

Developing Tools for Optimizing School-Based Deworming in the Context of Integrated Neglected Tropical Disease Control

Functional Requirements and Technical Options
for an Open Access Data Platform



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20/12/2012

Report prepared on behalf of the Global Atlas of Helminth Infection (GAHI) project, London School of Hygiene & Tropical Medicine (LSHTM)

This work was supported by a grant awarded to LSHTM from the Bill & Melinda Gates Foundation entitled Optimizing Mass Drug Administration Regimens and Policies (OPP1033751)



Summary

This report was undertaken by Avia-GIS on behalf of the Global Atlas of Helminth Infection (GAHI) project, based at the London School of Hygiene & Tropical Medicine (LSHTM). This work was supported by a grant awarded to LSHTM from the Bill & Melinda Gates Foundation entitled *Optimizing Mass Drug Administration Regimens and Policies* (OPP1033751).

The aim of this report is to identify the functional requirements and technical options for an open access data platform that will help countries plan and implement cost-effective school-based deworming in the context of integrated neglected tropical disease control.

The first part of the report describes the functionalities offered by several currently existing web mapping platforms, including NTD, non-NTD, and non-health platforms. Based on user's identified needs and expert opinion, these functionalities were grouped into four categories: mandatory, important, optional, and other functionalities. Mandatory functionalities included the possibility to visualize raster and vector data, create a legend, zoom/pan, and get feature information by clicking on the map. Important functionalities included the option to add map elements (scale, grid, and locator map), query map attribute data, turn on/off individual layers, display the map full screen, and print/save the map. The creation of spatial buffers, the possibility of adding labels, and changing the legend layout were identified as optional functionalities.

The second part of the report focuses on web mapping tools (proprietary as well as free and open source software) that are most appropriate to meeting the needs of the project and that are capable of addressing at least the mandatory and important functionalities, which were identified in the first part of the report. We provide a description of the basic concepts of client-server architecture, Open Geospatial Consortium (OGC) standards, and free and open source software. Finally, we discuss four popular web map servers that can function as building blocks for developing an open access mapping platform.

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1 Background

This report presents a state-of-the-art review of existing web mapping platforms relevant to neglected tropical diseases (NTDs) (Box 1) and a review of possible design options for an open access mapping platform. The work is conducted under the auspices of a Bill & Melinda Gates Foundation funded project entitled *Optimizing Mass Drug Administration Regimens and Policies* (OPP1033751), which has as one of its aims the development of (i) a global, open access data platform that provides information on the geographical distribution of soil-transmitted helminth (STH) infection and other NTDs, and (ii) a user-friendly spatial planning tool for school-based deworming and NTD control.

The state-of-the-art study includes the following sections:

1. Existing web mapping platforms including at least all platforms, tools, and systems mentioned in the project document and expanding to other relevant NTD, non-NTD, and non-health platforms.
 - Data content and quality
 - Offered functionalities
2. Existing tools (proprietary and free and open source software) and methodologies, which are capable of addressing the proposed functionalities of 'The System'.

Box 1. List of 17 diseases covered by WHO-NTD classed in three categories according to priorities

1. NTDs covered by Gates Project (5)
 - Lymphatic filariasis
 - Onchocerciasis
 - Schistosomiasis
 - Soil-transmitted helminthiasis
 - Trachoma
2. NTDs with strong link to Gates project (4)
 - Cysticercosis/Taeniasis
 - Dracunculiasis (guinea-worm disease)
 - Echinococcosis
 - Fascioliasis
3. Other NTDs (8)
 - Buruli Ulcer
 - Human African trypanosomiasis
 - Chagas disease (American trypanosomiasis)
 - Dengue/Severe dengue
 - Leishmaniasis
 - Leprosy
 - Rabies
 - Yaws

2 Introduction to web mapping

Web mapping is the process of designing, implementing, generating, and delivering maps on the World Wide Web. The global spread of the Internet combined with the increasing demand for spatial information has led to a rapidly growing use of web maps. A major advantage of web mapping systems in comparison to desktop systems is that no mapping software needs to be installed on the end-user's computer. Recent advances allow for the development of complex interfaces that can be run on a web browser without installing additional software components (e.g., plug-ins) thanks to the use of widely adopted standards, thereby alleviating most of the cross platform operational issues and increasing the accessibility. Moreover, web maps provide easy and fast access to up-to-date spatial information from multiple sources and across multiple scales.

The landscape of web mapping has changed fundamentally in the last decade thanks to several technological innovations, e.g., the increase in computing power and bandwidth capacity, the termination of GPS Selective Availability, the development of standards such as the Open Geospatial Consortium (OGC) standards, and the development of Internet technologies such as eXtensible Markup Language (XML), Asynchronous JavaScript and XML (AJAX), and Simple Object Access Protocol (SOAP) (Haklay et al. 2008, Li & Gong 2008). A major breakthrough was achieved in 2005, when Google implemented a tile-based mapping system that facilitated interactive zooming and panning. Subsequently, Google released an Application Programmer Interface (API) that enabled programmers to place data on top of a Google base map and make this map available to anyone (Peterson 2012). The Google Map API and others such as MapQuest and Yahoo! APIs, have made web application development more accessible and have provided a new way of providing web mapping services (Haklay et al. 2008, Li & Gong 2008).

The growing popularity of web mapping services has also led to a boost in the development of free and open source software (FOSS) technologies for geographic data collection, storage, analysis, and visualization. The quality of FOSS software has been constantly improving and has matched the functionality offered by proprietary software (Boulos & Honda 2006, Deshpande & Riehle 2008), which has resulted in a rapidly increasing number of FOSS projects in many domains, e.g., sociology, tourism, and transportation (Ball 2009, Evans & Sabel 2012, Steiniger & Hunter in press).

Web mapping has also proved its value in disseminating information with the goal of improved public health. For instance, web maps have been developed for mapping and sharing information on diseases and outbreaks (Freifeld et al 2008, Gao et al 2008, Brownstein et al 2009, Brooker et al 2010), for mapping the range and abundance of disease vectors (Hay et al 2010), and for developing public health decision support systems (Driedget et al 2007).

3 Review of web mapping platforms

This report focuses on existing static and dynamic web mapping platforms. A static web map is considered here the digital equivalent of a paper map, with no animation or interactivity. A dynamic web map, on the other hand, is defined as any map in which the user can manipulate the display of the map, from simply zooming and panning on the map to querying the data displayed. The characteristics of the web maps reviewed in this report range from basic cartographic elements and functions to complex functionalities.

3.1 Definitions of cartographic elements and functionalities

The following elements and functions were inspected for each of the mapping platforms:

- Adding label: describes whether the user can add text labels to the map;
- Buffer: describes whether the user can define a spatial buffer on the map;
- Change layout: describes whether the user can change the legend, e.g., the transparency and legend colors;
- Compare: describes whether two or more separate maps can be displayed at the same time, enabling the viewer to visualize and compare, e.g., a data layer at different locations or time periods;
- Draw: describes whether the user can draw points, lines, or polygons;
- Dynamic map: defined here as a map which can be manipulated by the user;
- Full screen option: enables the user to display maps in full screen mode (the map then takes up the entire window);
- Grid: describes whether grid marks or grid lines are displayed on the map;
- Identify: describes whether the user can retrieve information about features at a specific location by clicking on that portion of the map;
- Legend: describes whether a legend is provided, listing the symbols used on the map and what they mean;
- Locator map: describes whether a locator map is provided, showing the location of a particular geographic area within a larger geographical context with which the reader can be expected to be familiar;
- Overlay: describes whether the user can turn on/off individual data layers to combine two or more layers;
- Print/save: describes whether the user can print or save the map, e.g., as PDF, JPEG, or other format;
- Query: describes whether queries can be performed;
- Raster: describes whether or not raster layers are used, i.e., images made up of pixels (e.g., satellite images);
- Scale: describes whether a scale of the map (in verbal, numeric, or graphic form) is provided;
- Static map: defined here as a map which cannot be manipulated by the user;
- Time animation: allows the user to view how certain indicators change over time;
- Vector: describes whether or not vector layers are used, i.e., files made up of points, lines, and/or polygons (e.g., outlines of countries, roads and rivers, cities);
- Zoom/pan: describes whether the user can zoom in and out and pan/move the map by clicking on the map and dragging in any direction you want to go (up and down as well as left and right).

3.2 Selection of web mapping platforms

We selected a number of static and dynamic web maps, with special focus on the NTDs mentioned in Gates Project Document (Table 1) and some other relevant NTDs (Table 2). However, dynamic NTD mapping platforms were relatively scarce and, therefore, we broadened our focus to include non-NTD mapping platforms and even non-health platforms as well. The offered functionalities of the NTD and non-NTD mapping platforms are discussed in detail in sections 3.3 and 3.4, respectively. An overview of these functionalities is provided in section 3.5.

