DIGITAL ATLAS – AN OPEN ACCESS SOLUTION TO SPATIAL INFORMATION ANALYSIS FOR WATER RESOURCES MANAGEMENT IN HAITI

ATLAS NUMÉRIQUE - UNE SOLUTION D'ACCÈS LIBRE À L'ANALYSE D'INFORMATION SPATIALE POUR LA GESTION DES RESSOURCES EN EAU EN HAÏTI

ATLAS DIGITAL - UNA SOLUCIÓN DE ACCESO ABIERTO PARA EL ANÁLISIS DE LA INFORMACIÓN ESPACIAL PARA LA GESTIÓN DE LOS RECURSOS HÍDRICOS EN HAITÍ

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Abstract

The provision of tools to support Water Resources Management is an important mechanism used by the Florida International University Global Water for Sustainability (GLOWS) Program to assist governments in developing countries in Asia, Africa and the Caribbean. Among such instruments the Digital Atlas is a simple user-friendly tool that allows the visualization and analysis of spatial data in the form of maps. A Digital Atlas was developed for Haiti, which allows the conceptualization of water availability and demand at the national and regional level as part of the water resources management process. Digital Atlases has been developed using the open source atlas publishing software GeoPublisher. The Digital Atlas can be installed on any computer from a memory drive, it is independent of operating systems and does not need an internet connection. It is designed so that no prior GIS experience is necessary for Haitian users to utilize the instrument and produce custom made user-interactive maps. A brief description of the Digital Atlas tool is presented followed by examples of the type of products that can be generated for Haiti. The open source, platform independent Digital Atlas has the potential to be widely used as a demonstrative and analytical tool for facilitating sustainable water resources management.
Key Words: Digital Atlas, water resources management, GIS, open source code, Haiti

Résumé

La fourniture d'outils pour appuyer la gestion des ressources en eau est un mécanisme important utilisé par le programme Global Water for Sustainability (GLOWS) de l'Université Internationale de Floride pour aider les gouvernements des pays en développement d'Asie, d'Afrique et des Caraïbes. Parmi ces instruments, l'Atlas Numérique est un outil simple et facile à utiliser qui permet la visualisation de données spatiales sous la forme de cartes. Un Atlas Numérique a été élaboré pour Haïti qui permet de conceptualiser la disponibilité et la demande d'eau aux niveaux national et régional dans le cadre du processus de gestion des ressources en eau. L'Atlas Numérique a été développé à l'aide du logiciel d'édition d'atlas open source GeoPublisher. L'Atlas Numérique peut être installé sur n'importe quel ordinateur à partir d'un lecteur de mémoire, est indépendant des systèmes d'opération et n'a pas besoin d'une connexion Internet. Il est conçu de telle sorte qu'aucune expérience précédente de SIG n'est nécessaire pour les haïtiens d'utiliser l'instrument et de produire des cartes interactives personnalisées. Une brève description de l'Atlas Numérique est présentée, suivie d'exemples du type de produits qui peuvent être générés pour Haïti. L'Atlas Numérique à code source libre et indépendant de la plate-forme peut être largement utilisé comme instrument de démonstration et d'analyse pour faciliter la gestion durable des ressources en eau.
Mots clés: Atlas Numérique, gestion des ressources en eau, SIG, logiciels open source, Haïti

Resumen

La provisión de herramientas para apoyar la Gestión de Recursos Hídricos es un mecanismo importante utilizado por el Programa Global Water for Sustainability (GLOWS) de la Universidad Internacional de Florida para ayudar a los gobiernos de los países en desarrollo de Asia, África y el Caribe. Entre estos instrumentos, el Atlas Digital es una herramienta fácil de usar que permite la visualización de datos espaciales en forma de mapas. Un Atlas Digital fue desarrollado para Haití, el cual permite la conceptualización de la disponibilidad y demanda de agua a nivel nacional y regional como parte del proceso de gestión de los recursos hídricos. El Atlas Digital ha sido desarrollado usando software de publicación de código abierto de GeoPublisher. El Atlas Digital se puede instalar en cualquier computadora a partir de una unidad de memoria, el mismo es independiente de los sistemas operativos y no necesita una conexión de Internet. Este está diseñado para que los usuarios haitianos no necesiten experiencia previa en SIG para utilizar el instrumento y producir mapas personalizados interactivos. Una breve descripción de la herramienta del Atlas Digital se presenta seguida de ejemplos del tipo de productos que se pueden generar para Haití. El Atlas Digital de código abierto, independiente de la plataforma computacional, tiene el potencial de ser ampliamente utilizado como una herramienta demostrativa y analítica para facilitar la gestión sostenible de los recursos hídricos.
Palabras clave: Atlas Digital, gestión de recursos hídricos, SIG, software de código abierto, Haití,

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1. INTRODUCTION

Institutional Challenges in spatial data visualization

A picture is worth a thousand words, as the old adage goes. The ability to visualize spatial data, such as rainfall distribution, groundwater availability and locations of water users in the form of maps is essential for effective water resources management. Maps enable a concurrent examination of water availability and water demand in a region, bringing to the surface patterns and links between demand and supply that are not otherwise readily evident from tabular data alone. Maps also enable effective communication between different stakeholders and sectors involved in water resources decision-making. Geographic Information Systems (GIS) advances spatial analysis to a deeper level, by allowing users to select different layers of data, zoom into a desired scale (not possible with paper maps), obtain information specific to features, and proceed with a variety of spatial analysis and modeling.

Despite the utility of maps and GIS, it is not uncommon in developing countries to have hydrological data languish in a spreadsheet format, with very little further analysis being performed with the data. This lack of analysis, interpretation and dissemination of the data to water managers presents a large opportunity loss. While many water management institutions have technical departments with some staff trained in the use of Geographic Information Systems (GIS), challenges remain in the production of and access to maps useful for different tasks. End users such as managers and decision makers must depend upon technical GIS departments to produce maps with current data. The rapid evolution of GIS application software poses another challenge for departments to stay up-to-date with technology.

