An Open Source WebGIS Framework for Collaborative Research for Food Security in West Africa

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Abstract

Food security is often regarded as a social and agricultural issue, especially for resource-poor farmers in Sub-Saharan West Africa. The region is classified as developing, with limited data availability, poor communication, and limited research infrastructure (FAOSTAT, 2012). To address these pressing needs, the University of Saskatchewan leads a multinational research team developing solutions for food security of smallholder farmers in this region. This research has established a comprehensive geodatabase from multi-source and heterogeneous datasets. The geodatabase helps researchers develop sophisticated theorized solutions to address food security issues. Moreover, an effective online WebGIS framework prototype has been designed and implemented using open source tools to publish the geodatabase together with research results. Both the geodatabase and the WebGIS serve as collaborative tools to improve data accessibility and enhance research communication, aiding efforts to establish and maintain regional food security.

Background and Relevance

Food security is a pressing issue for countries in West Africa, due to an unpredictable climate and low soil fertility (IDRC, 2015). Food insecurity disproportionately affects small landholders (farmers) in rural areas who have limited access to agricultural inputs, infrastructure, and credit. Accordingly, a vast number of development and research projects have focused on various elements of food security for smallholder farmers; these projects include, but not limited to, water management to improving fertilizer efficiency, crop rotations, and micro-financing (IDRC, 2014, 2015; FAO, 2016; Zezza and Tasciotti, 2010). Africa as a continent is classified as developing; the availability of regional or continental data is limited. Moreover, collaboration among countries has not been well established. This calls for a collaborative research tool that can help disseminate and assimilate data from various research teams and projects (sites).

The University of Saskatchewan is part of a multinational research team – including researchers from the Universities of Saskatchewan and Manitoba, Canada, Obafemi

Awolowo University and Usun State University, Nigeria and Université de Parakou, Benin Republic – working on the benefits of fertilizer microdosing to improve soil fertility and yields in western Africa. To advance the completeness of the research, the College of Agriculture is collaborating with an Information and Technology based, GIS group at the University of Saskatchewan known as "The Spatial Initiative." The objective of this collaboration is to develop a user-friendly research tool, given a title as "Online West African Agriculture System" for publishing and sharing food security related datasets amongst researchers and other stakeholders (e.g., local farmers and NGOs). To make this collaboration more effective various categories of data were collected from multiple online resources, see Table 1 for the current data sources. Effectively managing and using datasets from multiple sources and at various resolutions poses unexpected challenges. Although there are few issues associated with working in a desktop GIS environment (e.g. ESRI© ArcGIS®), sharing the data through WebGIS causes challenges, including:

- Easy accessibility: stakeholders in Africa often have issues with accessing the internet or a computer. Mobile devices are the primary tool of communication for farmers. An effective WebGIS should be accessible to mobile platforms with responsive designs and require less data payload than in western countries.
- Requirements of the end use data: With multiple stakeholders, an effective WebGIS should be customizable for various audiences. The system needs to be able to allow policymakers and government officials with a scientific background or GIS skills to gain political insights, while still being a useful resource for farmers. It should also allow researchers and power users to download the original data for advanced academic research. Most importantly, it should also help local farmers and agricultural extension agents better manage their crops.
- High performance: this collaboration effort currently includes data for 5 African countries with various datasets. The database is expected to grow significantly over time in dimensions of data sources, participating countries, and both temporal and spatial resolutions. An effective WebGIS needs to maintain performance as the database expands.
- Effortless maintenance and scalability: the WebGIS should have low technical barriers and be easily deployed and maintained over the long-term. It should have a self-diagnostic capability for easier troubleshooting, as well as for the deployment of new WebGIS servers and allocation of more resource servers as needed.
- Cost-effectiveness: being a developing continent with limited financial support, a WebGIS should be as cost-effective as possible. This will make it possible to transfer all WebGIS resources in Africa as is one of the objectives of this collaboration.

This research aims to address the challenges mentioned above by first creating a central geodatabase and then developing an effective WebGIS framework to publish the geodatabase and facilitate research collaboration.

Methods and Data

Database development

We started the project by developing the central database for the countries of Benin Republic, Burkina Faso, Mali, Niger, and Nigeria Africa (Figure 1). Data for other western African countries can be added as projects are added. The major types of data closely related to food security have been collected through a multinational research collaboration (Table 1). These multiple sources were organized to establish the project's central geodatabase in the File Geodatabase format using ESRI's ArcGIS. The central geodatabase was then used for both a case study (e.g. identifying the contributing factors for crop productivity) and the development of the "Online West African Agriculture System."