Table 1. NTD platforms mentioned in Gates Project Document

Mapping initiative	NTDs ¹	Agency ²	Sources of data	Description of platform
Global Neglected Tropical Diseases Database	Sch, STH Other NTDs in progress	Swiss TPH	Structured searches of published and unpublished sources	Bibliographical database, tabular form, including information on location, year, ages, and prevalence No mapping platform currently available
African Programme for Onchocerciasis Control	Oncho, loiasis	WHO	Field surveys using REMO or RAPLOA	Downloadable, static country level maps of oncho and <i>Loa loa</i> distribution that identify areas requiring community-directed treatment with ivermectin
USAID NTD Treatment Maps	LF, Sch, Oncho, STH, Tr	NTD Control Program (RTI)	Treatment data reported by country grantees to the NTD Control Program	Downloadable, static country level maps of USAID supported treatments of LF, Oncho, Sch, STH, and Tr
Global Atlas on Trachoma and Trichiasis	Tr	LSHTM and ITI	Structured searches of literature and unpublished data from program managers	Downloadable, static country level maps of the distribution of active trachoma in children under 10 years and trichiasis in adults ≥ 15 years
International Coalition for Trachoma Control	Tr	ICTC	SAFE activities as reported by NGOs	Downloadable, static country level maps of implementation of SAFE components
Atlas of the Global Distribution of Schistosomiasis	Sch	WHO	Published and unpublished sources	Static country maps showing presence/absence of Sch
Global Atlas of Helminth Infection	STH, Sch LF in progress	LSHTM	Structured searches of published and unpublished sources	Downloadable, static country level maps of survey data, predictive prevalence, and districts requiring mass drug administration
Preventive Chemotherapy and Transmission Control Databank	LF, STH, Sch, Tr	WHO	Country PCT data as officially reported to WHO	Static country profiles including estimates of populations at risk, population requiring PC, and programme coverage. Dynamic mapping by country. Country level tabular summaries and maps can be downloaded

¹ LF=lymphatic filariasis; Oncho=onchocerciasis; Sch=schistosomiasis; STH=soil-transmitted helminthiasis; Tr=trachoma

² ICTC=International Coalition for Trachoma Control; ITI=International Trachoma Initiative; LSHTM=London School of Hygiene & Tropical Medicine; RTI=Research Triangle Institute; Swiss TPH=Swiss Tropical and Public Health Institute; WHO=World Health Organization

Table 2. Data platforms related to other NTDs (not mentioned in Gates Project Document)

Mapping initiative	NTDs ¹	Agency ²	Sources of data	Description of platform
WHO	Cy	WHO	WHO 2010b	Static map of countries and areas at risk of cysticercosis, 2009
WHO	Chagas	WHO	WHO 2010b	Static map. Distribution of cases of <i>Trypanosoma cruzi</i> infection, based on official estimates and status of vector transmission, worldwide, 2006–2009
WHO	Ech	WHO	WHO 2010b	Static map of the distribution of <i>Echinococcus granulosus</i> and cystic echinococcosis worldwide, 2009
WHO	Yaws	WHO		The current status is being assessed
Rabnet	Human & animal rabies	WHO	Country-level and admin. level 1 data. Data entry restricted to designated national rabies focal points	Planned to generate interactive maps and graphs using human and animal rabies data No mapping platform currently available
Atlas of human African trypanosomiasis	HAT	WHO	Village-level data from SSNCPs, NGOs and research institutes	Downloadable, static maps of HAT foci
Chagas Research Map Repository	Chagas	Chagas Disease Foundation	Research institutes	Interactive map showing research sites
Leishmaniasis e-compendium	Leish	WHO	Peer reviewed literature	Interactive maps showing research studies on Leishmaniasis epidemiology
DengueMap	Dengue	Boston Children's Hospital	A variety of electronic sources	Interactive maps on disease outbreak Identical to HealthMap (§ 3.4.8)
Online Dracunculiasis Atlas	Dr	WHO	Community-level data reported to WHO by national programmes	Interactive, downloadable map of certification status of dracunculiasis eradication and epidemiological status of endemic countries Identical to PCT platform (§ 3.3.11)
Global Buruli Ulcer Initiative	BU	WHO	Community-level data using standardized forms, reported to WHO	Interactive, downloadable map of the number of new cases of Buruli ulcer reported, 2010 Identical to PCT platform (§ 3.3.11)
Global Health Observatory Leprosy	Leprosy	WHO	Data reported to WHO	Interactive, downloadable maps showing prevalence rates and new cases detection rates Identical to PCT platform (§ 3.3.11)

¹BU=Buruli ulcer; Cy=cysticercosis; Dr=dracunculiasis; Ech=echinococcosis; HAT=human African trypanosomiasis; Leish=leishmaniasis

²WHO=World Health Organization

3.3 NTD web mapping platforms

3.3.1 *Rapid Epidemiological Mapping for Onchocerciasis*

Organization: World Health Organization (WHO), Geneva

URL: <http://www.who.int/apoc/countries/en/>

Key reference: WHO 1998; Noma et al. 2002

Summary: The African Programme for Onchocerciasis Control (APOC) has made important contributions to NTD mapping. Prior to implementing control, APOC supports each country to implement the Rapid Epidemiological Mapping of Onchocerciasis (REMO) method. REMO was developed by the UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases to rapidly identify priority areas for community-directed treatment with IVM (CDTI). APOC uses REMO not only to visualize the priority areas for mass distribution of IVM, but also permits an estimation of the burden of disease and the total number of individuals to be treated (by overlapping the REMO map with a population map). To date, mapping has been completed in 19 African countries: Angola, Burundi, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Ethiopia, Gabon, Kenya, Liberia, Malawi, Mozambique, Nigeria, Rwanda, Sudan, Uganda, and the United Republic of Tanzania. As countries have been successful in controlling onchocerciasis, many are now conducting new REMO assessments to provide updated maps.

A list of all countries for which REMO maps have been made is available on the WHO website. By clicking on the country's name, the user obtains the country profile, which consists of a fact sheet and the REMO map. The fact sheet has a simple layout with headings and bullet points, providing information on key epidemiological indicators (onchocerciasis status, people affected, IVM coverage). The REMO maps are static maps that display the areas where CDTI is needed.

3.3.1.1 Key features of the REMO maps

Geographic coverage: Africa, 19 countries.

Locator map: No.

Map grid: Yes.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the map can be downloaded as JPEG.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

3.3.2 *Rapid Assessment Procedure for Loiasis*

Organization: World Health Organization (WHO), Geneva

URL: <http://www.who.int/apoc/raploa/en/>

Key reference: Takougang et al. 2002; Zouré et al. 2011

Summary: The Rapid Assessment Procedure for Loiasis (RAPLOA) was developed by the UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases with financial support from APOC. The tool uses a simple questionnaire on the history of visible worms (*Loa loa*) moving in the lower part of the eye, to predict whether or not loiasis is present at high levels in a community. It is important to assess the level of loiasis endemicity in a community before initiating mass treatment with IVM against onchocerciasis as severe adverse reactions may occur in people who have a high intensity of *Loa loa* infection. Thus, the RAPLOA maps help in the planning of community-directed treatment with IVM, by identifying areas where IVM treatment for onchocerciasis can be safely implemented.

Mapping was completed in the onchocerciasis and non-onchocerciasis endemic areas in 11 African countries: Angola, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Ethiopia, Gabon, Nigeria, and Sudan. These prevalence maps are based on survey data collected in more than 4,700 villages. Kriging was used to produce spatially smoothed contour maps of the interpolated prevalence of eye worm and the predictive probability that the prevalence exceeds 40 %, which is a good predictor of high-risk communities.

Similar to the APOC platform, a list of all countries for which RAPLOA maps have been made is available on the WHO website. Click on the country's name to get the static RAPLOA map.

3.3.2.1 Key features of the RAPLOA maps

Geographic coverage: Africa, 11 countries.

Locator map: No.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the maps can be downloaded as JPEG.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

3.3.3 USAID NTD treatment maps

Organization: NTD Control Program, RTI International

URL: <http://ntd.rti.org/about/index.cfm?fuseaction=static&label=about>

Summary: This 5-year program is designed to support national NTD control and elimination programs and to integrate and scale up delivery of preventive chemotherapy for lymphatic filariasis, schistosomiasis, trachoma, onchocerciasis, and soil-transmitted helminthiasis.

3.3.3.1 Key features of the USAID NTD treatment maps

Geographic coverage: 16 countries worldwide, mostly Africa.

Locator map: Yes.

Map grid: No.

Scale: Yes.



Legend: Yes.

Print/save: Yes, the maps can be downloaded as PNG.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

Comments: Information is available on the data collected (reporting forms downloadable).

3.3.4 Global Atlas on Trachoma and Trichiasis

Organization: London School of Hygiene and Tropical Medicine, the International Trachoma Initiative at The Task Force for Global Health (Atlanta), and The Carter Center (Atlanta).