In Haiti, as in other developing countries, there are several constraints hampering the widespread adoption and continued upgrading of GIS software and applications, such as:

1. ArcGIS, the industry standard in spatial analysis is expensive, even with special developing country pricing.
2. ArcGIS cannot be freely installed on any number of computers – licenses allow for a fixed number of users at a given time, or a fixed number of computers.
3. Open Source GIS software, such as Q-GIS and GRASS, while being free, has a steep learning curve. A dearth of technical trainers, poor internet connectivity and the relatively large investment of time necessary for self-learning of open source GIS pose hurdles for the majority of water resources management professionals, especially those who are mid-career.
4. Internet connectivity is very patchy and slow, which also restricts the download of large files, such as Digital Elevation Models, raster files and satellite images.

Even when a department has GIS skills, the necessity of renewing ArcGIS licenses on a yearly basis poses an additional financial burden. We have come across numerous instances in developing countries of GIS programs grinding to a halt because the software does not work unless the license is renewed. This is a very unfortunate loss of effort, because GIS depends on ground data that is expensive and time-consuming to collect over large regions.

The Digital Atlas – universally easy access to mapping tools

With these limitations and challenges in mind, a practical mapping solution for water managers is a Digital Atlas. The Digital Atlas is a very recent application that is freely installable in any computer, is self-contained in terms of maps and data and enables users to combine and classify different layers of information to create their own customized maps. In addition, the Atlas also provides an interface for analyzing thematic maps that is similar to a GIS, thus allowing the user to select features to get underlying information from databases. Digital Atlases has been developed using the open source atlas publishing software GeoPublisher (http://en.geopublishing.org/) for a variety of applications such as natural resources management in Benin and Morocco (Impetus, Germany), water resources management and vulnerability assessment in Namibia (Cuvewaters), Jordan (GLOWA, Germany) and Tanzania (GLOWS-FIU, 2014; GLOWS-FIU, 2015). These atlases are being widely used by water resource management institutions, educational institutions and NGOs in cooperation with local communities.

Figure 1 illustrates some of the varied types of thematic maps that can be created with a Digital Atlas. The upper left quadrant shows a drainage map with rivers and wetlands along with monitoring stations (not shown) that can be clicked on to get graphs for monthly and annual discharge. The upper right quadrant shows a map of average annual rainfall isohyets. The lower right map depicts the geology of the region, while the lower left part of the figure shows an administrative map with district/ward boundaries, towns and transport infrastructure. The Atlas can be structured so that each feature in a particular map can be clicked on to display additional information. For instance, one can click on a given town on a map to get its population, gender ratio, percentage of employment, public health status, etc. In our experience, the Atlas empowers water resource managers and professionals to easily make their own maps at a desired scale, select features and use customized color schemes and symbols, using them for presentations and reports.

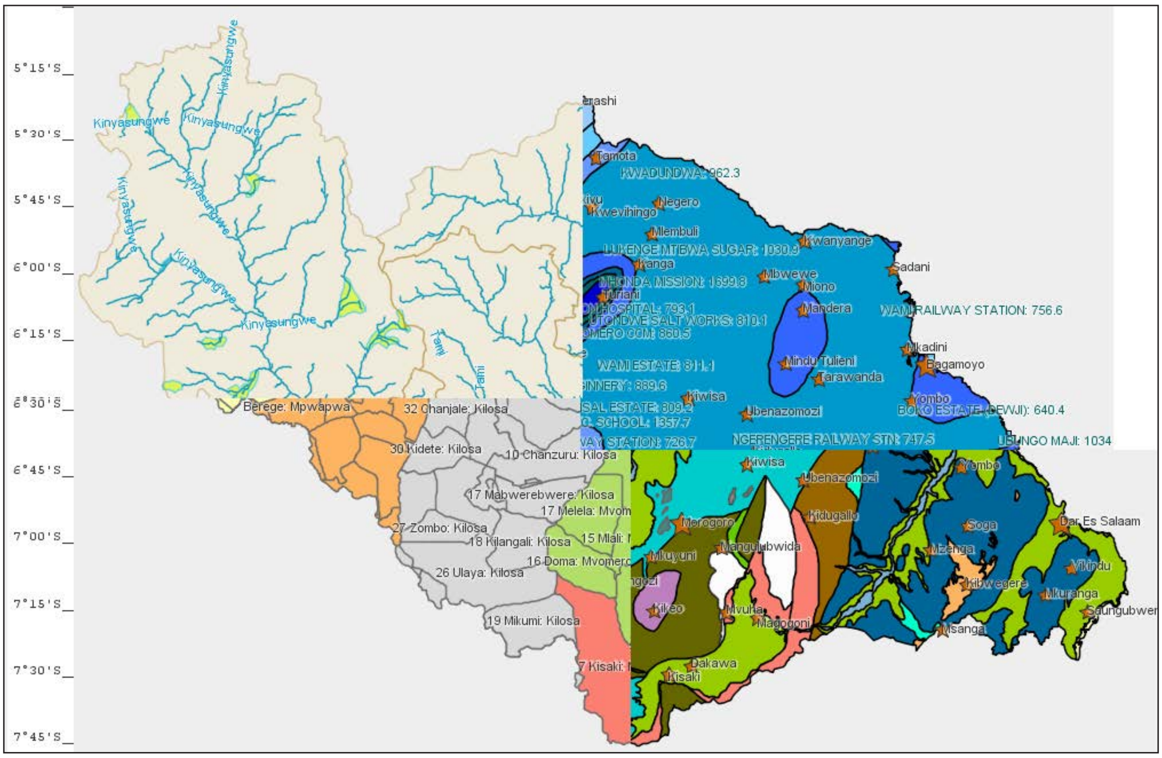

Figure 1. Examples of thematic maps that can be created in a Digital Atlas. From upper left clockwise, a map of rivers (left upper), rainfall (upper right), geology (lower right) and administrative (lower left)

Maps for this figure have been taken from the Wami Ruvu Basin, Digital Water Atlas (GLOWS 2015).

