Spatial Knowledge and Information Canada, 2019, 7(1), 1

Using WebGIS as a Tool for Agricultural Development with African Indigenous Vegetables

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ABSTRACT

Food security is a high priority for much of Africa. In the Benin Republic and Nigeria, research teams are developing tools and strategies to alleviate stress caused by food insecurity. An innovative approach to addressing food security is to use a Web-based GIS system, but this system requires a comprehensive collection of data. For the study area, this data was previously unavailable. Tools such as a map interface and gross profit calculator were created to enhance the web-based system. Research data was then integrated to provide recommendations to smallholder farmers of the region. This approach can serve as a model for future development research around the world.

1. Introduction

Based on Gross National Income, 52 of the world's 124 developing nations are in Africa (United Nations, 2018). The majority of these countries face food insecurity. Food insecurity is defined as a lack of nutritious food. Economic development is one potential solution to improving food security. Uncertainties associated with climate change and food insecurity make this a developmental challenge. Without improvement at the market level, countries cannot develop economically, resulting in continued malnourishment.

The MicroVeg project seeks to address economic and social issues within the Benin Republic and Nigeria. The project is a collaboration involving the University of Parakou, the Benin Republic, Osun State, Obafemi Awolowo Universities in Nigeria, and the Universities of Saskatchewan and Manitoba, in Canada (Adebooye, Akponikpe, Oyedele, Peak, & Aluko, 2017). To address data access and availability limitations and to enable the use of GIS data an integrative, multidevice, multiplatform GIS database was developed on a Web-based system, known as WebGIS. This work builds on the framework and goals outlined by Li et al., (2017). WebGIS was designed using MicroVeg research data allowing farmers, researchers, and Non-Governmental Organizations (NGOs) to access data. This system is managed by The Spatial Initiative (TSI), University of Saskatchewan, and can be viewed at www.microveg.ca.

2. Methods and Data

Figure 1 shows the framework of the WebGIS development process. The model is divided into three categories: data, WebGIS, and agricultural (project) extension.