URL: www.trachomaatlas.org

Key reference: Polack et al. 2005; Smith et al. 2011

Summary: The overall goal of this Atlas is to provide up-to-date, publicly accessible information on the geographical distribution of active trachoma in children (< 10 years) and trichiasis in adults (> 15 years), which is essential for appropriate targeting of the SAFE strategy. Although many countries have insufficient data to generate reliable estimates of disease burden, the Atlas provides the most detailed information currently available on the global distribution of trachoma.

Polack et al. (2005) describe how the database was built. In summary, data from population-based prevalence surveys (conducted after 1980 for trichiasis and after 1987 for active trachoma) were derived from formal and grey literature and entered in Excel. Data included the source of the data, location (site name, type of location, region and district, and coordinates), year of sampling, survey methodology, characteristics of the surveyed population, and number of individuals examined and graded positive. District-level data were available for 33 of the 55 endemic countries (139 surveys in total), highlighting the paucity of reliable data in many trachoma-endemic countries. Because of differences in sampling methodology, time periods, and age groups surveyed, prevalence data were banded into broad groups to limit overinterpretation of the data. The following bands were selected for their relevance to WHO control recommendations: for active trachoma in children 0, 0-10, 10-30, and >30 % and for trichiasis in adults 0, 0-1, 1-5, and >5 %.

Maps showing the district-level prevalence estimates of active trachoma and trichiasis are available online. Maps can be searched for by country (55 in total), infection type, and map type using the drop-down list at the top of the page or by selecting a continent and country on the interactive map on the main page. The actual database with the underlying data is not publicly accessible.

3.3.4.1 Key features of the Global Atlas on Trachoma and Trichiasis

Geographic coverage: Global, 55 countries.

Locator map: Yes.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the maps can be downloaded as JPEG or PDF.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

Comments: Good information is available on the data collected, the methodology, and how to interpret the maps.

3.3.5 International Coalition for Trachoma Control

Organization: International Coalition for Trachoma Control

URL: www.trachomacoalition.org

Summary: Building on the Global Atlas on Trachoma and Trichiasis, the International Coalition for Trachoma Control (ICTC) has recently developed a sister website that shows the districts where components of the SAFE strategy to eliminate blinding trachoma are currently being implemented by non-governmental organizations and national partners. Maps have been constructed for 19 African countries and 1 Asian country. Together, the two trachoma cartographic resources provide a comprehensive picture of the contemporary burden of trachoma and current progress towards the goal of its elimination.

Static maps are available online on four topics: (i) surgery for trichiasis, (ii) antibiotic distribution, (iii) facial cleanliness, and (iv) environmental change. These maps can be searched for by country using a drop-down list at the top of the web page. The underlying data is not publicly available online.

3.3.5.1 Key features of the ICTC maps

Geographic coverage: 19 African countries and 1 Asian country.

Locator map: Yes.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the maps can be downloaded as JPEG or PDF.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

3.3.6 Atlas of the Global Distribution of Schistosomiasis

Organization: World Health Organization (WHO), Geneva

URL: <http://www.who.int/wormcontrol/documents/maps/en>

Key reference: Doumenge et al. 1987

Summary: In 1987, the bilingual (English and French) Atlas of the Global Distribution of Schistosomiasis was published, which shows the occurrence of human schistosomiasis infection in 76 countries worldwide, along with tables of observed prevalence for each study location. The Atlas is a compendium of data on the epidemiology of schistosomiasis, which

was derived from epidemiological surveys reported in the available scientific literature, official reports from Member States, WHO Headquarters and Regional Offices and intergovernmental agencies such as OCCGE (Organisation de Coordination et de Coopération pour la lutte contre les Grandes Endémies) and OCEAC (Organisation de Coordination pour la lutte contre les Endémies en Afrique Centrale), and unpublished data.

On the WHO website, there is a list of the available country maps. Clicking on a country name brings you to the right chapter of the atlas (PDF document) in which a brief overview of the situation is presented: (i) the distribution of the infection as derived from epidemiological surveys; (ii) the climatic and physical conditions in the country, and (iii) any human activities, for example, the building of dams or irrigation systems which increase infection rates. A static map (scanned paper map) is presented, which shows the natural hydrographic network, the elevations of the terrain, general topographical features, and the administrative and geographical boundaries. The presence or absence of schistosomiasis is represented by small or large circles of different colors according to the species type (*S. haematobium*, *S. mansoni*, *S. intercalatum*, *S. japonicum*). Each map is accompanied by a table, which recapitulates all the data available by administrative regions and localities according to: the prevalence of one or more forms of schistosomiasis, the technique used to examine the urine or faeces, the characteristics of the population examined, and the bibliographic reference from which the data has been extracted.

3.3.6.1 Key features of the Schistosomiasis Atlas

Geographic coverage: Global, 76 countries.

Locator map: Yes.

Map grid: Yes.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the entire Atlas chapter can be downloaded as PDF.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

Comments: Good information is available on the data collected, the methodology, and how to interpret the maps.

3.3.7 Global Atlas of Helminth Infections

Organization: London School of Hygiene & Tropical Medicine and the Partnership for Child Development at Imperial College, London.

URL: www.thiswormyworld.org

Key reference: Brooker et al. 2000, 2009, 2010

Summary: The overall goal of The Global Atlas of Helminth Infection (GAHI) is to provide an open access, global information resource on the distribution of soil-transmitted helminthiasis and schistosomiasis, with the specific aims of (i) describing the global distribution and prevalence of infection of each species (*Ascaris lumbricoides*, *Trichuris trichiura*, *Necator americanus*, *Ancylostoma duodenale*, *Schistosoma haematonium*, *S. mansoni*) and (ii) highlighting geographical areas for which further survey information is

required. Due to the diagnostic method typically used in field surveys, the two species of hookworm (*S. haematonium* and *S. mansoni*) were not distinguished.

Estimates of infection prevalence were derived from cross-sectional surveys conducted since 1980 (formal and grey literature) and then collated into a single database according to specified inclusion criteria. Where multiple surveys of the same location were carried out at different times, the most recent results were used. Abstracted data included details on the source of the data, location of survey, characteristics of the surveyed population, survey methodology, number of individuals sampled, and the number positive for each helminth species. The eligible surveys were geo-positioned using electronic sources and imported into Arc Map 9.3 (ERSI, USA). Point estimates of prevalence were categorized according to WHO prevalence thresholds used to denote treatment requirements: <0.1, 0.1–19.9, 20–49.9, and 50–100 %. To date, more than 10,000 surveys have been identified, catalogued, and mapped. The potential usefulness of the data to identify at-risk populations for which data are scarce, is enhanced by using Bayesian model-based geostatistics to predict the prevalence of infection with each species in as yet unsurveyed areas.

Per country, general country data (demographic variables, population at risk) is available online, together with three types of static maps: (i) survey data maps, showing the prevalence of worm infection based on survey data; (ii) predictive risk maps (for STH only), showing the probability that infection warrants mass treatment according to recommended WHO thresholds; and (iii) control planning maps (for STH only), showing which districts require mass treatment or where further surveys are probably needed. Additionally, all mapped references and sources for geographical data are listed. Maps can be searched for by country, infection type, and map type using the drop-down list at the top of the web page. The user can also click on the (dynamic) map to view or download the available maps. The actual database with the underlying data is not publicly accessible.

3.3.7.1 Key features of the GAHI maps

Geographic coverage: Global.

Locator map: Yes.

Map grid: Yes.

Scale: Yes.

Legend: Yes.

Print/save: Yes, the maps can be downloaded as JPEG or PDF.

Detailed data downloadable: yes, data aggregated at the school or community level can be downloaded in csv format for Kenya, Eritrea, Uganda, and Burundi. Individual-level data can be downloaded for a selection of research studies (Brazil community survey, Uganda community survey, and Kenya school survey).

Dynamic: No.

Time to load: less than 30 seconds.

Comments: Good information is available on the data collected, the methodology, and how to interpret the maps.

3.3.8 The Atlas of human African trypanosomiasis

Organization: World Health Organization, Geneva

URL: http://www.who.int/trypanosomiasis_african/

Key reference: Cecchi et al. 2009; Simarro et al. 2010

Summary: The World Health Organization committed itself to supporting human African trypanosomiasis (HAT) endemic countries in their efforts to remove the disease as a public health problem. For this reason WHO launched the HAT Atlas initiative, jointly implemented with the Food and Agriculture Organization of the United Nations (FAO), in the framework of the Programme Against African Trypanosomiasis. The central feature of the Atlas of HAT is the mapping at village level of all new cases of HAT reported during a ten-year period (2000–2009). Reports by National Sleeping Sickness Control Programmes, non-governmental organizations, and research institutes were collated and the relevant epidemiological data were entered in a database, thus incorporating the results of active screening of over 2.2 million people and cases detected in health care facilities engaged in passive surveillance. Mapping has been completed in 23 out of 25 sub-Saharan countries that reported on HAT occurrence in 2000–2009: Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Ghana, Guinea, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sudan, Togo, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe. Work is in progress to process data from the two remaining countries having reported on HAT in the study period: Angola and the Democratic Republic of the Congo. Eight countries listed as endemic have provided no report on the HAT situation in 2000–2009: Burundi, Ethiopia, Gambia, Guinea-Bissau, Liberia, Niger, Senegal, and Sierra Leone.