Digital Atlas Features at a glance:

- No internet connection is necessary to run the Digital Atlas.
- The Atlas can be installed on any operating system as a self- contained set of vector/raster data and Java environment files.
- This set of folders is portable and can be transferred using a CD, external memory or stored on the web.
- Information for each thematic map is displayed as a set of overlaying layers. The user can change color, symbols, size and filter data for each layer to create custom maps that can be saved as images for reports, presentations, etc.
- The user is able to zoom into a map to have greater spatial detail, access information pertinent to a particular site and combine different layers of data without the need of a GIS.
- The user can combine different layers for analysis of linkages. For example, to evaluate the relationship between evapotranspiration and land cover, or between rainfall and discharge.

The ease of use and lack of installation restrictions has led the Digital Atlas to be readily accepted by a wide range of technical and nontechnical professionals in the water resources sector in the countries for which this tool was developed. Here we briefly describe one use of the Atlas by the water resource ministry in Tanzania.

An example of a Digital Atlas in use: Wami Ruvu Basin, Tanzania

The Digital Atlas for the Wami Ruvu Basin is a geospatial information gateway on various sectors and thematic areas connected with water resources: topography, erosion vulnerability, geology, climate, ecosystem, surface and groundwater resources, monitoring wells and hydrologic data, water use permit locations, public health, administrative, demographic and infrastructure. In addition, a literature section includes a collection of relevant publications for the region of interest. The Atlas for the Wami Ruvu basin has been jointly developed by the Ministry of Water, Tanzania and GLOWS-FIU (GLOWS 2015). The Ministry of Water has since then been developing atlases for other river basins in Tanzania (e.g.. Lake Rukwa Basin Atlas).

As an example of the use of an Atlas, Figure 2 shows the locations and water yield of groundwater wells in the Wami and Ruvu river basins of Tanzania overlaid on an annual average rainfall map. This map was produced with the Tanzania Digital Atlas tool and used to examine the rising concerns about groundwater depletion, falling water tables and the sustainability of water resources in the semi-arid region of the capital city of Tanzania, Dodoma. A list of borewells, for which water permits were issued by the Ministry of Water of Tanzania, existed in spreadsheet format and was mapped to show the areas with high water extraction. This information is being used to choose locations for installing groundwater monitoring wells as well as in examining supplementary options for water supply, given that this is a rapidly urbanizing region. Seeing the clustering of borewells on a map makes it easier to communicate the groundwater depletion issue with policymakers and the general public. The same map is being used to analyze the high concentration of borewells in the major coastal city of Dar-es-Salaam, indicating the potential danger of seawater intrusion into coastal wells accompanying high groundwater extraction rates. This situation could render unusable these wells, thereby compromising a source of fresh water for this high water demand coastal area.

Other types of maps, such as those presenting overlaying rainfall distribution with topography and land cover/land use can indicate whether infiltration or runoff might be the dominant process in a catchment, and suggest the locations of discharge and water quality monitoring stations as well as strategies to store water for year-round supply. The referred products constitute a valuable tool for the development and implementation of natural resources management at the national and sub-national level.

The User Manual for the Atlas (GLOWS 2015) describes several examples of spatial analysis possible with the Digital Atlas. One example describes how to identify the vulnerability of coastal and estuarine areas to flooding from sea level rise. The approach is to reclassify the color elevation scale of the topographic map (Digital Elevation Model) contained in the Atlas to a very fine resolution scale such as 1 meter apart in the coastal areas (mean sea level, 1 m, 2m, 3m and so on). Such a rendering makes it easy to identify low-lying areas that are at the greatest risk of flooding. Areas inland from the coast that are in a river floodplain can be at a greater flooding risk than coastal areas at some vertical distance from the sea, such as on a promontory or cliff. These and other concepts are also explained in the Tanzania Water Atlas Book (GLOWS 2014).