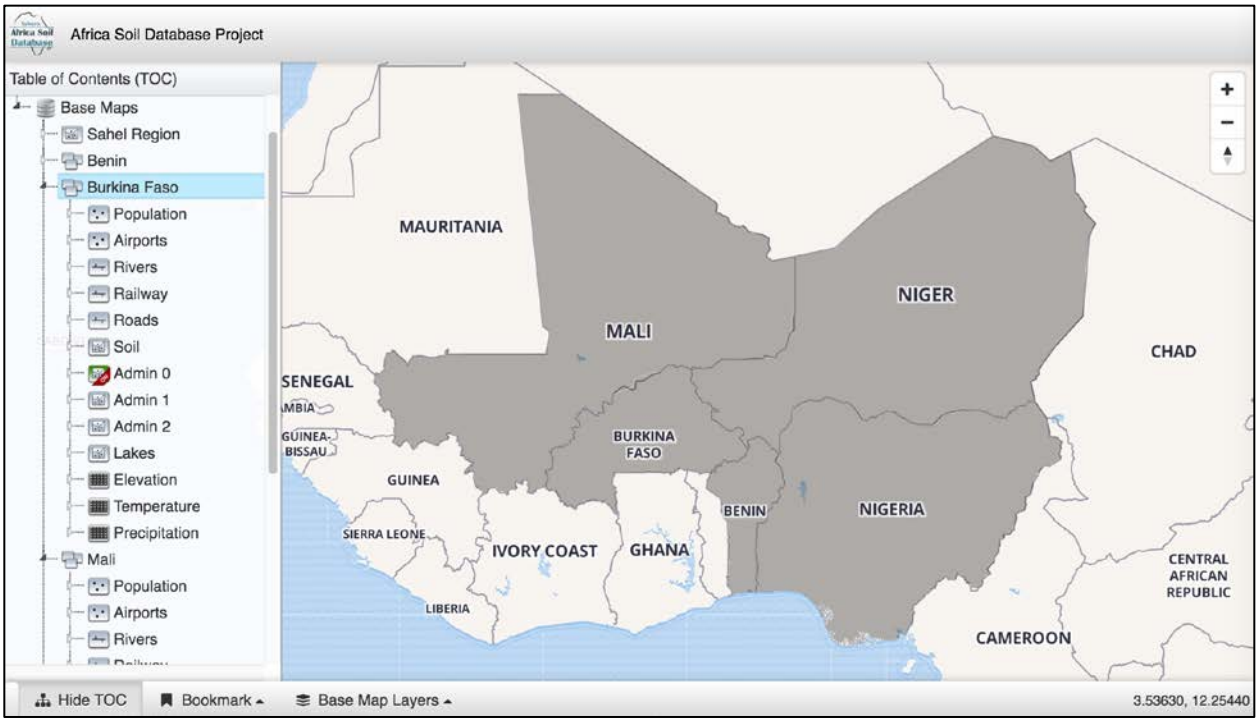

Figure 1: The online WebGIS with the current study area highlighted in shade

Besides incorporating these datasets, existing research data have also been added to the database. Bacon et al. (2014) started data collection to illustrate potential relationships amongst seven research sites. The database was then refined by Minielly et al. (2015). Different organizations are continually incorporating higher quality data, and elevation is a prime example. Previously Bacon et al. (2014) and Minielly et al. (2015) had access to a DEM with 10km resolution. The current research is imminently incorporating a finer DEM dataset from the U.S. Geological Survey with 30m spatial resolution (USGS, 2014). Several datasets into our geodatabase have undergone such improvements.

