0.174*(Pmm) - 62	WTF. ΔS = h * Sy * A
	Rainfall (mm) ↓									
2014	682.3	66.2	136.6	123.0	135.7	70.6	167.4	103.0	56.7	104.8
2015	711.5	69.0	141.8	128.4	140.8	77.9	176.1	110.6	61.8	107.0
2016	774.7	75.1	152.1	139.3	151.0	93.7	193.4	126.7	72.8	121.6
2017	747.4	72.5	147.7	134.7	146.7	86.9	186.1	119.8	68.0	104.8
2018	556.0	53.9	109.9	96.3	109.3	39.0	123.3	67.2	34.7	91.8
2019	1184.0	114.8	202.2	195.8	200.6	196.0	281.1	219.4	144.0	176.8
2020	717.9	69.6	142.9	129.5	141.9	79.5	177.9	112.3	62.9	104.7
2021	895.4	86.8	169.2	158.1	168.0	123.9	222.9	155.8	93.8	
2022	797.3	77.3	155.5	143.0	154.4	99.3	199.3	132.3	76.7	
Average (39 Years)		62.9	128.5	116.3	127.7	67.8	154.3	96.5	54.8	118.6
Overall Average		103.0								

Where Rg = groundwater recharge from rainfall in million cubic meter (MCM), Pin = annual precipitation in inches, Pcm = annual precipitation in centimeter, Pmm = annual precipitation in millimeters, WTF = watertable fluctuation method, SΔ = change in storage, h = water level fluctuation between pre- and post-monsoon seasons, Sy = specific yield, A = area of fluctuation in different lithology. All values in MCM, except rainfall

The estimates given in Table 5 is based on specific infiltration factor associated with the geological strata, such as alluvium, alluvial plain, valley fill, semi-consolidated limestone, weathered and fractured granite, schist, gneiss, marble, and phyllite. Recharge is subject to a large variation between years ranging from 48 to 163 mm/year depending on the amount of rainfall the specific years. As recharge is a determining factor for the replenishment of groundwater the available groundwater resources for water supply vary from year to year.

Projection of future population

The historical demographic data from 1901 to 2011 (Census of India, 2011) and projected population developments (2021-2100) using the linear method, geometric method, arithmetical increase method, incremental increase method, and exponential method (Stillwell et al., 2011) are summarized in Table 6.

The population projections given in Table 6 indicate that the geometrical increase and linear methods result in higher projected populations compared to other methods. After a comprehensive comparison of population growth trends over the past century and population forecasts obtained from various methods, it is observed that the incremental increase method is a suitable and accurate projection for the future population. So, an incremental increase method is considered here, and according to this method, the population is expected to reach 1.64 million by the end of 2071 and 2.19 million by the end of 2100.

	S. No.	Census Year	Projected Population by				
			Linear method	Geometric method	Arithmetical increase method	Incremental Increase method	Exponential method
Population by Census of India	1	1901	58,072	58,072	58,072	58,072	58,072
	2	1911	42,699	42,699	42,699	42,699	42,699
	3	1921	44,726	44,726	44,726	44,726	44,726
	4	1931	57,568	57,568	57,568	57,568	57,568
	5	1941	80,616	80,616	80,616	80,616	80,616
	6	1951	131,767	131,767	131,767	131,767	131,767
	7	1961	166,602	166,602	166,602	166,602	166,602
	8	1971	262,328	262,328	262,328	262,328	262,328
	9	1981	413,732	413,732	413,732	413,732	413,732
	10	1991	577,605	577,605	577,605	577,605	577,605
	11	2001	754,017	754,017	754,017	754,017	754,017
	12	2011	884,264	884,264	884,264	884,264	884,264
Projected Population by Various Methods	13	2021	1,635,348	1,157,187	959,372	973,934	911,982
	14	2022	1,710,456	1,188,736	966,883	983,702	914,801
	15	2026	2,010,889	1,323,775	996,927	1,024,230	926,165
	16	2031	2,386,431	1,514,345	1,034,481	1,078,167	940,568
	17	2041	3,137,515	1,981,739	1,109,589	1,196,961	970,051
	18	2051	3,888,599	2,593,390	1,184,697	1,330,317	1,000,458
	19	2056	4,264,140	2,966,734	1,222,252	1,402,456	1,016,017
	20	2061	4,639,682	3,393,824	1,259,806	1,478,236	1,031,818
	21	2071	5,390,766	4,441,307	1,334,914	1,640,716	1,064,161
	22	2081	6,141,849	5,812,089	1,410,023	1,817,759	1,097,518
	23	2091	6,892,933	7,605,955	1,485,131	2,009,363	1,131,920
	24	2100	7,568,908	9,689,315	1,552,728	2,194,257	1,163,803