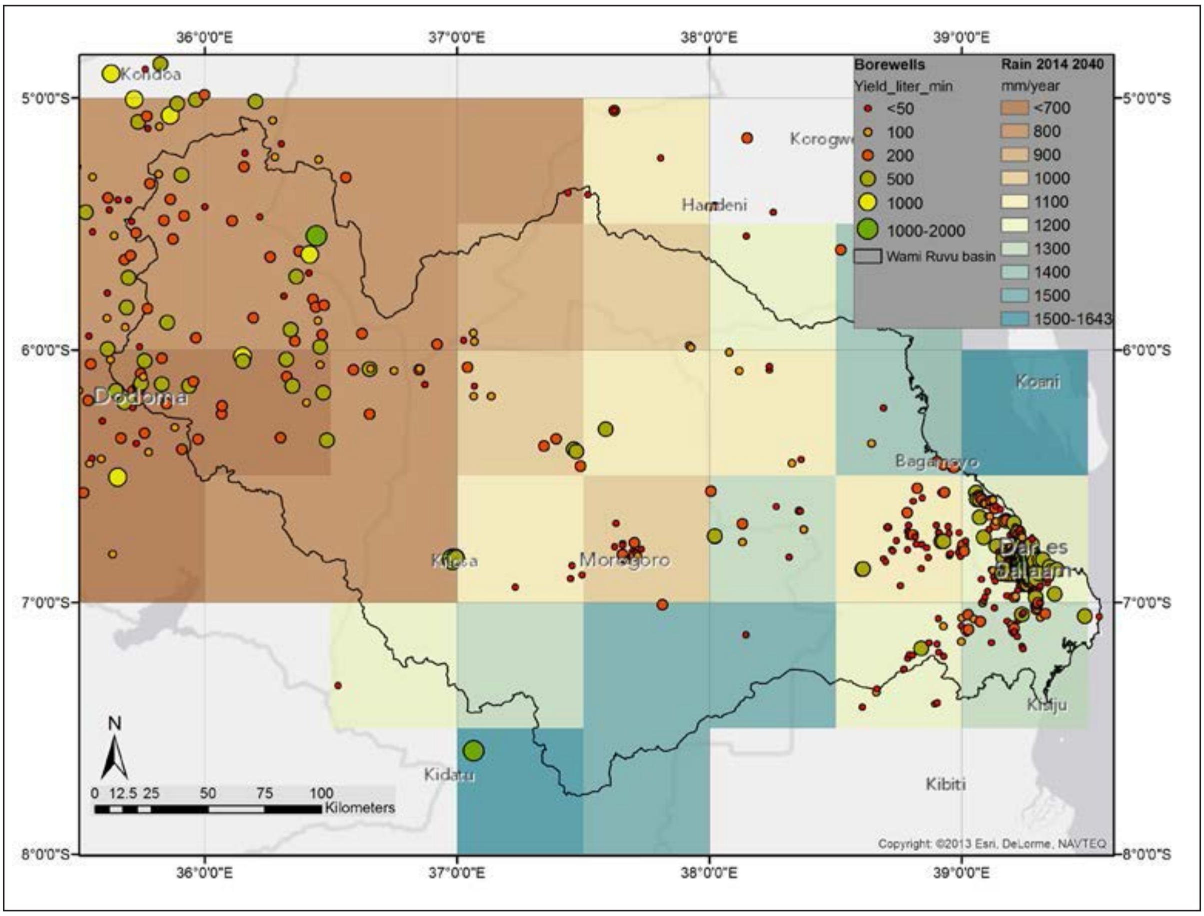

Figure 2. Borewell locations and annual rainfall in the Wami Ruvu Basin of Tanzania, showing concentrations of borewells in the semi-arid Dodoma region (left side of map) and at Dar es Salaam by the coast (right). Borewell water yield in liters/minute is shown in circles of different sizes and colors. GLOWS - FIU 2014

2. METHODS

From the field to the user's screen: The process of Atlas development

The Digital Atlas consists of a group of electronic files located in folders containing the programs, data, and the Java operating environment that is required for the Atlas to run. Once this set of folders is installed into a computer, clicking on the executable file runs the Atlas. A user cannot accidentally change the data in an Atlas. However, this security feature also means that a user cannot update an Atlas. Updating however is easily possible by atlas developers, that is, anyone who is familiar with using GeoPublisher to create an atlas. Familiarity with GeoPublisher can be obtained in a day's training.

In addition to the GeoPublisher software being freely downloadable, the atlas developer needs to either obtain GIS shapefiles from local and/or global sources, or structure shapefiles from tabular data with geographical coordinates (location information). Gathering and checking data for accuracy is typically by far the most time and effort-intensive step in map development. Spatial data (whether hydrological, ecological, climate, landscape, water use or demographic) is collected and used to create ESRI shapefiles (data geo-referenced with geographic coordinates) through GIS. The shapefiles are then imported into the Digital Atlas as layers (Figure 3). Ready-to-use shapefiles are also available from other sources, both from Haiti institutions and international data bases. Supplementary descriptive information is added for each layer, as well as for thematic maps. This information can be accessed by clicking the icon with the letter "i" on each layer as well as for the entire thematic map. The Atlas is then saved and exported as a data-driven executable (Figure 3), which can be copied onto a memory drive and loaded on to other computers, or set up as a web download.

Updates to the Atlas are thus possible by developers such as hydrologists and technicians in the various Water Resources Management Institution with knowledge of GIS and a basic understanding of GeoPublisher that can be acquired in one day short tutorial. An updated shapefile is created and imported into the Atlas using GeoPublisher, and recompiled and re-exported as an executable set of files and data (Figure 3). The development of the Atlas is complemented with hands on training to end-users within the country. For example, GLOWS has offered a series of atlas user and developer trainings in Tanzania for several years. Staff in the Ministry of Water in Tanzania who received training have gone on to create new digital atlases for several river basins in this country, evidence of the ease of creation and use of these atlases, as well as the ability to pick up these skills. Similar training exercises are being tailored for Haiti.