Table 1: List of major data sources used to create the Web GIS project in West Africa

Group	Features	Data Source	Format
Boundaries	Political Boundaries	Diva-GIS	vector (polygon)
	Sahel Region	NOAA	raster (jpeg)
Climate Variables	Precipitation	World Climate	raster (geotiff)
	Temperature	World Climate	raster (geotiff)
Human Geography	Airports	ShareGeo Open	vector (point)
	Population	Geonames, ESRI	vector (point)
	Towns and Cities	Geonames	vector (point)
Physical Geography	Soil Types	EU Soil Atlas	vector (polygon)
	Elevation	Diva-GIS	raster (geotiff)
	Lakes	Diva-GIS	vector (polygon)
	Rivers, Roads	Diva-GIS	vector (polyline)

The WebGIS Framework

A WebGIS framework prototype is developed to effectively manage, publish, visualize, and analyze the multi-source dataset while addressing specific challenges mentioned above (in the background section). It is built exclusively using open source tools and takes full advantage of open standards (Representational State Transfer web services, JavaScript Object Notation, or JSON) to ensure top performance, security, and interoperability while still maintaining flexibility and cost-effectiveness. Figure 2 shows the overall design of this research, with a focus on the implementation of the WebGIS framework. The comprehensive research involves three components: data, desktop GIS, and WebGIS (with its back-end and front-end), with all three linked by the central geodatabase of this project.

Data component: The data component of the project involves designing and populating a geodatabase. Necessary data cleaning, cataloguing, documentation, and table operations (normalization, joining, indexing) are performed within the project geodatabase in the GDB format (ESRI). The imported project data can be grouped as raster layers, vector layers, as well as non-spatial tables. Metadata for all layers is registered in a configuration file used by the WebGIS component for various reasons. First to track all layers' table schemas that allow the back-end WebGIS to administer published layers and facilitate table operations requested through the front-end WebGIS. Secondly, it establishes the logical data structure for the front-end WebGIS to portray the relationships of the project data better. Finally, to define rules for front-end visualization and analysis. This configuration file is implemented in the JSON format due to its conciseness, readability, and being effortless to define and update. This

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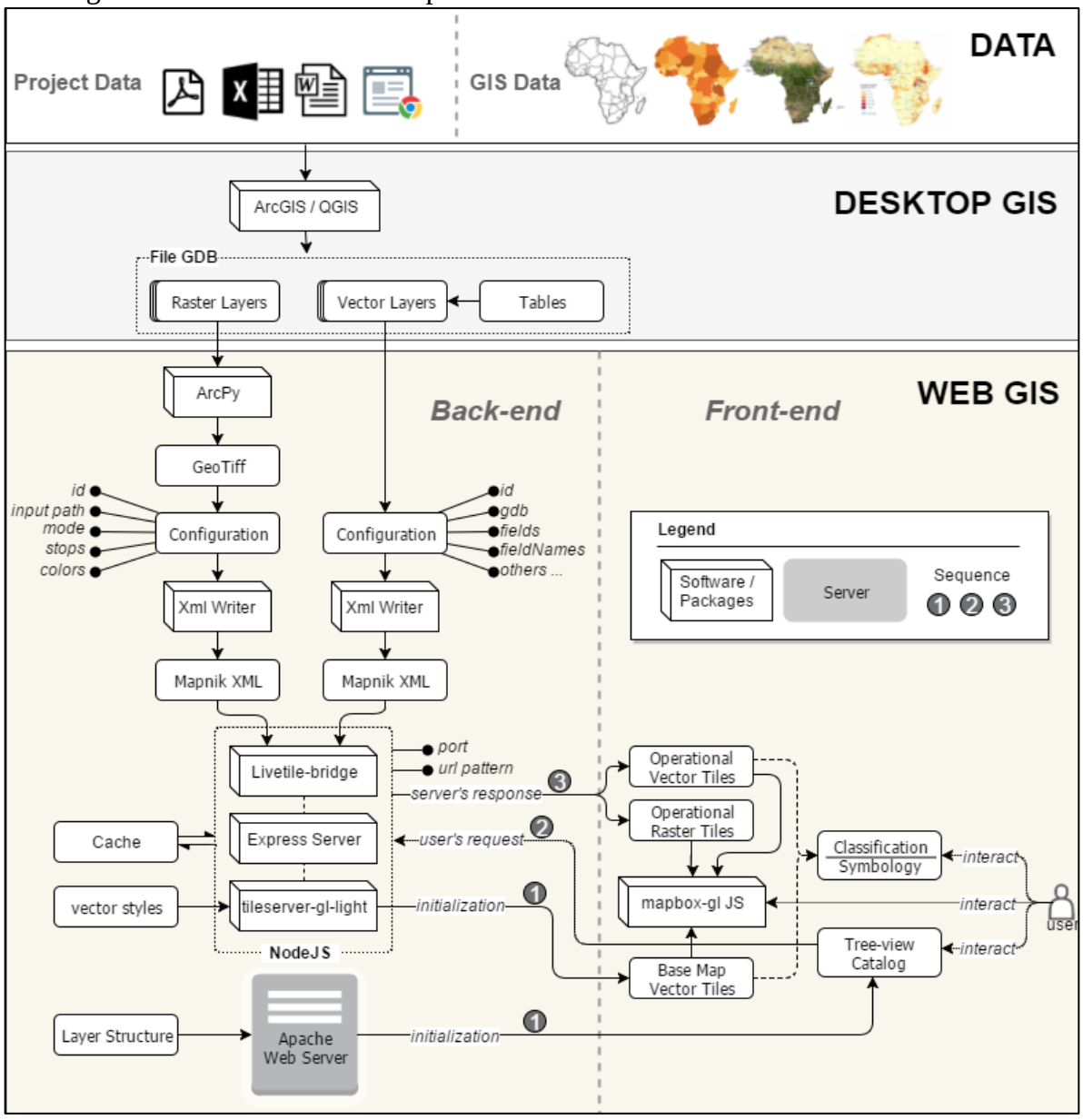