As the most evident application of the Atlas of HAT, maps of the foci in disease-endemic countries are available online. The website presents a list of all HAT endemic countries. You can click on a country you are interested in, and a map of the country showing HAT foci will appear. You can also click on the name of the focus you are interested in to get the zoomed map.

3.3.8.1 Key features of the HAT maps

Geographic coverage: Africa, 23 out of 25 endemic countries.

Locator map: Yes.

Map grid: Yes.

Scale: Yes.

Legend: Yes.

Print/save: Yes, you can download the maps as PDF.

Detailed data downloadable: No.

Dynamic: No.

Time to load: less than 30 seconds.

Comments: The text on the maps is hard to read.

3.3.9 Chagas Research Map Repository

Organization: the Chagas Disease Foundation, Watkinsville

URL: <http://www.chagasfound.org>

Summary: The main objectives of the Chagas Disease Foundation are to (i) educate and train researchers, (ii) disseminate information on control and prevention, and (iii) develop policies for the sustainable prevention of Chagas disease. The Chagas Research Map Repository is an online interactive map showing the research efforts on Chagas disease and provides a

platform for identifying potential research collaborators. Researchers can enter their research site online, which provides them the ability to advertise and promote their work to the research and global community.

3.3.9.1 Key features of the Chagas Research Map Repository

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: Yes.

Legend: No.

Print/save: No.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: Yes. Click on the map markers to get information related to Chagas research.
- Query: Yes. Basic search options (country, study leader, and additional search terms).
- Vector: Yes.
- Raster: Yes.
- Overlay: No. The data layer is displayed on top of Google Maps (Map, Satellite, and Hybrid) but cannot be switched on or off.
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: Little information provided.

3.3.10 *Leishmaniasis e-compendium*

Organization: World Health Organization (WHO), Geneva

URL: <http://apps.who.int/tools/geoserver/www/ecompendium/index.html>

Key reference: Hendrickx et al. 2010

Summary: The e-compendium is a geo-referenced bibliographical tool that compiles peer-reviewed literature on leishmaniasis epidemiology from the past 25 years, made available online. The e-compendium is not a risk map. It records the regions in which research efforts were undertaken and for which peer-reviewed articles were identified. The goal is to offer a brief summary of the epidemiological situation by country using a user-friendly interface in an interactive mapping format. The e-compendium currently contains data on the Mediterranean basin, the African continent, Central America, South America, the Indian subcontinent, and Southeast Asia. It is being developed in collaboration between the department of Neglected Tropical Diseases at WHO and two EU-funded consortia (Leishmed and Leishrisk). The site uses GeoServer as map server.

3.3.10.1 Key features of the e-compendium

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: No.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Clicking on a triangular icon on the map gives the relevant bibliographical information and a weblink to its abstract or full article if freely available. Or this is how it is supposed to work. Currently, it does not work.
- Query: No.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. The map consists of 5 layers: reservoirs, sandflies, HIV-coinfection, cutaneous leishmaniasis, and visceral leishmaniasis. These layers can be turned on and off and are displayed on top of a base layer (Google Maps: Hybrid, Streets, Satellite, or Physical).
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: Good instructions on how to use the site. No detailed information is given on the methodology or data. The map is very basic and of low-quality (e.g., lack of cartographic elements, overlapping labels,...). Furthermore, it is not possible to zoom out to the global view.

3.3.11 Preventive Chemotherapy and Transmission Control Databank

Organization: World Health Organization (WHO), Geneva

URL: http://www.who.int/neglected_diseases/preventive_chemotherapy/databank/

Key reference: Yajima et al. 2012

Summary: The Preventive Chemotherapy and Transmission Control (PCT) databank contains compilations of historical and current information on disease-specific epidemiological situations, the geographical overlapping of NTDs, and progress of preventive chemotherapy (PC) implementation. WHO has developed a Joint Reporting Form (JRF) to standardize and structure the data collection (WHO 2010a). A major drawback of the database is that it does not typically receive data from other sources such as non-governmental organizations, which often provide deworming treatment to at-risk populations as a component of child/community health campaigns. Adding NGO treatment data (e.g., the [Global NGO](#)

[Deworming Inventory](#)) to the databank is therefore a prerequisite in order to get a more complete picture of deworming activities around the world.

The method of data collection and compilation used to establish the PCT databank is explained in Yajima et al. (2012). In summary, epidemiological data are gathered for each country and the population requiring PC is calculated for each disease by taking into consideration the areas where the disease is transmitted and the age groups targeted for treatment. Subsequently, the data are validated and entered in the database using Microsoft Access. A number of disease-specific epidemiological indicators are then calculated for each implementation unit (IU), usually the second-level administrative unit or district. The most recent data on prevalence of infection available at district level are used to analyze the epidemiological situation. If no data from district level are available, but data from surveys implemented in lower administrative units are available, then the average of the different surveys is used to estimate the district-level data (i.e., a cause for data quality concern). For each country, disease-specific maps are produced based on the level of endemicity in each IU using the geographic information system software (ArcGIS v9, ESRI, USA). The implementation data of each country is then summarized to present the national-scale coverage of a series of disease-specific indicators (e.g., programme coverage). Major updates of the PCT databank are published every quarter.

Three online outputs are available: (i) the PCT country profiles, which provide a summary of the most recent epidemiological and implementation data available in the PCT databank for each NTD-endemic country, (ii) the annual update in the Weekly Epidemiological Record on the progress of PC interventions of specific NTDs, and (iii) a dynamic mapping platform. The online PCT databank has currently four modules, covering lymphatic filariasis, soil-transmitted helminthiasis, schistosomiasis, and trachoma. Country level tabular summaries and maps are downloadable. Key indicators are: number of people requiring PC, number of people targeted, reported number of people treated, and drug coverage. The data can be searched for by WHO region, country, or reporting year. An important drawback of the online PCT databank is that the data are presented at country level and, thus, cannot capture the fine-scale heterogeneity of infection patterns and tend to overestimate the numbers of individuals requiring treatment, leading to program inefficiencies.

3.3.11.1 Key features of the online PCT maps

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: Yes, the map can be printed or exported as JPEG or PNG.

Detailed data downloadable: No.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map to get the indicator's value.
- Query: Yes. Basic. Data can be searched for by region, country, and year.
- Vector: Yes.
- Raster: No.
- Overlay: No.

- Compare: No. It is not possible to view two or more maps at the same time. However, the time bar is very useful to see the indicator's value change over time. Furthermore, several countries can be selected at the same time, which makes it possible to compare values using the 'time series chart' and 'bar chart'.
- Advanced spatio-temporal animation: Yes (time animation).
- Buffering: No.
- Adding labels: Yes.
- Draw points/lines/polygons: Yes. There is a 'shape editor window' that allows the user to add custom shapes to the map.
- Change legend/layout: Yes. Users can change the transparency, the legend colors, and the breakpoints between colors (the number of divisions and distribution by quantile, equal interval, natural breaks, continuous, and standard deviation).

Time to load: less than 30 seconds.

Comments: Information on how to use the online PCT databank is provided. The same mapping platform (with the same layout and functionalities) has also been used for other NTDs: [dracunculiasis](#), [buruli ulcer](#), [human African trypanosomiasis](#), and [leprosy](#).

3.4 Non-NTD web mapping platforms

3.4.1 Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique

Organization: The Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA) initiative is non-institutional and runs in the spirit of an open collaboration. A group of African scientists, based at institutions across the continent, work co-operatively towards achieving the overall objectives.

URL: <http://www.mara.org.za>

Key reference: MARA/ARMA 1998

Summary: The MARA/ARMA collaboration was initiated to provide an Atlas of malaria for Africa, containing relevant information for rational and targeted implementation of malaria control. The main objectives of this initiative was to (i) map malaria risk in Africa through collection of published and unpublished malaria data and through spatial modeling of malaria distribution, seasonality, and endemicity, (ii) disseminate relevant information to national and international decision makers and other end users, and (iii) develop capacity in malaria/health GIS. To date, over 10,000 data points have been collected from published and unpublished sources. Several static maps have been produced: prevalence maps based on empirical malaria prevalence data, and theoretical maps based on long-term climate data. The theoretical maps include distribution maps (showing the potential distribution of stable malaria transmission), endemic/epidemic risk areas (re-classification of the distribution maps), duration of malaria transmission season, and start/end of transmission season. Other maps are: population distribution, administrative boundaries, and topographical features. Additionally, the distribution maps were combined with the population distribution map to estimate the number of people at risk of malaria (in table format).