Table 6. Projected population (2021-2100) by various methods in Ayad River Basin

Udaipur holds significant importance as a major tourist destination in India, attracting a substantial number of visitors throughout the year. Given the high influx of tourists, it becomes essential to consider the impact of the tourist population on the overall demographic dynamics of the region. The presence of many tourists can significantly influence various aspects, including water demand, and resource management. Available tourist population data from 2000 to 2022 has been collected from Udaipur Municipal Corporation (UMC) and projected the tourist population from 2026 to 2100 through incremental increase method, which is given in Table 7.

S. No.	Year	Tourists' population (No.)	S. No.	Year	Tourists' population (No.)
1	2000	812,507	19	2016	932,815
2	2001	719,586	20	2017	1,021,485
3	2002	572,879	21	2018	1,136,946
4	2003	597,630	22	2019	1,185,606
5	2004	659,330	23	2020	400,527
6	2005	739,880	24	2021	963,060
7	2006	770,530	25	2022	1,532,905
8	2007	739,270	26	2026	1,552,980
9	2008	757,676	27	2031	1,584,558
10	2009	712,312	28	2041	1,669,324
11	2010	755,313	29	2051	1,782,907
12	2011	753,143	30	2056	1,850,504
13	2012	777,612	31	2061	1,925,306
14	2011	753,143	32	2071	2,096,520
15	2012	777,666	33	2081	2,296,551
16	2013	847,425	34	2091	2,525,397
17	2014	887,056	35	2100	2,755,996
18	2015	891,987			

Table 7. Tourist population (2000-2022) and projected tourist population (2031-2100)

The tourist population in the year 2020-2021 significantly declined compared to the records of the past 20 years due to the impact of the COVID-19 pandemic. In the estimation of future water demand, consideration has been given to the dynamics of rural-urban population and tourist population.

Projection of future water demand

Future water demand refers to the projected quantity of water required to meet the needs of a growing population, expanding industries, and changing patterns of water use over time (Boretti et al., 2019). It is essential to estimate future water demand accurately to ensure sustainable water management and allocation. Factors such as population growth, urbanization, industrial development, agricultural expansion, and climate change can influence water demand patterns (Kirby et al., 2022). Among the diverse techniques available for water demand projection, this study adopts simple methods for the estimation.

The total water demand for Udaipur town, considering its resident population of 451,100 (as of 2011) and an estimated floating population of 30,000, is estimated to be 65 million liters per day (MLD). This calculation is based on the water supply norm of 135 liters per capita per day (lpcd) (CDP, 2014, pp. 68). The total water demand for all sectors, including domestic, industrial, institutional, tourist, and floating population, was 115 MLD (million liters per day) according to data from PHED in 2011 (IUC, 2020). As outlined in the City Development Plan of 2041 (CDP, 2014), the projected demand for raw water in the Udaipur city is anticipated to reach 101 MLD (Million Liters per Day) by 2021, 122 MLD by 2031, and further increase to 148 MLD by 2041.

Considering the literature reviewed, the raw water demand has been determined using the per capita water supply norms of 135 LPCD (liters per capita per day) for domestic, industrial, institutional, and tourist populations. Additionally, 30% of the total water supply has been allocated for agricultural practices in Ayad river basin. Consequently, the per capita raw water demand has been projected to be approximately 175 LPCD (liters per capita per day). Based on the aforementioned information, the projected future water demand is presented in the Table 8.