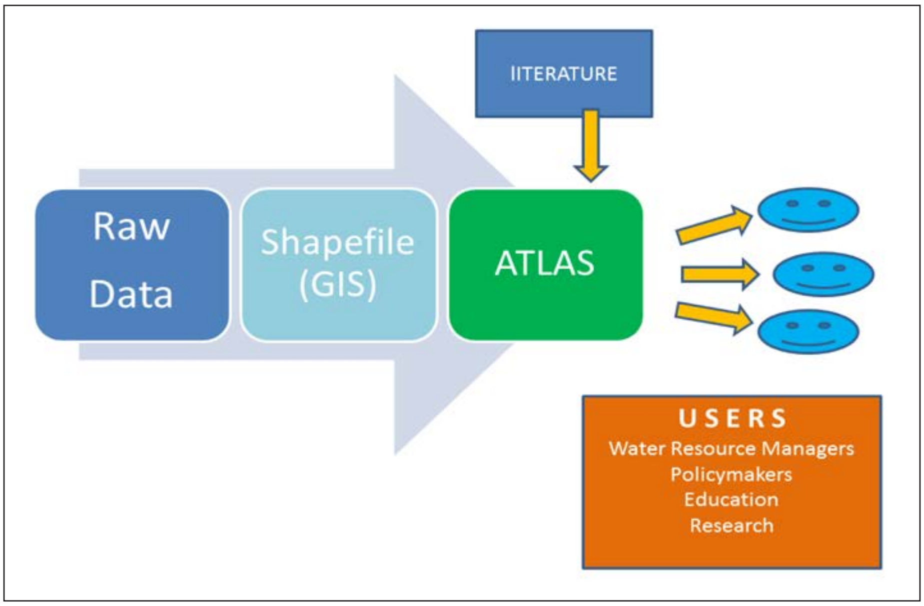

Figure 3. Steps in the development and use of a Digital Atlas

3.RESULTS AND DISCUSSION

The Water Resources Digital Atlas for Haiti

Here we briefly describe a Digital Atlas for Water Resource Management that has been developed for Haiti. Most of the data has been provided to FIU by Haitian government institutions related to water resources with additional sources such as MODIS data (NASA/University of Montana) for evapotranspiration, Climate Wizard for precipitation and temperature predictions, Google Earth Engine for forest gain/loss/cover and IUCN for biodiversity data.

Organization of the Haiti Water Atlas

Data in the first version of the Atlas has been organized into the following categories:

1. Climate – precipitation, wind/hurricanes, solar radiation and temperature.
2. Landscape – land use/land cover, soil types, geology.
3. Ecosystem – forest areas, forest cover loss/gain over the period 2000-2014.
4. Administrative – administrative units, roads, places of public interest, healthcare facilities.
5. Water Resources – river network, hydrogeology (aquifers), wetlands and surface water reservoirs.
6. Risk – hurricanes, soil erosion and landslides.

Functionality of the Haiti Water Atlas

Under each category are thematic maps, i.e. maps that display information on a certain theme, such as land use, rainfall, or water quality monitoring sites. Each thematic map is composed of a set of layers that can be turned on and off to display or hide that layer. The order of the layers can also be interchanged by dragging a layer up or down in the menu. This functionality is useful to achieve control on the order of overlaying layers. For instance, a layer of rivers can be shown over the topographical map, so that no part of the river network is hidden by elevation contours or other features on the topography layer.

The user manual for the Atlas describes the contents in detail. It includes a guide to using the features of the Atlas in order to customize the display of information by choosing symbols, colors and filters. Raster databases, such as those containing topography or evapotranspiration data, in which each cell or pixel on the map is associated to a variable numerical value, can be classified into ranges or groups as per the user's specifications. For example, the scale and range of an elevation gradient for a topography map can be set at 100 meter intervals, or 200m, or 300m, as required.

Examples of analysis enabled by the Atlas

Some examples of maps that can be created using the Digital Atlas for Haiti are shown below.

1. *Forest cover and forest cover loss:* Figure 4 depicts forest cover in Haiti in 2000 with a 4 point classification scale in quartiles represented by deepening shades of green, as can be seen on the left side map panel. Figure 5 shows subsequent forest cover loss over the period 2000-2014 as areas in red. To see forest loss in detail, the Atlas allows the user to zoom in up to a resolution of 30 m (each cell or dot in the map represents an area of30m by 30m on the ground). The data categorization used in these maps is based on the work of Hansen *et al.* (2013) who classified forest cover on Landsat 7 and Landsat 8 images from 2000 to 2012, thereby deriving changes in forest cover. Combining this map with river drainage and topography layers indicates the areas highly susceptible to soil erosion and sediment transport. Linking forest loss maps with a map of roads and human settlements can indicate the proximity of transportation infrastructure and human demand for wood, thereby identifying areas that need conservation on a priority basis.

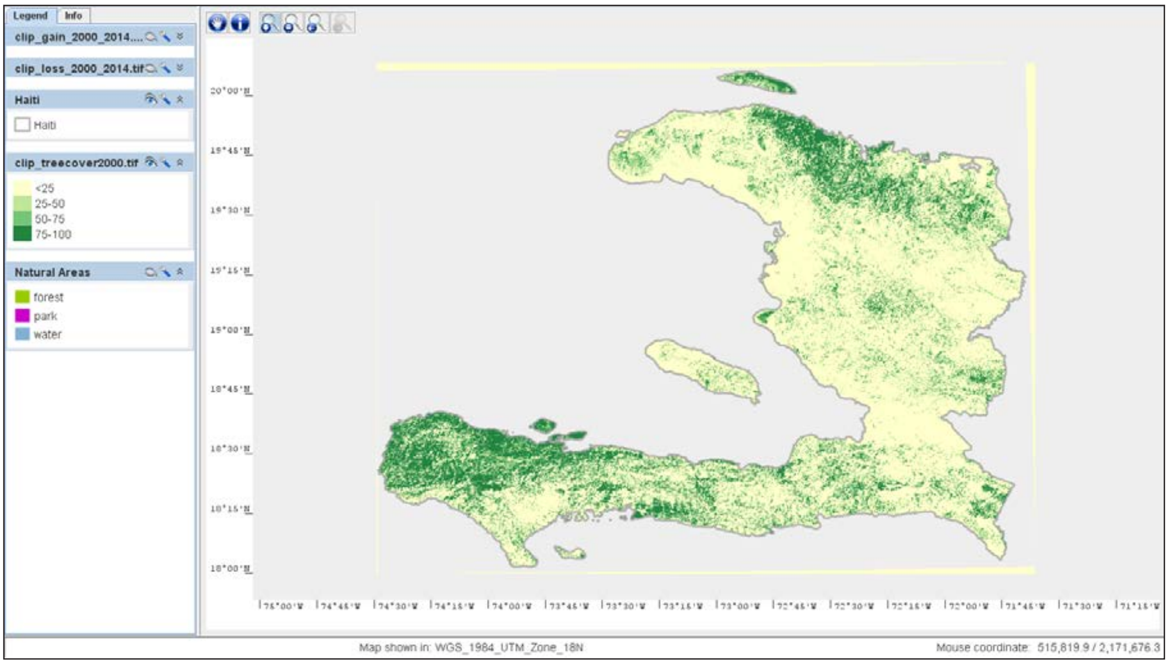

Figure 4. Percent Forest Cover in the year 2000 in Haiti in four classes – under 25%, 25-50%, 50-75% and 75-100% as depicted in legend on the left panel. Data Source: Hansen et al (2013) and Google Earth Engine. Map produced by the Geopublisher-based Digital Atlas