On the MARA website, a table is available with an overview of all available static maps. Click on the name of a map to download it.

3.4.1.1 Key features of the MARA/ARMA maps

Geographic coverage: Africa.



Locator map: No.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: Yes. Maps can be downloaded as PDF or Windows Bitmap (BMP).

Dynamic: No.

Time to load: less than 30 seconds.

Comments: There is good information on how the maps were constructed and how they should be interpreted. It would have been nice to be able to search for a specific map by country and map type (e.g., the Malaria Atlas Project). The website looks very outdated.

3.4.2 *Bacille Calmette-Guérin World Atlas*

Organization: McGill University, Montreal

URL: <http://www.bcgatlas.org/>

Key reference: Zwerling et al. 2011

Summary: The Bacille Calmette-Guérin (BCG) vaccine continues to be the only vaccine used to prevent tuberculosis. Despite nearly a century of use, BCG remains controversial, with known variations in BCG substrains, vaccine efficacy, policies, and practices across the world. The interactive website provides detailed information on current and past BCG policies and practices for over 180 countries. The atlas is designed to be a useful resource for clinicians, policymakers and researchers alike, providing information that may be helpful for better interpretation of TB diagnostic tests as well as in the design of novel TB vaccines that are under development.

The user can select a country from the drop-down box, or use the interactive map on the website to select and view all available information concerning that country's BCG policies and practices.

3.4.2.1 Key features of the BCG World Atlas

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: No.

Print/save: No.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover over the map to see the country's name, and click on the map to get more information regarding BCG.
- Query: No.
- Vector: Yes.

- Raster: No.
- Overlay: No.
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: The interactive map solely serves to select a country. Low quality, basic interface.

3.4.3 International Travel and Health Interactive Map

Organization: World Health Organization, Geneva

URL: <http://apps.who.int/ithmap/>

Summary: The International Travel and Health Interactive (ITHI) map provides information on health risks for travellers.

3.4.3.1 Key features of the ITHI map

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: No.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: No.
- Query: No.
- Vector: Yes.
- Raster: No.
- Overlay: Yes.
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: Instructions on how to use the interactive map are provided. However, no detailed information is given on the methodology or data. Very basic, low-quality interface.

3.4.4 AIDSInfo

Organization: UNAIDS

URL: <http://www.unaids.org/en/dataanalysis/datatools/aidsinfo/>

Summary: AIDSInfo is an online data visualization and dissemination tool to facilitate the use of AIDS related data in countries and globally. AIDSInfo is populated with multisectoral HIV data, including AIDS spending, epidemiological estimates, country-reported programmatic data, and National Composite Policy Index responses from government and civil society. AIDSInfo's data visualization capabilities allow for rapid production of charts, tables, and interactive maps, along with export of data and graphics to numerous formats.

3.4.4.1 Key features of the AIDSInfo map

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: No. A link can be copied to the current map so the map view can be accessed again in the future, but it is not possible to print or export the map. The underlying data can be downloaded as Excel file.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map to get the indicator's value.
- Query: Yes, but very basic (only for time period).
- Vector: Yes.
- Raster: No.
- Overlay: No.
- Compare: No. The tool does not allow the user to view two or more maps at the same time. However, the time bar is very useful to see the indicator's value change over time.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: There is no information on how to use the site or how to interpret the data, but the interactive map is quite easy to use. There is an 'information button', but it doesn't work. The website looks very modern. The maps are rather basic (for instance, there is no base layer).

3.4.5 Malaria Atlas Project

Organization: The Malaria Atlas Project (MAP) is a joint project between the Malaria Public Health & Epidemiology Group, Centre for Geographic Medicine, Kenya and the Spatial



Ecology & Epidemiology Group, University of Oxford, UK, with collaborating nodes in Americas and Asia Pacific Region.

URL: www.map.ox.ac.uk

Key reference: Hay and Snow 2006; Guerra et al. 2007

Summary: The Malaria Atlas Project aims to disseminate free, accurate, and up-to-date information on malaria and associated topics, organized on a geographical basis. The MAP database contains more than 3,000 spatially independent parasite rate estimates from community surveys conducted since 1985. These include more than 3,000 *Plasmodium falciparum* and more than 1,000 *Plasmodium vivax* estimates in 74 countries.

On the website, you can find a suite of static maps and estimates relating to three topics: (i) malaria risk, (ii) inherited blood disorders, and (iii) mosquito vectors. Maps can be searched for by region, country, topic, and subtopic (depending on topic). The web site also allows the user to visualize the data more interactively through 'kmz' files that enable the data to be displayed in Google Earth. The interactive data explorer allows the user to visualize the geographical spread of data points available for download. Two data types are available: parasite rate and *Anopheles* dominant vector species (DVS) occurrence.

3.4.5.1 Key features of the MAP

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: The static maps can be downloaded as PDF or PNG. The interactive map cannot be printed or saved. The database can be downloaded as Excel File.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: No.
- Query: Yes. Basic. Data can be searched for by country and vector species.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. Several layers can be displayed on top of the Google Earth base layer: endemicity, country boundaries, available surveys, confidential surveys, and presence and absence points.
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: Information is provided on how to use the site and the interactive data explorer. Also, additional information is provided regarding the data, malaria vectors, and control measures.



3.4.6 Atlas of Geographic Variation within the Medicare Program

Organization: ArcGIS Resource Center

URL: http://atlas.esri.com/Atlas/CMS_Atlas.html

Summary: The Atlas combines four years (2007–2010) of spending, utilization, patient quality, and patient safety data and looks at important changes over time specific to key indicators. The data displayed are provided by the Centers for Medicare & Medicaid Services for the Institute of Medicine's (IOM) Geographic Variation Data Request.

Interactive maps are nested in three themes (standardized costs, what drives costs, and 30-day readmissions) for easy access and exploration. The units displayed on the map are called Hospital Referral Regions. Arrows on the legend box allow you to move from map to map and theme to theme.

3.4.6.1 Key features of the Medicare Program maps

Geographic coverage: United States.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: No.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Click on the map to open a pop-up with additional details, and comparison year-over-year.
- Query: Yes. Basic. There is a 'search' function to find a location on the map.
- Vector: Yes.
- Raster: No.
- Overlay: No.
- Compare: No. However, clicking on the map gives you a year-over-year comparison chart (but no map).
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: There are no instructions on how to use the site but the site is quite self-explanatory. Information on each data layer is provided. The colors used are not very attractive though.

3.4.7 The World Heritage List

Organization: UNESCO

URL: <http://whc.unesco.org/en/list>

Summary: The World Heritage List includes 962 properties forming part of the cultural and natural heritage. To be included on the list, sites must be of outstanding universal value and meet at least one out of ten selection criteria.

The interactive map includes 745 cultural, 188 natural, and 29 mixed properties in 157 States Parties.

3.4.7.1 Key features of the World Heritage List

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes. However, the legend is provided on the website, not on the map itself.

Print/save: No.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map marker to get the name and a picture of the heritage site. Both name and picture are in fact a link to a web page with a description of the site.
- Query: Basic. There are several filter options (country, year inscribed, category, theme,...). Additionally, you can also filter on 'criteria' to find those sites that satisfy one or more criteria, which could be considered a more advanced filter option.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: 1-2 minutes.

Comments: No information on how to use the map, but the site is quite self-explanatory.

3.4.8 HealthMap

Organization: Boston Children's Hospital

URL: <http://healthmap.org/en/>

Key reference: Brownstein and Freifeld 2007; Freifeld et al. 2008

Summary: HealthMap is a freely accessible, automated electronic information system for querying, filtering, integrating, and visualizing unstructured reports on global disease outbreaks. HealthMap acquires data from a variety of electronic sources, including news through the Google News aggregator, expert-curated accounts such as ProMED Mail, and validated official alerts such as World Health Organization announcements. Through the use of automated text processing algorithms, the system classifies alerts by location and disease and then overlays them on an interactive geographic map, thereby bringing structure to an

information flow that would otherwise be overwhelming to the user or obscure important and urgent elements.

3.4.8.1 Key features of HealthMap

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: No.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Click on a map marker to see information.
- Query: Advanced. There are several filter options. Data can also be filtered by time period, which can be defined by the user. Also, to limit information overload and provide focused news of immediate interest, data can be filtered by category (outbreaks, warnings, international significance).
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. Disease outbreak data are displayed on top of a base layer (Google Maps: Terrain or Satellite). The advanced search option allows you to display the diseases, locations, and feeds you are interested in by clicking on or off the checkboxes to make layers visible or not.
- Compare: No.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: No information on how to use HealthMap is provided. The layout is similar to the Leishmaniasis e-compendium, WWARN, and the World Heritage List, but HealthMap is probably the most contemporary looking map. Information overload could be a problem though. An interactive map of global dengue activity ([DengueMap](#)) was collaboratively developed and hosted by HealthMap.