Year	Projected population*	Projected tourist population#	Estimated water demand for domestic, institutional, industrial, tourism, and agricultural purposes	
			Million liters / day (MLD)[1]	MCM / year[2]
(1)	(2)	(3)	(4)	(5)
2021	973,934	963,060	176.7	64.5
2022	983,702	1,532,905	178.6	65.2
2026	1,024,230	1,552,980	185.8	67.8
2031	1,078,167	1,584,558	195.2	71.3
2041	1,196,961	1,669,324	216.1	78.9
2051	1,330,317	1,782,907	239.6	87.5
2056	1,402,456	1,850,504	252.3	92.1
2061	1,478,236	1,925,306	265.6	97.0
2071	1,640,716	2,096,520	294.2	107.4
2081	1,817,759	2,296,551	325.4	118.8
2091	2,009,363	2,525,397	359.1	131.1
2100	2,194,257	2,755,996	391.7	143.0

* Please refer to Table 6, # Please refer to Table 7.
[1] The estimation incorporates the projected population (Column-2), inclusive of a floating population of 30,000, and the daily tourist population (Column-3/365). This approach is employed to assess water demand for domestic, institutional, industrial, tourism, and agricultural purposes.
[2] Conversion from MLD to MCM/Year: (Column-4/1000) *365

Table 8. Estimated water demand for domestic, institutional, industrial, tourism, and agricultural purposes (2021-2100)

Estimation of groundwater resources and future water demand

The estimation of groundwater resources and future water demand is a vital undertaking in water resource management, necessitated by the imperative of ensuring sustainable water supply for growing populations and evolving socio-economic needs (Carrard et al., 2019). This process involves a comprehensive assessment of both the available groundwater reserves and the projected demand for water in the years ahead. For this analysis, we have obtained predicted rainfall data corresponding to climate change RCP4.5 and RCP8 scenarios, as presented in Table 4. Utilizing these rainfall datasets, we have applied the rainfall infiltration factors (RIF) method to estimate the groundwater recharge, a detailed expansion of which is available in Table 5. In our attempt to forecast future population figures, we have employed four statistics methods such as arithmetical increase, geometrical increase, incremental increase, and state urban increase. Upon comprehensive assessment, we have determined that the incremental increase method offers the most accurate population projection, for detail please refer to Table 6. Drawing from these projected population figures and considering prevailing agricultural practices in the Ayad river basin, we have conducted estimations of water demand for domestic, institutional industrial, tourism, and agricultural purposes. The specifics of this estimation can be referenced in Table 8. To encapsulate the outcomes of our analysis, we have consolidated relevant statistics in Table 9. Subsequently, we have conducted a comparative analysis, comparing our estimated groundwater resources with the future water demand for domestic, industrial, and agricultural purposes.

Year	Scenarios	Rainfall (mm)	Estimated groundwater recharge (MCM)	Projected population	Future water demand for domestic, industrial, tourism, and agricultural (MCM)	Water surplus or deficit (%)
Mean annual rainfall today*		641.4	62.9#			
2021	Observed Rainfall	895.4	86.8	973,934	64.5	34.7
2022		797.3	77.3	983,702	65.2	18.6
2026	RCP4.5 Climate Change Scenarios for Predicted Rainfall	686.2	66.5	1,024,230	67.8	-1.9
2056		696.3	67.5	1,402,456	92.1	-26.7
2091		822.2	79.7	2,009,363	131.1	-39.2
2026	RCP8.5 Climate Change Scenarios for Predicted Rainfall	599.7	58.1	1,024,230	67.8	-14.2
2056		726.6	70.4	1,402,456	92.1	-23.5
2091		903.7	87.6	2,009,363	131.1	-33.2
	* Long period average (LPA) (1901-2022), # Estimated groundwater resource (average 39 years)					

Table 9. Estimated groundwater recharge, projected population, and future water demand for domestic, institutional, industrial, tourism, and agricultural activities for year 2026, 2056, and 2091

The mean annual rainfall in the Ayad river basin, spanning 122 years, stands at 641.4 mm. Correspondingly, the estimated average groundwater resource over the same period is 62.9 million cubic meters (MCM). The future water demand for the years 2021 and 2022 surpasses the estimated groundwater resource by 34.7% and 18.6%, respectively. Notably, there is a reduction in this percentage for 2022, a trend likely influenced by the interplay between groundwater resources and annual precipitation. The observed 12% decrease in rainfall during 2022 compared to 2021 is a contributing factor to this shift.