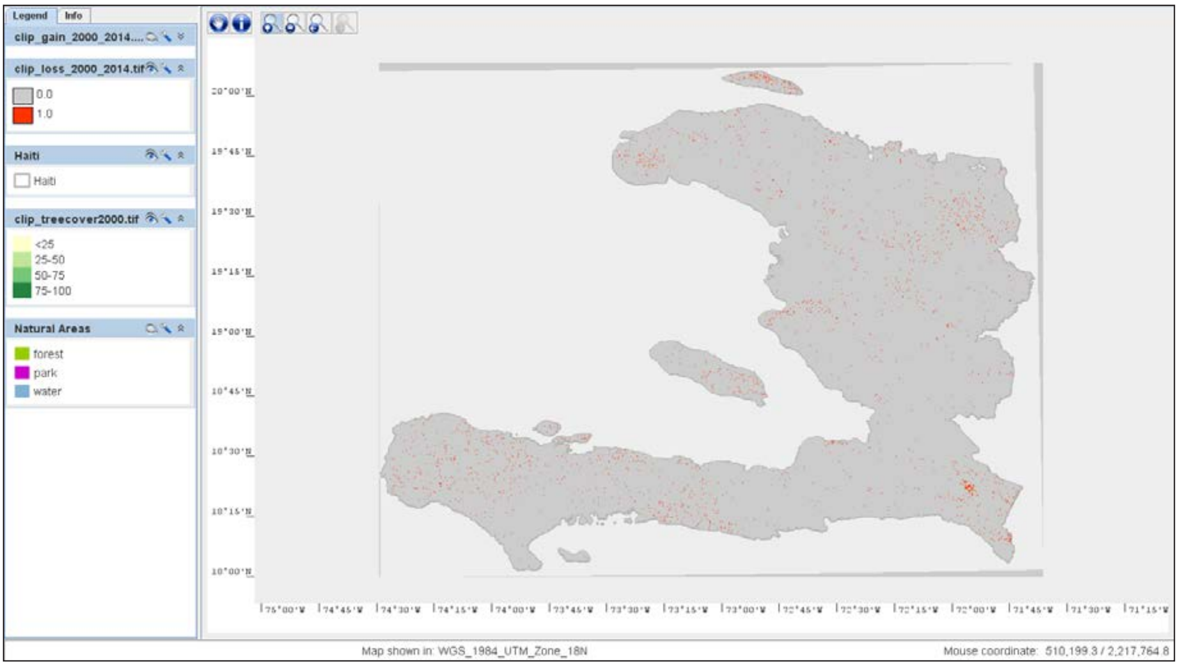

Figure 5. Forest Cover loss (2000-2014) shown in red in Haiti. Data Source: Hansen et al (2013)

2. *Hydrogeology:* Another example of a product developed using the Atlas is a hydrogeology map showing the different aquifers in Haiti. This thematic map also includes a river layer, which if turned on, would display over the hydrogeology layer, thereby displaying the geographical distribution of both groundwater and surface water in an area. Additional layers of information, such as location of towns, roads and districts, can provide a spatial reference for the above water resources. These layers can be turned on and off by clicking on the eye symbol present on the title bar of each layer (left side of maps where the legend is shown). As described earlier when presenting the example for Tanzania, spatial depiction of water resources in relation to water demand (in towns, for agriculture and industry) is necessary for understanding current water demand, forecasting future demand and identifying sustainable management strategies to meet water demand without compromising the sustainability of water sources. For instance, positioning the locations of new groundwater monitoring wells requires relating knowledge of locations of high water demand with the locations of water sources, to be able to detect conditions and trends in the water table drawdown and replenishment in real time, and thereby instill water conservation measures as required.

