SUSTAINABLE AGRICULTURE THROUGH GIS

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Abstract

Geographic Information Systems (GIS) and cartographic tools have emerged as crucial instruments for addressing global food security challenges arising from climate change and an expanding population. This study investigates the incorporation of GIS and cartographic tools into agriculture to improve productivity, sustainability, and environmental preservation. We present a versatile GIS library for sustainable agricultural applications employing Leaflet.js, an open-source JavaScript library. The library merges GPS data from agricultural equipment with OpenStreetMap base maps, enabling farmers to visualize and analyze information about their fields, such as the paths taken by tractors and other farm machinery. Surface areas of agricultural fields are calculated using numerical integration techniques, like Simpson's rule, which is then integrated into the web application. Potential applications of GIS and cartographic tools in agriculture encompass precision agriculture, water resource management, land-use planning, crop monitoring, and pest and disease management. The study also examines the advantages, challenges, and prospects of employing GIS and cartographic tools in agriculture. The library is documented and accessible to the agricultural community, with anticipated extensive applications in precision agriculture.

Keywords: Geographic Information Systems (GIS), precision agriculture, crop monitoring, reusable GIS libraries

Agriculture has been a vital aspect of human civilisation since its inception, providing sustenance and resources essential for survival. With the global population projected to reach 9.7 billion by 2050 (Arora N.K., 2019) and the potential impacts of climate change on agricultural production, adopting Geographic Information Systems (GIS) and geographical maps in agriculture has become increasingly significant. Enables capturing, storing, manipulating, analysing, and visualising geographic data, providing valuable insights and aiding decision-making, planning, and resource management in various applications, including agriculture. GIS in agriculture can improve crop management, reduce waste, and increase productivity. Similarly, geographical maps are a valuable tool for sustainable agriculture, providing information about soil types, moisture levels, topography, and other crucial factors influencing crop growth and yield.

The potential of Geographic Information Systems - GIS (Tang W., Selwood J., 2003) and geographical maps for sustainable agriculture is immense. These technologies have revolutionised how we manage and analyse spatial data, and in agriculture, they can be used to improve productivity, resource management, and environmental conservation. This scientific article will explore how GIS and geographical maps can be integrated into agriculture to enhance sustainability and productivity. We will discuss the benefits of using these technologies, such as increased efficiency, reduced waste, and improved yield. Furthermore, we will examine some case studies where GIS and maps have been successfully used in agriculture, including precision agriculture (Lowenberg-Deboer J., 2004), water resource management, land-use planning, crop monitoring, and pest and disease management. We will also discuss the challenges and limitations of implementing these technologies, such as data quality, interoperability, and accessibility.

This article aims to demonstrate the importance of GIS and geographical maps in sustainable agriculture and encourage their wider adoption in the agricultural industry. By harnessing the power of these technologies, farmers and agricultural professionals can make informed decisions about land use, resource management, and crop production. By processing data using

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mathematical integration rules such as Simpson's rule before integration into web applications using open-source libraries such as Leaflet.js (Leaflet. Leaflet - a JavaScript library for interactive maps.) with OpenStreetMap, farmers can implement precision farming practices, leading to cost savings, reduced environmental impact, and improved crop yield. Ultimately, integrating GIS and geographical maps into agriculture can contribute to a more efficient and sustainable food production system, which is crucial for meeting the food demands of a growing population while protecting the environment.

MATERIAL AND METHOD

The location data harvested from GPS-enabled farm equipment can be used to compute surface areas of farmland or specific crop areas. The mathematical formula for this calculation is called “the trapezoidal rule”, which involves dividing the area into a series of trapezoids and calculating their areas before summing them up. The trapezoidal rule formula for computing surface areas involves the following steps:

Step 1 - Divide the area into a series of equally spaced segments or strips along the X-axis.

Step 2 - Measure the distance between each pair of adjacent GPS points along the X-axis to determine the width of each trapezoid.

Step 3 - Measure the distance between the GPS points along the Y-axis to determine the height of each trapezoid.