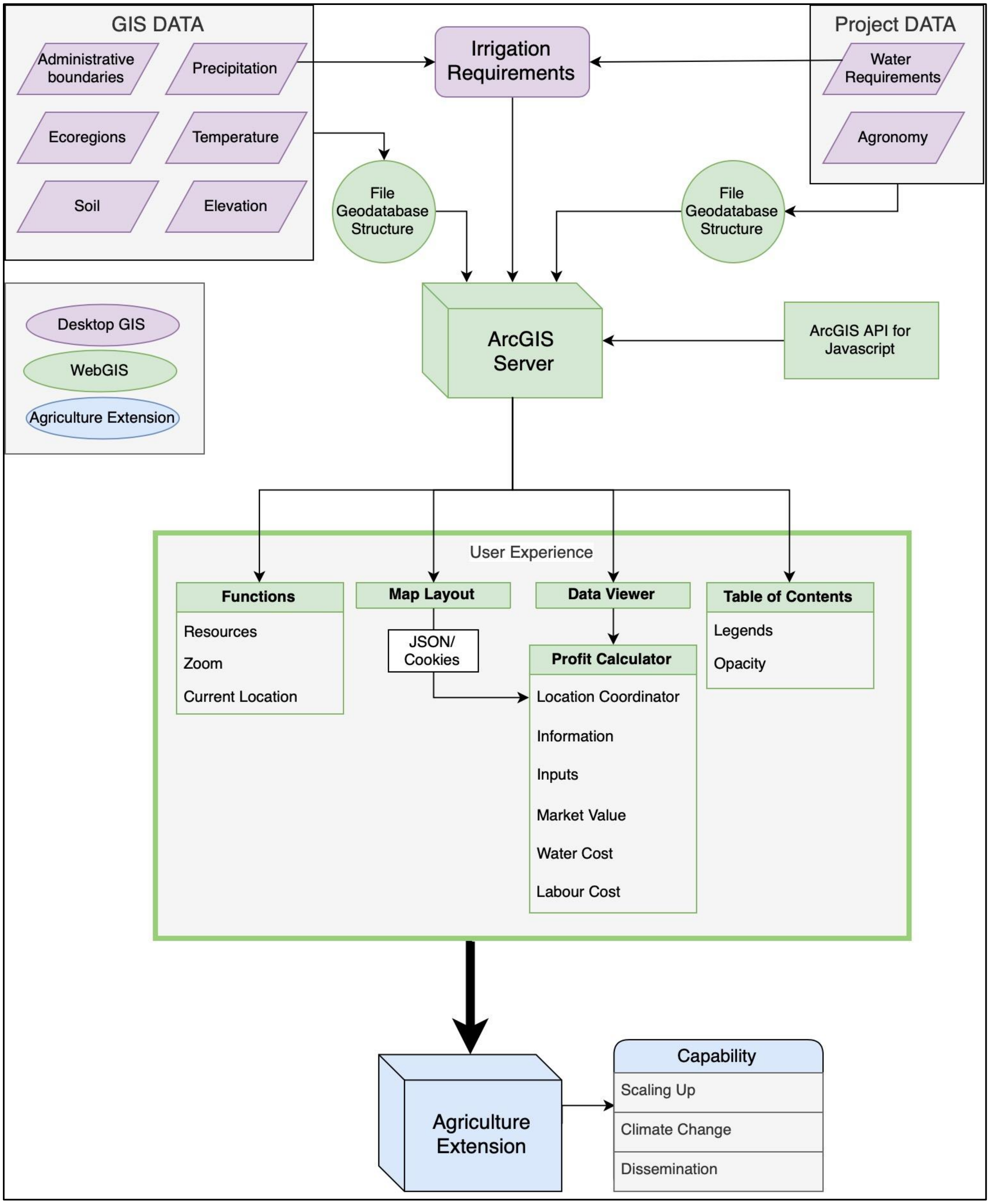

Figure 1 WebGIS Development Framework.

2.1 Data Management

As described in Minielly et al. (2018) the data came from various sources and in several formats. A range of research data was included to allow for extrapolation of site-specific characteristics from the database. Each dataset originated from a research institution and thus has multiple citations associated with its development.
The WebGIS application helps farmers and researchers access GIS data without extensive training. Data were grouped into six types: Precipitation, Temperature, Elevation, Administrative boundaries, Ecoregions, and Soil (Figure 1). Additional datasets including hydrology, infrastructure, and municipalities, were not used for agronomic modelling.

The ecoregion data required additional processing to be used in WebGIS. A systematic approach to address inconsistencies in nomenclature was undertaken. As a project three regions were used to categorize the data; however, these regions did not contain any spatial reference (Adebooye, Akponikpe, Oyedele, Peak, & Aluko, 2017; Olson et al., 2001. In contrast, with the help of the Food and Agriculture Organization of the United Nations (FAO), Olson et al. (2001) created a dataset that contained 25 ecoregions within the scope of the project. To match the terminology of the project, Olson et al. (2001) dataset were reduced to 3 larger regions. This reduction of ecoregions was achieved by consulting both the data within the dataset and researchers. With the spatial attributes to support the ecoregion terminology for the project, a new standard for the project was established allowing for a more comprehensive understanding of the effects of the study.

Much of West Africa, including the Benin Republic and Nigeria, have limited climate monitoring; thus, neither regional-scale nor country-scale climate data exist. Therefore, a global climate dataset was used. Often, global data is either coarse in resolution, nor current, and poses potential data integration issues. *WorldClim* published a climate dataset with a variety of variables at 1 km^2 resolution, with complete global coverage, suggesting it is an ideal dataset; unfortunately, the latest published data was for the 1970 - 2000 climate normal.