Figure 2: Overall design of the WebGIS framework prototype

Desktop GIS: GIS refers to GIS workstations capable of data processing and analysis with desktop GIS packages. This research uses ESRI© ArcGIS® and open source QGIS for managing project geodatabase (in ESRI© File GDB format) as well as data manipulation, visualization, and analysis. The main objective of desktop GIS is to: *a)* manage the project geodatabase (in ESRI© File GDB format), as well as manipulating

data of miscellaneous formats; *b)* conduct advanced data visualization and analysis for data mining and knowledge discovery, especially to support building scientific models (e.g. crop yield estimation); *c)* assist the design and implementation of the WebGIS. Researchers and power users can download the original copy of all data layers available in the central geodatabase from the front-end of WebGIS, allowing them to conduct advanced analysis using their local Desktop GIS environment.

WebGIS component: The WebGIS component consists of a back-end for publishing project (GIS/non-spatial) data or server-side analysis as services and a front-end for presenting published services in a user-friendly graphic user interface (GUI). Both the front-end and back-end are built using open source tools.

NodeJS-based GIS server solutions are selected for the back-end to overcome the limitation of conventional WebGIS architectures. *a)* Most WebGIS use a full installation of GIS server software to publish raster and vector datasets for front-end consumption (examples of ArcGIS Servers or open source GIS servers can be found in Government of Canada, 2012, 2016a, 2016b). The process of deploying the GIS server (installation and configuration) is both tedious and challenging due to its high dependence on the specific server environment. The NodeJS solution streamlines the process of server deployment with a pre-defined configuration script. *b)* Due to the research's high priority on responsiveness in delivering large datasets to clients, vector tiles are chosen as the solution (instead of conventional raster-based alternatives). Vector tile technology is an open standard, and it significantly improves WebGIS' performance with binary data compression and allows full design flexibility at the front-end, producing high resolution and custom rendering with considerably smaller file sizes (Mapbox, 2016).

The front-end is designed with 2 GUI versions – the User GUI is designed for regular end users' data visualization, analysis, and extraction; whereas the Admin GUI implements appropriate access control and authorization designed to *a)* monitor the project database, *b)* author and maintain published services, *c)* update project data and configuration, *d)* trouble-shoot project configuration. The user's GUI is built with open source mapping APIs (e.g. Mapbox WebGL JavaScript library) and other JavaScript framework libraries (e.g. Bootstrap, jQuery).

To demonstrate how the WebGIS works, relevant activities are labeled in Figure 2 from the system's initialization (step 1) to the user's request to load a data layer (step 2) to the server's response with data as well as its appropriate rendering (step 3).

Results

A central geodatabase and online WebGIS platform have been developed with the intention of increasing collaboration amongst the research groups around the world,

more specifically between Canada and West African universities. The geodatabase is designed to synthesize heterogeneous datasets from multiple sources and functions as the central hub both for offline, advanced research analysis and online collaborative WebGIS platform. The online West African agriculture system is developed to overcome the limitations of conventional WebGIS architecture by adopting flexible and efficient design from open source tools.