Step 4 - Calculate the area of each trapezoid using the formula:

$$area = (width/2) * (height1 + height2).$$

Step 5 - Sum up the trapezoids' areas to obtain the total surface area of the farmland or crop area.

While the trapezoidal rule is widely used for computing surface areas, more precise mathematical techniques such as composite Simpson's rules can be utilised. Simpson's rule involves fitting a second-degree polynomial to three adjacent points on a curve and then integrating the polynomial to approximate the area under the curve. The formula for Simpson's rule is:

$$\int_a^b f(x)\,dx \approx (b-a)/6\,[f(a) + 4f((a+b)/2) + f(b)],$$

where f(x) is the function to be integrated, a and b are the lower and upper limits of integration, and (a+b)/2 is the interval's midpoint.

The composite Simpson's rule extends this method by dividing the area into a series of equally spaced subintervals and applying Simpson's rule to each subinterval. The formula for the composite Simpson's rule is

$$\int_a^b f(x)\,dx \approx (\Delta x/3)\,[f(x0) + 4f(x1) + 2f(x2) + 4f(x3) + ... + 2f(x(n-2)) + 4f(x(n-1)) + f(xn)]$$

where $\Delta x = (b-a)/n$, n is the number of subintervals, and x0, x1, x2, ..., xn are the endpoints of the subintervals.

Farmers can obtain more accurate surface area estimates for farmland and crop areas using these more precise mathematical techniques. This can inform decisions about resource allocation, such as planting density and irrigation, leading to improved agricultural yields and increased profitability.

RESULTS AND DISCUSSIONS

One of the key components of a GIS application is the base map layer, which provides the background on which other layers can be added.

Several base map providers are available, each with advantages and disadvantages. For instance, Google Maps offers various map types, including satellite and terrain, which can be useful for agriculture applications. However, using Google Maps requires paying for each tile request, which can quickly become costly.

Arcgis is another base map provider offering a wide range of base maps for GIS applications. While the base maps are free to use as long as the "Powered by Esri" attribution is included, a commercial license must be purchased for businesses. Additionally, fees are associated with each map usage, which can add up over time.

On the other hand, maps have a limited selection of base maps but offer a free plan with up to 1000 transactions per day. However, each map tile is counted as a transaction, which can limit the number of tiles that can be used in a single application.

The ANCPI base map provider is a good option for Romanian terrains due to its ease of integration and no cost. The maps provided by ANCPI can be accessed through their MapServer and can be used in GIS applications as long as proper attribution is included. However, one disadvantage of using ANCPI maps is that they are in the Romanian national projection system (EPSG:3844). It can be problematic when combining them with other base maps in a different projection system. Additionally, some of the maps provided by ANCPI may need to be more consistent or complete, which can limit their usefulness in certain applications.

Several popular GIS libraries are used for developing GIS web applications. One of the most commonly used libraries is the ArcGIS API for JavaScript (ESRI.ArcGIS API for JavaScript) which provides developers with access to ArcGIS services and data. The API offers many features and functionality, including 2D and 3D mapping, geocoding, routing, and geoprocessing. One of the main advantages of the ArcGIS API is its integration with other ArcGIS products and services, such as ArcGIS Online and ArcGIS Enterprise. However, the ArcGIS API requires a commercial license, which can be costly.

Another popular GIS library is OpenLayers (He Y. et al., 2019). This open-source JavaScript library provides developers access to various geospatial data formats and services, including OpenStreetMap, WMS, and GeoJSON. OpenLayers is highly customisable and offers a range of features. However, it can have a steep learning curve for developers who are new to GIS.

Leaflet.js (Edler D., Vetter M., 2019) is another widely used open-source GIS library that provides developers access to various mapping services and data sources, including OpenStreetMap, Mapbox, and Esri. The Leaflet is known for its simplicity and ease of use, making it a popular choice for developers who are new to GIS. Leaflet offers a range of features, including support for multiple base maps, tile layers, and vector data. One of the main advantages of Leaflet is its lightweight design, which allows for fast and responsive mapping. However, Leaflet may not offer as many features and functionalities as other GIS libraries.