3.4.9 World-Wide Antimalarial Resistance Network

Organization: The World-Wide Antimalarial Resistance Network (WWARN) brings together a broad range of expertise from across the global malaria community. The core team is comprised of the UK-based Secretariat, six scientific groups and three regional centers across Asia and Africa.

URL: <http://www.wwarn.org/>

Key reference: Bacon et al. 2007; Barnes et al. 2007; Plowe et al. 2007; Price et al. 2007; Sibley et al. 2007

Summary: WWARN provides a global platform for exchanging scientific and public health information on the emergence and spread of malaria drug resistance. It is a dynamic mapping tool to visualize the results of studies of antimalarial drug resistance in four areas: (i) clinical trials, (ii) pharmacology, (iii) *in vitro* drug testing, and (iv) molecular markers of resistance.

3.4.9.1 Key features of WWARN

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: Yes.

Legend: Yes. The legend also includes information on the active filters.

Print/save: No.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map marker to view limited study information. Click a map marker to get a study summary. To learn more about that particular study, click on "Investigate Study" to get a pop-up screen with additional details such as bibliographical information, study design, and results.
- Query: Advanced. The data can be filtered by group, component, treatment type, data type, species, and context. Also, a year range can be defined by the user.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. Data on drug resistance can be turned on and off and are displayed on top of a base layer (Google maps: Maps, Satellite, or Terrain).
- Compare: No.
- Advanced spatio-temporal animation: No. However, a new feature is being trialled: dynamic motion charts have been created to illustrate the Day 28 cure rate data across multiple years in two countries.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: less than 30 seconds.

Comments: How to use the site and how it was created is explained. Metadata is provided. The maps are similar to the maps of the Leishmaniasis e-compendium, but look much nicer (for instance, no redundant country labels).

3.4.10 Interactive Atlas of Heart Disease and Stroke

Organization: Centers for Disease Control and Prevention (CDC), Division for Heart Disease and Stroke Prevention

URL: <http://apps.nccd.cdc.gov/DHDSAtlas/>

Summary: Allows users to view interactive maps of several outcome types (e.g., mortality) of several health indicators associated with heart disease and stroke (e.g., heart failure) for the

United States. Maps can be viewed in three ways: (i) state maps with county level data, (ii) US maps with state data, or (iii) US maps with county data. Determinants of health — including a range of social, economic, and environmental factors that can influence health status — and health services can also be viewed. Health care facilities, roads, cities, and boundaries can be added with an overlay. Additionally, reports can be generated to view data associated with a specific county, state, or selection of counties or states. Reports display information for the chosen health indicator, and reports for individual counties also display demographic and socio-environmental data.

3.4.10.1 Key features of the Atlas of Heart Disease and Stroke

Geographic coverage: United States.

Locator map: No.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: Yes. Maps can be printed or saved as an image (PNG). Also, a link can be copied to the current map so the map view can be accessed again in the future. Reports can be printed, but cannot be saved in a spreadsheet format.

Dynamic: Yes.

- Full screen option: No.
- Zoom/pan: Yes. There is also a 'quick zoom' button to zoom directly to one of four pre-defined locations, a 'search' option to search for a certain county or state, and a 'selection' tool to select a group of counties using a selection box, shape, or point.
- Identify tool: Yes. By clicking on the map, you get the value and range, and also a link to the County Report and Summary Report.
- Query: Basic. The system uses pre-defined filters. Maps can be displayed by race/ethnicity, gender, age range (35+, 65+, under 75), and/or time period. These options vary depending on the health indicator and outcome type that is selected. In addition, users are able to display data that are spatially smoothed, thereby displaying stable health outcomes for more counties with small populations.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. The site has several layers that can be turned on or off. Overlay features are hospital locations, Community Health Center locations, roads, cities, congressional districts, hospital referral regions, and state boundaries that can be displayed on top of a thematic map to allow users of the map to orient themselves and/or provide information on access to health care.
- Compare: Yes. Two maps can be viewed side-by-side, which enables the user to compare two health care indicators for the same or different locations.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: No.

Time to load: 1-2 minutes.

Comments: Good information on methodology and how to use the site. Data sources and International Classification of Diseases codes are provided. The website and the maps look very nice.

3.4.11 STATcompiler

Organization: Monitoring and Evaluation to Assess and Use Results Demographic and Health Surveys (MEASURE DHS)

URL: <http://www.statcompiler.com>

Summary: STATcompiler allows users to visualize and explore hundreds of demographic and health indicators across more than 70 countries (developing and middle-income countries) in tables, column charts, line graphs, scatterplots, and dynamic maps.

On the site's welcome page, the user has to choose one of these categories. By clicking on the 'Thematic Map' button, a pop-up screen appears that asks the user to filter by region and country. A second pop-up screen appears, allowing the user to select one or more indicators. Data can be presented at national and sub-national level.

3.4.11.1 Key features of STATcompiler

Geographic coverage: Global.

Locator map: No.

Map grid: No.

Scale: Yes.

Legend: Yes.

Print/save: Yes. Maps can be exported as PNG file.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map to get the indicator's value.
- Query: Basic filter options: country and year.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. The thematic layers can be turned on and off for each country, and there are some overlay maps: mountain terrain, and country and city labels.
- Compare: No. The tool does not allow the user to view two or more maps at the same time. However, the time bar is very useful to see the indicator's value change over time.
- Advanced spatio-temporal animation: No.
- Buffering: No.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: Yes. Users can change legend colors and modify the breakpoints between colors (the number of divisions and distribution by quantile, equal interval, and natural breaks).

Time to load: less than 30 seconds.

Comments: Only limited information provided, but the site is quite intuitive. The maps are rather basic and the country and city labels certainly are not an enhancement.

3.4.12 School District Demographics System Map Viewer

Organization: National Center for Education Statistics (NCES), US Department of Education

URL: <http://nces.ed.gov/>

Summary: The School District Demographics System (SDDS) map viewer is a web-based resource that provides data for describing and analysing characteristics of school districts, children, and education. Data has been derived from the 2000 Decennial Census and American Community Survey (ACS), Common Core of Data (CCD), and National Assessment of Education (NAEP) Math and Reading. The SDDS Map Viewer is an online, highly interactive mapping tool, which allows users to view the school district demographic data and state-level NAEP data. School statistics can also be viewed on top of these thematic maps.

3.4.12.1 Key features of SDDS Map Viewer

Geographic coverage: United States.

Locator map: Yes.

Map grid: No.

Scale: No.

Legend: Yes.

Print/save: Yes. Maps can be printed, saved on clipboard, or exported as PDF or JPEG. Tabular data can be saved as CSV. There is also an option to export spatial data as ESRI shapefile, but it doesn't work.

Dynamic: Yes.

- Full screen option: Yes.
- Zoom/pan: Yes.
- Identify tool: Yes. Hover the cursor over the map to see information.
- Query: Advanced. There are several filter options. For each data layer, the user can select the range of values he is interested in.
- Vector: Yes.
- Raster: Yes.
- Overlay: Yes. Layers are displayed on top of a base layer (Streets, Satellite, Topo, or Canvas). The thematic layers can be turned on and off, as well as several overlay maps: congressional districts, school district boundaries, and school boundaries.
- Compare: Yes. Up to four states can be selected. Several theme layers and years can be compared side-by-side. However, this considerably slows down the site.
- Advanced spatio-temporal animation: No.
- Buffering: Yes. With the "Select Schools" map tool, you can create a buffer on the map. The buffer results are then displayed for the selected public schools.
- Adding labels: No.
- Draw points/lines/polygons: No.
- Change legend/layout: Yes. Users can change legend colors and the transparency of the thematic maps. Also, the 'data format tab' allows users to modify the breakpoints between colors. The basic variations are number of divisions, color ramp, and distribution by quantile, equal interval, and natural breaks. Users may also set custom breaks.

Time to load: 1-2 minutes.

Comments: Very interactive. However, only limited information provided on how to use Map Viewer and it may take some time for novice users to figure out how it works.



3.5 Overview of functionalities

Table 3 provides an overview of the static and dynamic mapping platforms discussed in sections 3.3 and 3.4 and the functionalities they offer.