The Central Geodatabase

Since the conception of this research, this project has been maintained by the Department of Soil Science, University of Saskatchewan. This ongoing research is still actively incorporating more data as it becomes available, mainly including scientific results from their research sites as well as updated finer resolution datasets (Figure 3). One long-term goal of this project is to scale up the research techniques to encompass the entire African continent.

The collated data has been heavily used in various agricultural research activities to improve food security in semi-arid West Africa. For example, Minielly et al. (2015) conducted Probability Analysis (ESRI, 2016) to investigate the variability of crop-related variables for several research sites with a fine-resolution probability that could benefit local growers (Figure 4). Research results can be readily published on the WebGIS platform to promote collaboration and knowledge discovery for research peers, local farmers as well as other stakeholders.

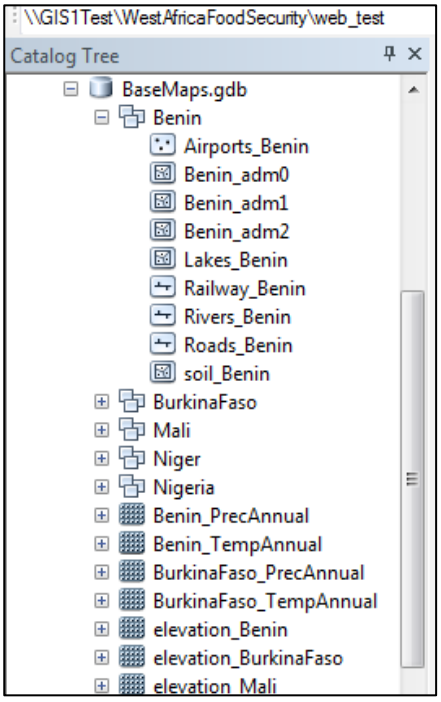

Figure 3: Data catalog of the central geodatabase created by ESRI ArcCatalog

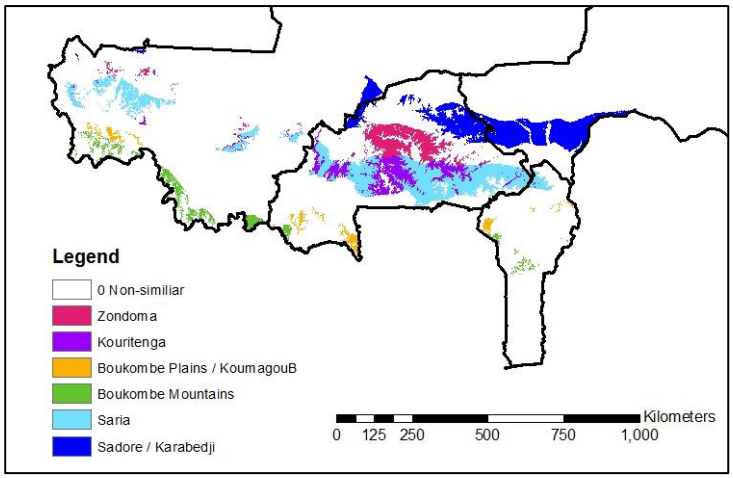

Figure 4: Probability surface showing regions that are similar in agronomic recommendations based combining research site results and the central geodatabase.

The Online West African Agriculture System

The key output of this research is a readily deployable Web GIS framework (available at http://gis1test.usask.ca/soil-db, see Figure 1 for a screenshot). The WebGIS has a similar data structure to the server's central geodatabase (Figure 5), thus allowing researchers to switch between the two databases seamlessly.