Variables such as soil classification, elevation, and administrative boundaries serve as supplementary data to aid MicroVeg researchers. Per the FAO soil classification system, the most comprehensive soil survey of the MicroVeg region was completed at a scale of 1:3,000,000 (Jones et al., 2013). Elevation data were at the same resolution as climate data. General relief can be noted, but little else (U.S. Department of the Interior, 1996). Administrative boundaries, including country boundaries and governmental subdivisions, are used to approximate locations for additional interventions (Hijmans, Guarino, & Mathur, 2012).

The final, and arguably most novel information obtained for WebGIS, is the incorporation of agronomic research data from the project. The MicroVeg project focused on four Under-utilized Indigenous Vegetables (UIV). For each UIV the optimal yield, fertilizer rates, and water requirements were obtained. Project data also included the location of 102 research sites (Adebooye et al., 2017; Adebooye, Akponikpe, Oyedele, Peak, & Aluko, 2018). The UIVs are commonly accepted crops. With additional research, the nutritional value of these UIVs is increasing. Therefore, with increased adoption, these UIVs might be essential to alleviate regional food insecurity.

Equation 1. Irrigation requirement function. Values recorded as percentages.

$$H_2O_{(UIV)} = \frac{water\ needed - precipiation}{water\ needed} * 100$$

Optimum water use was obtained for each UIV and each ecoregion. When the optimum water value for each UIV is compared to the precipitation value, there is a significant portion of the region that does not receive sufficient rainfall to produce indigenous vegetables at optimal rates without irrigation. Calculating the water deficiency of each UIV was an essential step to establish a stronger relationship between water use and food security. Equation 1 describes how irrigation requirements were calculated and used. The resulting data are presented in percentages, allowing for an illustration of where water is needed. Values represent water shortages. The values suggest that if a farmer wants to grow a UIV in a region where the value is 100 percent, then all the estimated water requirements would need to come from irrigation.

Values that range from 100 percent to zero indicate the amount of irrigation required. Any value lower than zero means that there is enough precipitation and no irrigation is needed. The lowest value reported by the model was - 2000 percent, in the southern portion of Nigeria. This region receives more than 2500 mm of rain a year.

The water requirement is derived using equation 1; its value represents the amount of additional water required via irrigation based on previous selections within the calculator. The value is scaled to litres per ha, matching yield data.

Equation 1 is used multiple times within the WebGIS database. In the data viewer, the resulting values of the equation are shown as the irrigation requirement for each of the UIVs. Moreover, the results are used in the profit calculator to calculate any associated costs and the volume of water to grow a UIV, if irrigation is required. In the profit calculator, the values are converted from percentages to litres per ha, which matches the inputted yield data.

2.2 WebGIS Framework

The second tier of Figure 1 outlines the WebGIS development. Data were prepared for the WebGIS database using the desktop version of the database. All the data were projected in WGS 1984 Web Auxiliary Sphere. Using ArcGIS server and JavaScript API, the data were transformed into the online database.
WebGIS includes a table of contents, zoom controls, and an option to go to the current location. In the table of contents (TOC), users have access to more features including resources, and legends, and they can modify layer opacity.

The gross profit calculator page was built using a mobile-friendly template. All the calculations and formulas are stored in a JavaScript file. In a separate window, the user sees the results of the calculation, which can be exported in a text file for further processing. GPS coordinates are necessary to run the profit calculator. Thus, by using JSON cookies, GPS information can be transferred among tools.

3. Results

The MicroVeg website and an online WebGIS system were developed to provide a tool for farmers. This tool helps them understand information such as precipitation, temperature, soil type, and to calculate the gross profit of a spatial location.

3.1 Homepage

Upon visiting www.microveg.ca, users can browse information and, resources of the MicroVeg project, as shown in Figure 2.