Groundwater resources has been estimated from projected rainfall based on RCP4.5 climate change scenarios. Upon comparing the estimated groundwater resources with future water demand, a notable deficit in available groundwater was identified for the years 2026, 2056, and 2091. Specifically, the future water demand escalates was determined to be 2%, 27%, and 39%, respectively. This observation underscores the significance of thorough assessments in projecting groundwater availability relative to future demand, emphasizing the need for sustainable water management practices in the face of changing climatic scenarios.

Similarly, the same pattern is found when we estimate the groundwater resources from projected rainfall based on RCP8.5 climate change scenarios. Available estimated groundwater resources deficit future water demand by 14%, 24% and 33% in the years 2026, 2056 and 2091, respectively. In both scenarios, projected groundwater resources deficit future water demand. But this is decreasing in the future, the main reason for this could be population growth and over-exploitation of groundwater resources.

The outcome of this estimation process provides information about the balance between groundwater resources and future demand, which can be carefully considered in future water resource management strategies. Based on these estimates, sustainable water allocation plans, efficient extraction practices, and policies to promote water conservation can be formulated.

Conclusion

Groundwater is crucial for ecosystems, livelihoods, and economic activities. Our study of the Ayad River Basin, from 1901 to 2022, provides insights into groundwater dynamics influenced by climate change and demographic trends. The average annual rainfall of 641 mm varied significantly, with notable wet and dry periods. Since 2010, wetter conditions have increased water resources, though not consistently boosting groundwater recharge due to topographical and geological factors.

Groundwater level analysis from 1984 to 2022 showed increasing trends near natural water sources and vegetation, while agricultural and urban areas experienced stable or declining levels. Land use changes, especially urbanization and intensified agriculture, impacted groundwater levels, emphasizing the need for sustainable planning. Population growth further stresses future water demand, with projections aiding in resource management.

Using the Rainfall Infiltration Factor (RIF) method, we estimated the average groundwater resource for 1984-2022 at 62.9 MCM. Future projections under climate scenarios (RCP4.5 and RCP8.5) suggest groundwater resources might exceed future demands initially but will face deficits by 2091 due to population growth and overexploitation. Sustainable management is crucial to address these challenges.

Our study highlights the interplay between natural processes and human activities, urging the adoption of sustainable water management practices. This approach prioritizes ecological integrity and socio-economic development to ensure water security for future generations in the Ayad River Basin.

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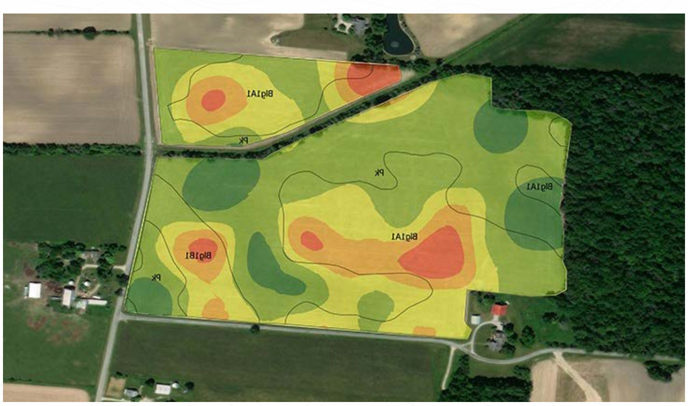
Mapping the Era of Sustainable Sustenance

Precision Agriculture's Next Chapter

Precision agriculture technology is redefining the science of feeding the planet. We're seeing new levels of efficiency, societal responsibility, and nutrition through the application of location intelligence and the emergence of a deep geospatial information consciousness.