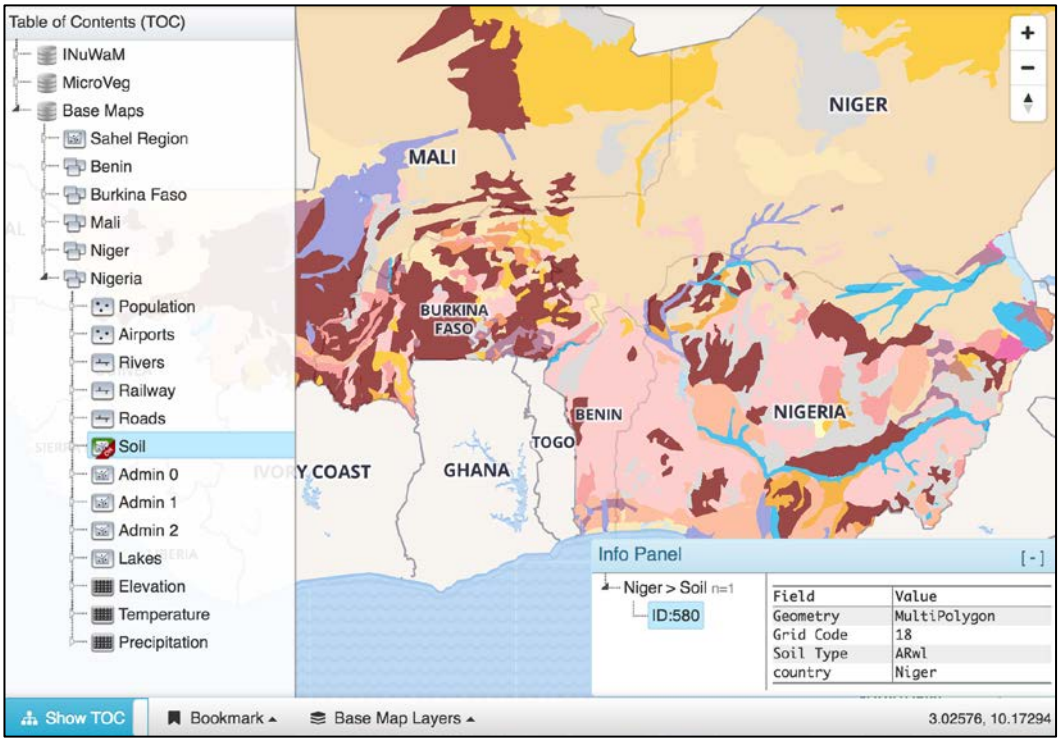

Figure 5. The developed WebGIS framework with its "Table of Contents" designed in similar data organization and user interface of the project central geodatabase (see Figure 3)

The WebGIS allows the user to explore a wealth of dataset for West Africa. Currently, the WebGIS supports previewing, querying, custom rendering, as well as downloading (Figure 6) all data layers. Even though the WebGIS has limited capabilities compared to desktop GIS (ArcGIS or QGIS), this platform proves critical in sharing heterogeneous datasets on the web for effective research collaboration. As this ongoing project assimilates more diverse datasets from various sources, our well-designed module will make project data updates and maintenance effortless.

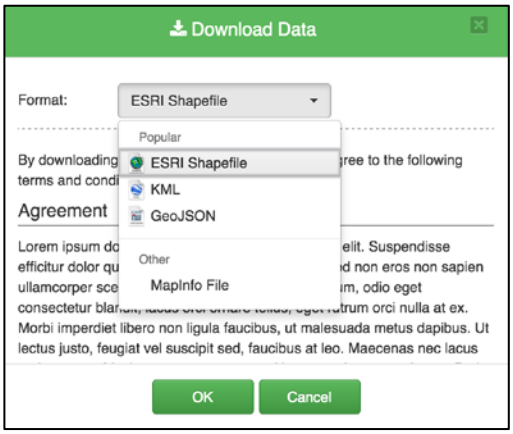

Figure 6. Downloading a data layer from the WebGIS platform in various formats provides flexibility to stakeholders

Conclusion

The goal of the online database, "Online West African Agriculture System" is to address some of the underlying questions surrounding food security. The objective is to make a system that is stakeholder friendly, yet a tool for furthering research. A project geodatabase was designed to catalogue datasets to facilitate this food security research. The most significant contribution of this research to date is establishing an effective WebGIS framework to share the project geodatabase as well as research results from collaborating peers around the world. Initial reviews suggest that is a robust platform that can improve data accessibility and facilitate research collaboration. There have been dedicated efforts by researchers to actively use and update the project database to facilitate building scientific models to address food security challenges.

Answering food security challenges in Africa makes this ongoing research vibrant and important. Three aspects of this research will be improved upon in the future. The project central geodatabase will serve as a long-term archive of heterogeneous datasets from diverse sources. Scientific modeling and results developed by the collaborated research teams will be incorporated into the central geodatabase and will be selectively moved to the online WebGIS platform for user-defined modeling. The WebGIS will implement more modules to allow richer online visualization and analysis options, based on input from the project's stakeholders.

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