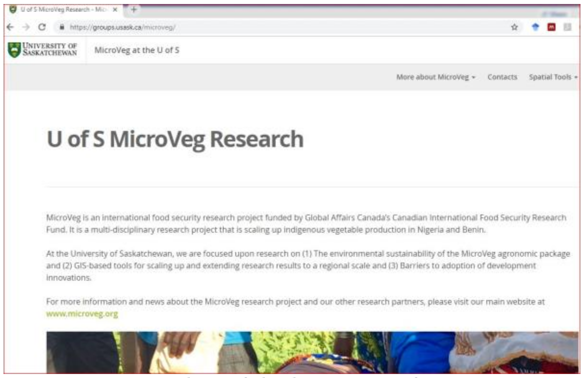

Figure 2 Screenshot of the homepage for MicroVeg.

3.2 WebGIS Tools

This WebGIS includes three tools for agriculture extension: a map layout, a data viewer, and a gross profit calculator. Zeng et al. (2017) describe the details of WebGIS and how each tool pertains to its respected interface.

3.2.1 Map Layout

Before the development of this database, researchers were only able to access limited data relevant to climate and food security and to access such data independent of one another. In WebGIS, the map layout and data viewer relies on data being extracted from multiple data inputs.

Figure 3 shows a sample view of the map layout. By using the map layout, users can look at an attribute. Data from different areas can be examined at various scales; this is useful for reviewing drought-prone regions, for example.

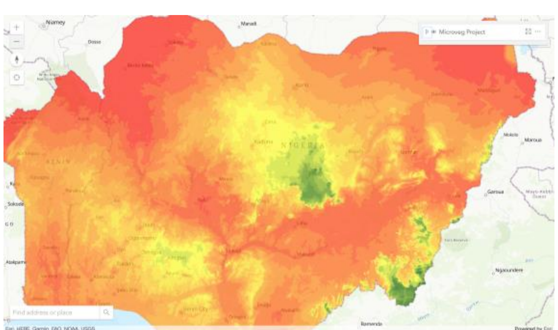

Figure 3 View of annual temperature using the Map Layout in WebGIS, microveg.ca.

3.2.2 Table of Contents

The WebGIS TOC, shown in Figure 4 is designed for a user who might not have used GIS previously. This TOC contains six significant data groupings, resources, opacity functions, and legends. This TOC combines ecoregion, research data, and administrative boundaries into one category and adds additional layers; which were previously separate in Figure 1.

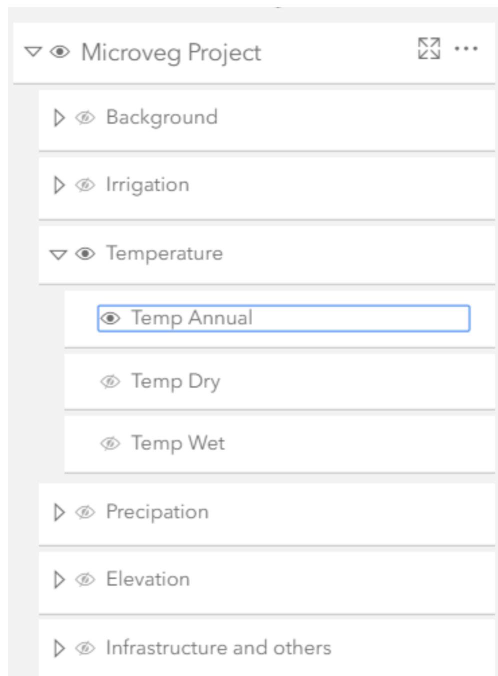

Figure 4 Sample view of the Table of Contents with Annual Temperature selected.

The legends are dynamic and will change depending on what layers are active. When multiple layers are active, the order in the TOC is the visual order, but users can modify the opacity or order of any layer. Resources also include a user manual, citations, and links to the homepage and gross profit calculator.

3.2.3 Data Viewer Popup Window

Complementary to the map layout is the data viewer, Figure 5. The data viewer gives a complete list of attributes for the selected spatial location. This tool provides all the information stored in the database, which can be exported or used in the gross profit calculator. The data viewer contains relevant information to ensure the success of farmers and NGOs aiding farmers.

As a resource, the data viewer gives multiple users the opportunity to review the same data. From this data, and communication, recommendations or management strategies can be discussed or implemented.