This comes not a moment too soon. Not only do we face the prospect of feeding 9.5 billion people by 2050, but the world has awakened to the unforeseen impacts—on our environment and our health—of previous revolutions in agriculture, including factory farms, deforestation, methane emissions from livestock, ocean pollution, and overfishing. Furthermore, there are concerns about the genetic modification of both crops and animals.

Fortunately, we now have promising solutions to meet these and other agricultural and agribusiness challenges of the 21st century, using geospatial technologies. These solutions are playing out in three key dimensions: microlocation, smart supply chains, and environmental stewardship.

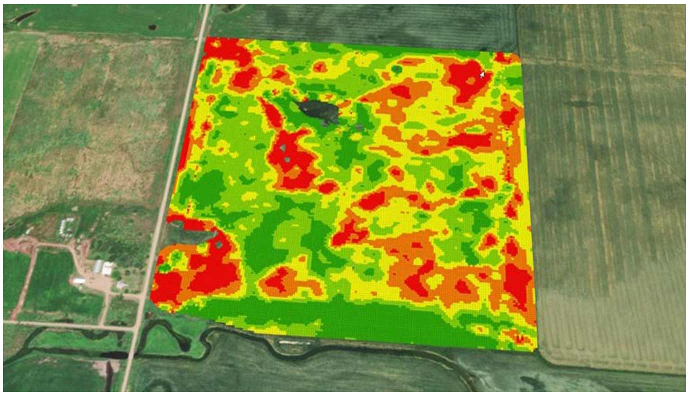
Welcome to the era of sustainable sustenance.

Microlocation, the nanogeography of precision agriculture technology - On a precision agriculture farm, advanced geospatial technology is everywhere, and it's location intelligent: mobile devices combined with smart maps, sensors embedded in both equipment and fields, and pickers equipped with trackable smart devices so that the farm operations manager can see where they were and when they picked that produce. That can help farm management isolate contamination issues so that food isn't unnecessarily destroyed, and it can help farmers identify their best produce so that they can repeat that success.

Soon artificial intelligence (AI)-based robots that are spatially aware will navigate a field to pick produce. Already, insurance companies are flying drones over fields after floods, fires, and tornados in order to do rapid damage assessment, promptly cut a check, and get farmers back on their feet. Some companies fly their fields toward the end of the growing season to analyse the vegetative index and get an indication of what the yield will be. That allows them to tell grain elevator workers to anticipate 5,000 bushels of corn, for example, letting them plan how many combines and tractor trailers they'll need to process it all.

The new ag supply-and-demand chain: from farm to fork - Modern agriculture is highly complex. On any given day, farmers are commodity brokers, bankers, chemists, agronomists, pickers, procurement managers, warehousers, machinists, meteorologists, and long-term gamblers. All farmers must now be technologists too. And despite the romantic trope of the solitary farmer in the field, all 21st-century farmers are inherent members of multipart, global supply chains.

Mapping the business ecosystem and the natural ecosystem is also important to the banks that provide farmers with the capital they need to run their business. Lenders need a system of record so that they know what's in their portfolio, which clients have what assets and liabilities, and which geographic areas are doing better—creating an automated valuation model to assess agriculture real estate values and determine which farmers are the best risks. And in low- and middle-income countries, location intelligence-based precision agriculture technology and data analytics offer billions of people the opportunity to leapfrog over millennia of learning for the improvement of productivity, nutrition, and sustainability.



Sustainable sustenance - We have learned that soil and the nutrients and biological ecosystems it supports are a finite resource. Once that soil is gone, there's no more farming. So applying precision ag helps farmers understand what amounts and kinds of nutrients to put into the soil; how much water is required to maximise a crop; and how much fertiliser and seed are needed and how much tillage is going on at an exact location—and all of that will help us understand how to protect our land for future generations.