	Locator map	Grid	Scale	Legend	Print/save	Coordinates	Full screen	Zoom/pan	Identify	Query	Vector	Raster	Overlay	Compare	Animation	Buffer	Adding label	Draw	Alter layout
Static mapping platforms																			
• Rapid Assessment Procedure for Loiasis (RAPLOA)	✗	✗	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Rapid Epidemiological Mapping for Onchocerciasis (REMO)	✗	✓	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Global Atlas on Trachoma and Trichiasis	✓	✗	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• International Coalition for Trachoma Control (ICTC)	✓	✗	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Atlas of the Global Distribution of Schistosomiasis	✓	✓	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Global Atlas of Helminth Infections (GAHI)	✓	✓	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Atlas of human African trypanosomiasis (HAT)	✓	✓	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Mapping Malaria Risk in Africa (MARA/ARMA)	✗	✗	✓	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dynamic mapping platforms																			
• Chagas Research Map Repository	✗	✗	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
• Leishmaniasis e-compendium	✗	✗	✗	✓	✗	✗	✓	✓	✓	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗
• PCT Databank	✗	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✗	✗	✗	✓	✗	✓	✓	✓
• BCG World Atlas	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
• International Travel and Health Interactive Map	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗
• AIDSinfo	✗	✗	✗	✓	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
• Malaria Atlas Project (MAP)	✗	✗	✗	✓	✗	✗	✗	✓	✗	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
• Atlas of Geographic Variation within the Medicare Program	✗	✗	✗	✓	✗	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
• The World Heritage List	✗	✗	✗	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
• HealthMap	✗	✗	✗	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
• World-Wide Antimalarial Resistance network	✗	✗	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
• Interactive Atlas of Heart Disease and Stroke	✗	✗	✗	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
• STATcompiler	✗	✗	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓
• SDSS Map Viewer	✓	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓

Table 3. Overview of functionalities of the static and dynamic mapping platforms reviewed (✗ functionality not present, ✓ functionality present)

4 Recommendations regarding functionalities

An important step during the design of a system is to rank and prioritize the different functionalities. Traditionally, the different functionalities are categorized into four categories:

- M- MUST have this (functionality is mandatory);
- S - SHOULD have this if at all possible (important but can be omitted);
- C - COULD have this if this does not affect anything else (optional functionality);
- W- WON'T have this time but would like in future.

The functionalities are usually assigned to one of the categories by combining user's identified needs on the one hand and expert opinion on the other hand. The Avia-GIS functionality assessment takes into consideration what the ideal world system would be, using the user's input, and then contrasts this to the technical and time constraints.

4.1 Ranking of functionalities of web maps

Based on Table 3, a proxy for the user needs was calculated in the following manner: if the functionality was present, it received a score of 1; if the functionality was absent, the score was 0. These scores were summed across all the systems and then averaged. This yields the user score (US).

In the next step, for each of the functionality, Avia-GIS opinion based on the ideal system and the technological complexity and thus potential budget and time constraints was reflected in the Avia-GIS score (AS).

The two scores were then combined to obtain the overall score (OS) per functionality. In the final step, the overall score is categorized according to:

- Score between 0.75 - 1.00 are considered as MUST
- Score between 0.50 - 0.75 are considered as SHOULD
- Score between 0.25 - 0.50 are considered as COULD
- Score between 0.00 - 0.25 are considered as WON'T

The scores are summarized in Table 4.

4.2 Mandatory functionalities

All maps must be able to display vector data (US=1, AS=1, OS=1). The vector data, such as administrative boundaries, road network, hydrological network, populated places, and schools, will provide the necessary backdrop for the map-viewer.

Similarly, the web map must be able to visualize raster data (US=0.64, AS=1, OS=0.82). While this functionality received a lower score by the users, Avia-GIS considers this integration necessary, as many maps indicating probability of presence of a pathogen are only available as raster data.

Basic display functionalities of both vector data and raster data such as zooming/panning (US=1, AS=1, OS=1), providing a legend (US=0.91, AS=1, OS=0.95), and identifying (US=0.86, AS=1, OS=0.93) are mandatory functions for any map to be provided via a web browser.

Table 4. Ranking scores for identified functionalities

Functionality	User Score (US)	Avia-GIS score (AS)	Overall Score (OS)	Category
Vector	1.00	1.00	1.00	MUST
Zoom/pan	1.00	1.00	1.00	MUST
Legend	0.91	1.00	0.95	MUST
Identify	0.86	1.00	0.93	MUST
Raster	0.64	1.00	0.82	MUST
Query	0.79	0.70	0.74	SHOULD
Scale	0.55	0.90	0.72	SHOULD
Overlay	0.64	0.70	0.67	SHOULD
Print/save	0.55	0.80	0.67	SHOULD
Full screen	0.50	0.80	0.65	SHOULD
Grid	0.18	0.90	0.54	SHOULD
Locator map	0.27	0.80	0.54	SHOULD
Change layout	0.21	0.70	0.46	COULD
Buffer	0.07	0.50	0.29	COULD
Add label	0.07	0.50	0.29	COULD
Compare	0.14	0.20	0.17	WON'T
Animation	0.07	0.10	0.09	WON'T
Draw	0.07	0.10	0.09	WON'T
Coordinates	0.00	0.10	0.05	WON'T

4.3 Important functionalities

The important functionalities can be grouped in the following groups:

- Adding map items
- Map querying
- Map printing

Adding map items such as scale, grid, and locator map received a lower score by the users (Scale: US=0.55, AS=0.9, OS=0.72; Grid: US=0.18, AS=0.90, OS=0.54; Locator map: US=0.27, AS=0.80, OS=0.54). Especially the scale is important: if the users want to assess distances between features for example, this is impossible if no scale is present on the map.

Map querying receives a similar score by the users and Avia-GIS (US=0.79, AS=0.7, OS=0.74) and provides a great added value in comparison to static maps: it allows the users to use simple queries based on spatial object attributes to select for example administrative units (for vector data) or pixels (for raster data). A special case of map querying is turning layers on and off (i.e., making them visible or invisible) to combine two or more layers. This allows the user to interactively investigate patterns in the various layers contained in the map. Because it greatly increases the interactivity level, the scores given by Avia-GIS and the users are both quite high (US=0.64, AS=0.7, OS=0.67).

Map printing should be present beyond the printing functionality of the web browser. A map with all its added map items and layers with the respective visibility, as specified by the user, should be shown in a separate window ready for print out (US=0.55, AS=0.8, OS=0.67).

4.4 Optional functionalities

Buffer functionalities can be considered as a dynamic functionality. Dynamic functionalities are defined as those that will trigger a spatial operation with user-defined parameters. This will in return trigger a spatial process on a server, which will then return the output.

In the case of the buffer functionality the user parameters would be:

- Radius of the buffer
- User-drawn feature to be used for buffer calculation

These dynamic functionalities have a high complexity and are therefore scored lower by Avia-GIS (AS=0.5) and by the users (US=0.07), but could be approximated and moved up the priority ladder.

The approximation would involve preparing buffer outputs for a limited set of predefined radii that the user can select from. The spatial output data layers are prepared beforehand so the buffer operation requires only loading from the server.

Labeling of features is also optional (US=0.07, AS=0.5, OS=0.29). While the technical challenges are low, text labels may overcrowd the displayed maps and thus decrease user friendliness.

Changing the layout received a very low score (OS=0.46) mainly due to the low US (US=0.21). Avia-GIS considers this functionality, which is tightly linked to the printing functionality, to be very important and has attributed a much higher score (AS=0.7). Based on these results, Avia-GIS would propose to move this functionality into the category of important functionalities.

4.5 Other functionalities

Both for vector and raster data, space-time analysis including Compare and Time Series are a very useful tool. However, this should only be considered at a later stage because this:

- Requires the presence of an extensive historic archive that can be used to generate the time series
- Needs dedicated software environment that is currently not readily available

Any development on this may jeopardize the development of all other identified functionalities and consequently, the scores for these functionalities are very low (Compare: US=0.14, AS=0.2, OS=0.17; Animation: US=0.07, AS=0.10, OS=0.09).

5 Development of a web mapping application

In the next sections, we provide a brief description of a general web mapping architecture and discuss some important OGC standards such as the Web Map Service (WMS) standard, Styled Layer Descriptor (SLD), Symbology Encoding (SE), and Filter Encoding (FE). We will also outline what is meant by free and open source software and explain three common software licenses. Finally, we discuss the project requirements and provide an overview of the major web map servers that can be employed to meet these requirements.

5.1 Web mapping architecture

A general web mapping architecture typically comprises of three components: the client side, server side, and data side (Sarup & Shukla 2012, Steiniger & Hunter 2012) (Figure 1). The client refers to the web browser (e.g., Mozilla Firefox, Safari, Internet Explorer) running on the end user's computer. On the server side, a web server (e.g., Apache) and a map server

(e.g., MapServer, GeoServer, Deegree, ArcGIS for Server) are required. The latter forms the core of the client-server architecture: the web map server includes functionality to query spatial databases, projection support, integration with other geographic libraries, as well as vector and raster support. The communication between client and server is based on standard Internet protocols. The client requests a map by sending an inquiry to the web server. The web server directs the inquiry to the map server that evaluates it, searches for the relevant geographical data in a spatial database, and generates the corresponding map. The map is then sent to the web browser, where it is integrated into a HTML page and sent back to the client browser. The client-server architecture requires a permanent connection to the Internet to permit a constant stream of information to be exchanged between client and server. As occasions may occur when this is not the case, contingencies to resolve this limitation are required. One possible solution involves developing caching, whereby events and interactions are stored on the client and transmitted to the server when connection is available. Software such as MapCache and GeoWebCache work by prefetching map content that is most likely to be requested next by the user. This significantly improves performance of the interface and the response time of map interactions. Additionally, we could define software libraries as further components, which provide specific functionality such as data conversion (e.g., GDAL/OGR, GeoTools), coordinate transformations (e.g., Proj4), data display (e.g., OpenLayers), or data analysis (e.g., GEOS, JTS).