Figure 5 Sample view of Data Viewer.

3.2.4 Gross Profit Calculator

The gross profit calculator utilizes data from the data viewer including irrigation requirements, fertilizer recommendations, and expected yields. By using the research data, the resulting outputs help estimate the profitability of the suite of tools MicroVeg is promoting to aide in alleviating food insecurity.
Some attributes within the profit calculator, such as expected yield and water requirements are geographical and thus not editable, these are extracted from the research data. All other attributes are editable, thus making this a dynamic tool.

Figure 6 shows a sample view of the gross profit calculator. The gross profit calculator allows farmers or NGOs to see how much more profitable one scenario is to another or current farming practices assuming that optimum yields and water management are achieved.

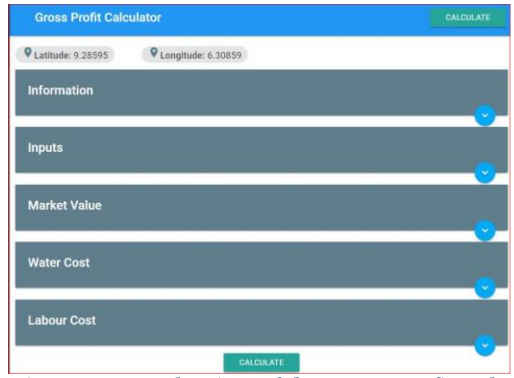

Figure 6 Sample View of the Gross Profit Calculator.

To use the profit calculator, it must be opened after a location has been selected and viewer in the data viewer. In this order, by using a JSON object a cookie with the pertinent information is sent from the data viewer to the gross profit calculator.

Conversions into various currencies allow farmers to understand the exported data better. Included currencies are the Canadian dollar (CAN), the West African Franc, the Benin Republic (XOF), the Nigerian Naira (NGN), the U.S. dollar (USD), and the Euro (EUR).

A user can input plot size in hectares (ha), square meters (m^2), or square feet (ft^2). Other variables that have multiple options include the season and the UIV of interest. Users are asked to “confirm” responses to ensure the correct information is pulled from the server. Once the confirmation button has been pressed both back, and front-end data are updated.

To obtain market information for a target region, a user can input estimations for an expected sale price, fertilizer and water usage, and labour costs into the gross profit calculator.

Fertilizer application rates are predefined for the user. For users, further explanation of the application rate, and the application technique can be obtained by talking to an extension agent or a researcher.

Labour can be inputted via simple or advanced fields to the calculator, depending on available information.

3.2.5 Agricultural Extension

The final tier of Figure 1 is the agricultural extension. This tier is not an independent aspect of the WebGIS application, but an outcome. By combining all the above elements, including irrigation requirements, researchers now have new tools to promote agriculture. By designing tools for specific groups, and incorporating other groups, dissemination of data and discussions can occur.

4. Conclusion

West Africa has a high rate of food insecurity and requires innovative tools to address this challenge. The Benin Republic and Nigeria now have new tools to address local and regional food insecurity through the research described in this manuscript. Climate and field-collected data were combined to create a comprehensive dataset for the MicroVeg project. With further collaboration more data, concerning both types and volume, can be inputted into the database. Thus, making this a robust and dynamic system for improving west African food security.

The tools described in the WebGIS database will be extended in the future to include updated climate data, climate modelling, and a GIS-driven scaling approach. It is hoped that this will support policy changes in the region. Climate change, economic reforms, and food insecurity are now more integrated than ever before. Our MicroVeg WebGIS tools are a starting point for discussions and the alleviation of food insecurity.

5. Acknowledgements

We thank the International Development Research Center (IDRC), Canada and Global Affairs Canada for funding MicroVeg Project 07983. The authors thank researchers and technical staff in the Benin Republic and Nigeria. The authors also thank the computer programmers and technical staff at The Spatial Initiative (TSI), the Social Sciences Research Laboratories (SSRL), at the University of Saskatchewan.

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