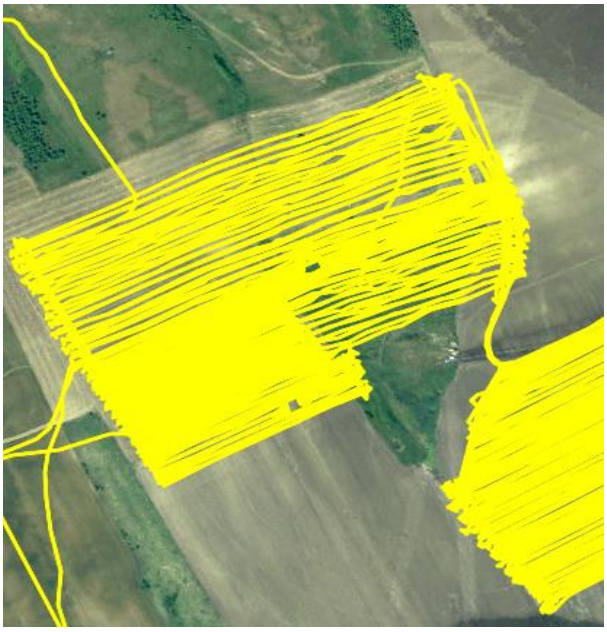

Figure 1 **Sample of farm equipment GPS trail**

Integrating GPS data from farming equipment into web applications has become increasingly popular in recent years. Web applications allow farmers to access and visualise GPS data in a user-friendly interface, making it easier to analyse and optimise their agricultural operations. Additionally, base maps, such as those provided by the ANCPI, can serve as a foundation for web applications and provide farmers with detailed geographic information about land use, hydrography, and administrative boundaries, which can be crucial when making decisions about crop management. One potential benefit of integrating GPS data and web applications is the ability to optimise crop management strategies. By analysing GPS data, farmers can make more informed decisions about irrigation, fertiliser application, and crop rotation. For example, by using data collected from GPS-enabled equipment, farmers can adjust irrigation schedules to ensure that crops receive the appropriate amount of water. This can reduce waste and improve crop yields.

The creation of a versatile GIS library can significantly improve sustainable agriculture applications. By developing a flexible and adaptable library, integrating various data sources becomes possible, giving farmers a powerful tool to analyse and enhance their farming operations. This library includes components for making and customising maps and different types of layers, like polyline and polygon layers, which can represent different kinds of spatial data.

Figure 2 **Tracking farm equipment across terrain**

Built using Leaflet.js (Edler D., Vetter M., 2019) and base maps from ANCPI, the library offers an easy-to-use and customisable platform for users to visualise and analyse their data. The library's flexibility also allows users to integrate their data sources, such as GPS information, from farm equipment. Users can use this library to create detailed and informative maps of their fields, including tractor and farm equipment trails, which can help optimise agricultural work and improve crop yield.

CONCLUSIONS

As demonstrated in this article, developing and implementing a reusable GIS library for sustainable agriculture applications has significant potential to revolutionise the agricultural sector. By leveraging the power of Leaflet.js and integrating GPS information with various base maps, farmers are provided with a versatile and user-friendly tool that can visualise and analyse crucial data for their fields.

The potential uses of GIS and geographic maps in agriculture, including precision agriculture, water resource management, land-use planning, crop monitoring, and pest and disease management, highlight this technology's diverse benefits. However, despite these advantages, it is imperative to acknowledge and address the challenges and barriers to widespread adoption, such as technological constraints, infrastructure, and accessibility for farmers in various regions.

By providing a well-documented and accessible GIS library for the agricultural community, this work contributes to the ongoing efforts to advance precision agriculture (Mulla D.J., 2013) and promote sustainable farming practices. Future research and development should address the existing challenges, refine the library's capabilities, and explore new, innovative applications that further augment agricultural productivity, sustainability, and environmental conservation.

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