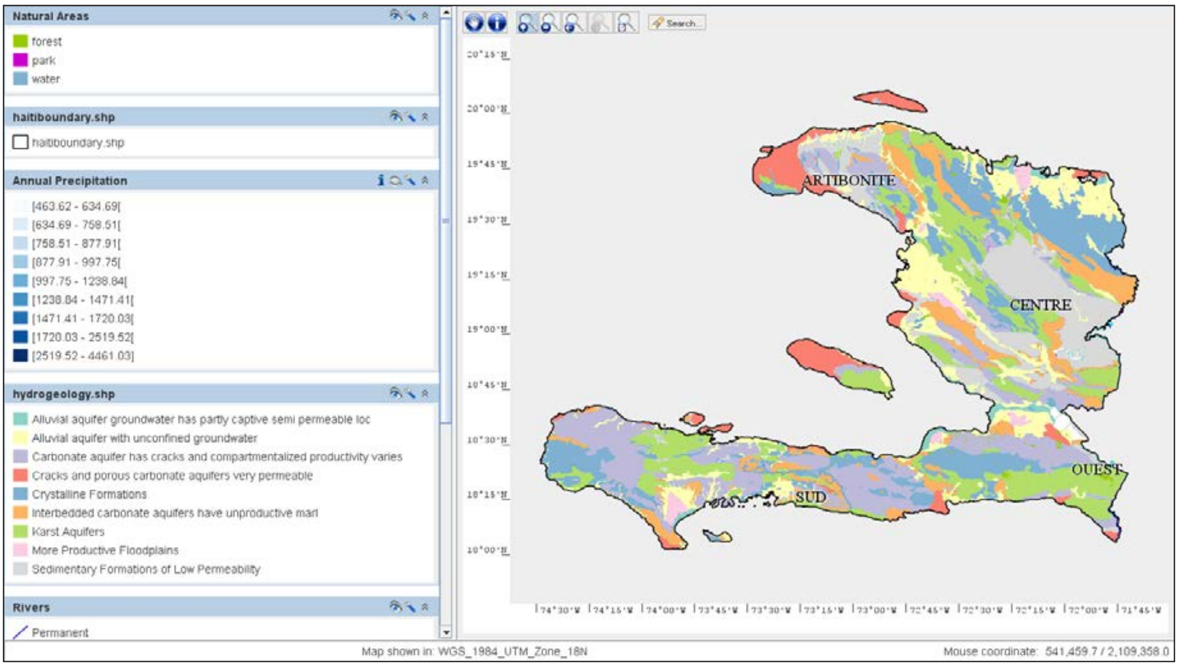

Figure 6. Hydrogeology of Haiti. Data Source: Government of Haiti

Some other examples of maps created by this Atlas are representations of erosion susceptibility zones (Figure 7), annual average rainfall at a 50 km grid (Figure 8) and a zoomed-in map of healthcare facilities along with rivers in the Port-au-Prince area (Figure 9). If river water quality data is available, this data can be combined with public health (disease outbreak and number of patients treated) maps, to indicate the linkages between water quality and public health for instance. Adding a layer of public health facilities can identify areas underserved by health facilities.

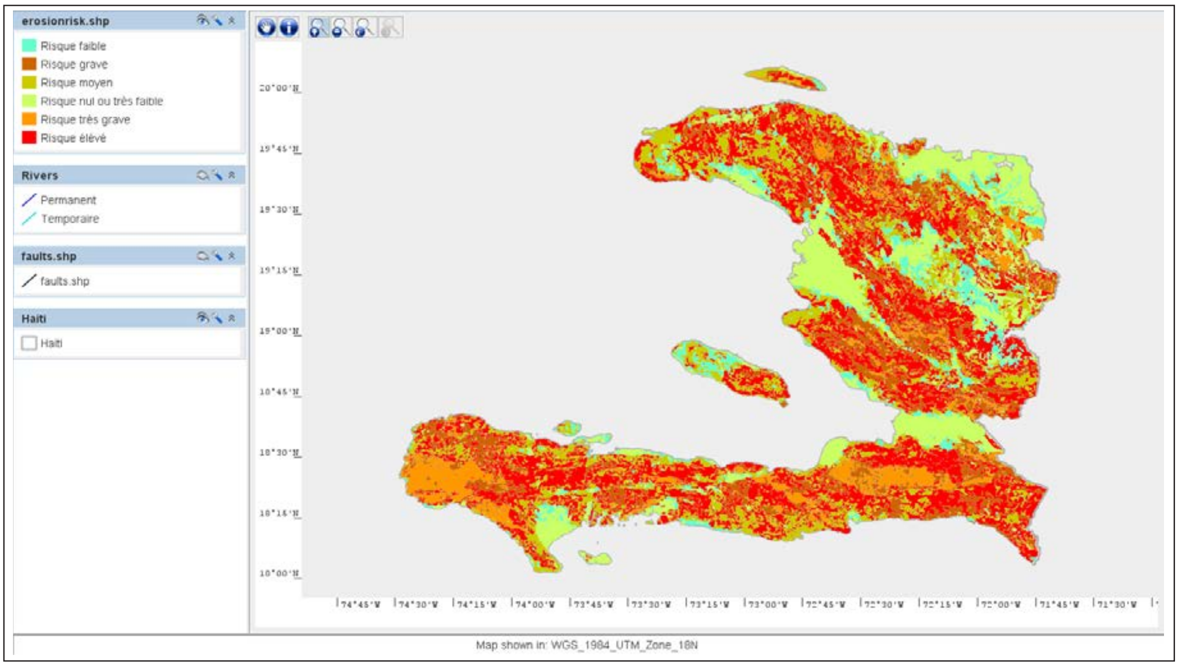

Figure 7. Erosion risk map for Haiti based on slope steepness, with red denoting areas of highest risk. Data Source: GIS analysis on ASTER-Digital Elevation Model courtesy NASA/Japan Space Research Organization