The rise of organic and sustainable agriculture and farming technologies over the past two decades has spawned many new businesses, ranging from Whole Foods to Indigo. Agricultural companies like Jackson Family Wines are working on practices such as planting a cover crop, a hedgerow, or riparian plants along a waterway for carbon sequestration. And traditional retailers like Walmart—along with many other Fortune 500 companies—are committing to a green future. In addition to its own decarbonisation goals, Walmart has established sustainability requirements for its suppliers.

"As a research scientist, my goal is to make sure that that margin of error is as thin as possible," says Dr. Angela Bowman, research scientist at John Deere. "I want to make sure that the data is exactly where it's supposed to be in space and time. Given some of the inherent errors within satellite data, for example, that's going to continually evolve. There are other margins of error that occur within data in the field. And I would argue that margins of error should be within a foot of accuracy."

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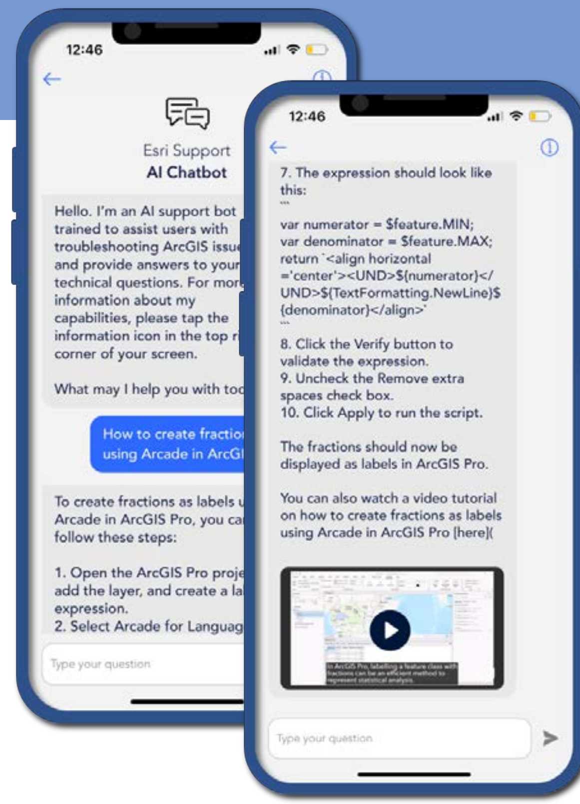

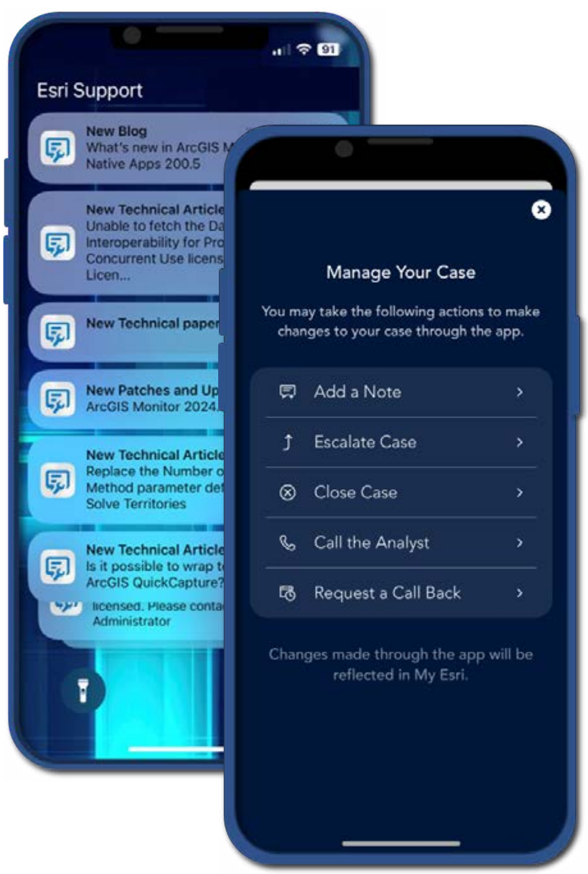

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