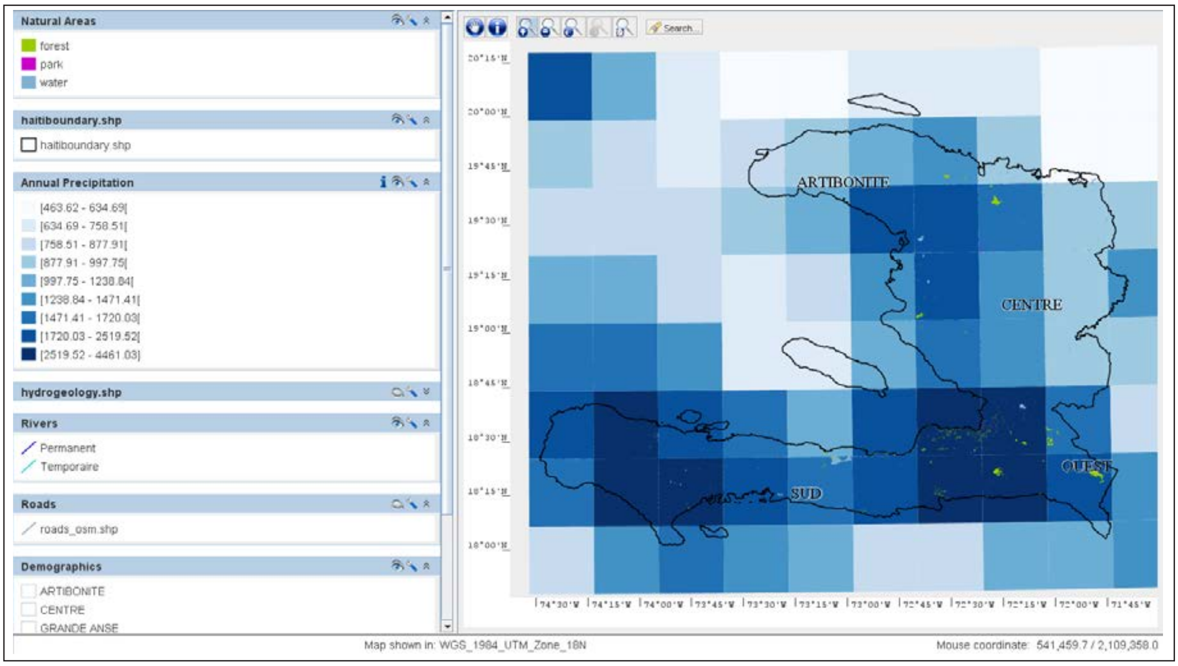

Figure 8. Average Annual rainfall for Haiti over 2000-2010. Legend on left shows rainfall scale from < 700 mm to > 4000 mm annual. Source: ClimateWizard

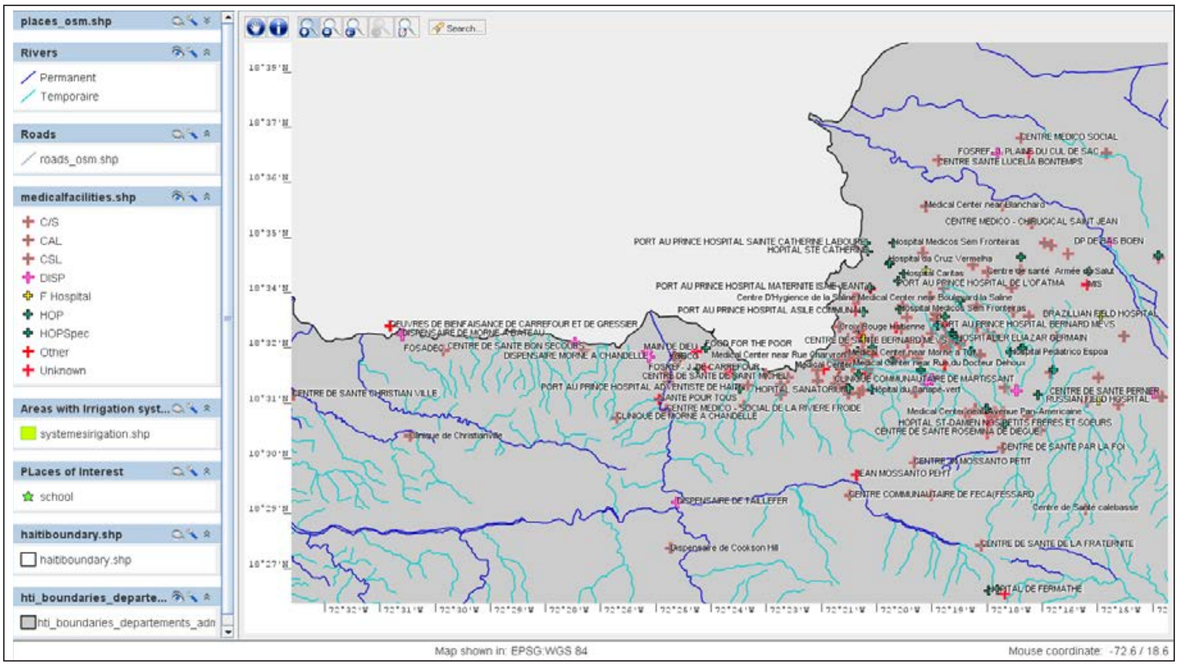

Figure 9. Close up of locations of healthcare facilities over a map of rivers for the Port au Prince area in Haiti. Data Source: Government of Haiti

The above presented maps are just a few examples of the possible products that can be generated by a user with the Haiti Water Resources Digital Atlas.

4. CONCLUSION: DIGITAL ATLAS - A UNIVERSAL TOOL:

The Digital Atlas can be freely and easily utilized by a wide spectrum of users engaged with water resources management such as water resources planners, managers, government policy/decision makers, hydrologists and scientists who can readily access and analyze the data by just referring to the developed accompanying User Manual. A key feature is that the Atlas is designed to be user-friendly; this has been proven in numerous instances in Tanzania, Rwanda and India, where the authors (FIU- GLOWS) have developed digital atlases that have been adopted by government and educational institutions. In addition, some institutions are also in the process of developing atlases for other river basins, following training in atlas development. Being user friendly, the Atlas enables water resources managers at all technical levels to analyze data and make their own maps, without having to necessarily rely upon a technical GIS department for creating maps.

The Atlas can also be utilized as a tool by educational institutions, community organizations and think-tanks to demonstrate linkages between geophysical, ecological, anthropogenic, administrative and infrastructural factors that influence the availability and management of water. The open source platform independent Atlas has the potential to be widely used as a demonstrative and analytical tool for facilitating sustainable water resources management. Water is a resource essential to every human being, and conversely is impacted by the actions of every individual. In that connection, the Atlas can easily be used in schools and colleges to demonstrate and inculcate the relationships between water, human activity, and the environment. In summary, the Atlas was developed to address the paradigm that a truly sustainable management scheme of water resources, which is harmonious with the ecosystems that maintain water availability and quality, can only be achieved when the vast majority of society is fully aware of the issues affecting water in their local region.

ACKNOWLEDGEMENTS

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