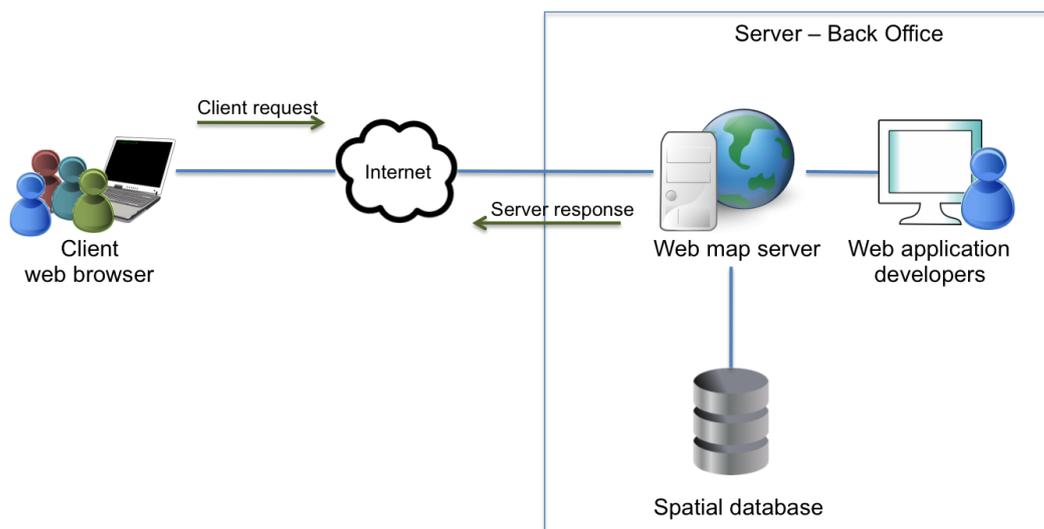


Figure 1. A general client-server architecture showing the connection between client webserver, web map server, and spatial database

5.2 OGC web mapping standards

The Open Geospatial Consortium (OGC) is an organization that has defined several open standards for the processing and exchange of geospatial data. The idea behind it is to allow interoperability between different servers and clients, thus allowing users to use software and data from a wide range of providers without costly and complex data conversion procedures. This should lower development costs, avoid duplication of effort, and prevent vendor lock-in (Walker et al. 2008). The Web Map Service (WMS) standard is the most widely used OGC standard to get maps of geospatial data and gain detailed information on specific features shown on the map. A map is defined here as the portrayal of geographic information as a digital image file that can be displayed in a web browser application (Open Geospatial Consortium Inc. 2006a). WMS-produced maps are generally rendered in a pictorial format such as PNG, GIF, or JPEG, or occasionally as vector-based graphical elements in

Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (WebCGM) formats. Two or more maps can be overlaid to produce a composite map by using image formats that support transparent backgrounds (e.g., GIF or PNG). Individual maps can be requested from different servers, thus enabling the creation of a network of distributed map servers from which clients can build customized maps. Unlike a Web Feature Service (WFS) and a Web Coverage Service (WCS), a WMS is not intended to provide access to the original unprocessed data behind the map. In order to request and manipulate the actual data, a WFS or WCS is needed for vector data and raster data, respectively. However, WFS and WCS may take a very long time to load since a lot of data has to be transmitted. Given the increasingly rapid development of software, this may change in the (near) future, but for the moment WCS and WFS are still quite unreliable as an operational service.

5.2.1 Web Map Service (WMS)

The WMS specifies a number of operations: GetCapabilities, GetMap, and GetFeatureInfo. The first two operations are mandatory for any WMS server (basic WMS). The GetCapabilities operation returns an XML document describing the service and the data collections from which clients may request maps while the GetMap operation returns a map of geospatial data. A queryable WMS not only satisfies these two requirements for a basic WMS but also supports the GetFeatureInfo operation, which returns the spatial and attribute data for particular features on a map. These operations can be invoked using a web browser by submitting requests in the form of Uniform Resource Locators (URLs). The content of such URLs depends on which operation is requested. For instance, when requesting a map via the GetMap operation, the URL indicates what information is to be shown on the map, what portion of the Earth is to be mapped, the desired coordinate reference system, transparency, and the width, height, and format of the output image. A core parameter of the GetMap operation is which style should appear on the map. A finite number of very basic, predefined styles are offered to display the individual map layers. The basic WMS deals with layers and styles that are “known” to the WMS and that are identified by name, so users have no way of defining their own styling rules.

Optionally, the WMS can be extended to allow user-defined symbolization of feature and coverage data instead of working with named layers and styles, using the OGC Styled Layer Descriptor (Open Geospatial Consortium Inc. 2007) and the OGC Symbology Encoding (Open Geospatial Consortium Inc. 2006b). The Styled Layer Descriptor (SLD) is an XML encoding that provides a map-styling protocol for communicating with a WMS about the appearance of individual map layers. Symbology Encoding (SE) is an XML styling language that the client and server can both understand. In brief, an SLD-enabled WMS retrieves features from a WFS and applies explicit styling information provided by the user in order to render a map, which makes it possible to style features differently depending on an attribute. For an SLD-enabled WMS, a number of additional operations apply: DescribeLayer returns an XML document describing the feature types of the layers specified in the request in order to set up an SLD, and GetLegendGraphic provides a mechanism for generating legend graphics as images.

A WMS also offers the capability to restrict which features are displayed by using the OGC Filter Encoding (FE) specification (Open Geospatial Consortium Inc. 2010). This standard defines both XML and KVP encodings for query and filter expressions in order to select a subset of features based upon specific attributes.

5.2.2 Component versus integrated WMS

If a WMS is to symbolize features using a user-defined symbolization, it is necessary to identify the source of the feature data. For example a WMS might symbolize feature or coverage data stored in a remote Web Feature Server (WFS) or Web Coverage Server (WCS), or it might only be able to symbolize data from a specific default feature/coverage store. There

is a wide range of possible relationships between a WMS and a WFS/WCS. In this regard, a distinction should be made between component and integrated servers (Open Geospatial Consortium Inc. 2007). Component servers are designed to be loosely coupled and work in any combination, whereas integrated servers are tightly coupled and can only work in particular configurations.

A component WMS has the following characteristics:

- It has no predefined named layers/styles but supports user-defined layers/styles;
- It only supports the WMS interface;
- It can symbolize feature/coverage data from any WFS/WCS to which it is directed and any GML data that is provided inline;
- Component servers using feature data are called Feature Portrayal Services, while those using coverage data are called Coverage Portrayal Services.

An integrated WMS has these characteristics:

- It has predefined named layers/styles;
- It only supports user-defined styles being applied to predefined named layers;
- It supports the WMS-interface and the GetCapabilities and the DescribeFeatureType requests of the WFS interface or the GetCapabilities and DescribeCoverage requests of the WCS interface;
- It can only symbolize feature/coverage data from the WFS/WCS with which it is integrated.

5.3 Free and open source software (FOSS) and FOSS licenses

The term ‘free and open source software’ is a combination of the terms ‘free software’ and ‘open source software’ that are often used synonymously (Steiniger & Hunter, in press). Definitions of the terms ‘free software’ and ‘open source software’ have been formulated by, respectively, the Free Software Foundation (FSF; <http://www.fsf.org>) and the Open Source Initiative (OSI; <http://opensource.org>). In essence, it means that the users of FOSS have the following four freedoms: (1) the freedom to run the program for any purpose, (2) the freedom to study and adapt the program for own needs, (3) the freedom to redistribute copies, and (4) the freedom to distribute copies of modified versions.

Table5: Differences between proprietary and FOSS licenses (modified after Perens 1999 and Steiniger & Bocher 2009)

License	Can be mixed with proprietary software	Modifications can be taken private and not returned to the public	Release changes under a different license
GPL	No	No	No
LGPL	Yes	Only original source must be returned to public	No
MIT	Yes	Yes	Yes
Proprietary	-	No	No

An important precondition is that the source code must be delivered with the software itself, i.e., not only the binary, executable files but also the program code written in the specific programming language. Both the FSF and the OSI have approved several licenses, the best-

known being the GNU General Public License (GPL), the GNU Lesser General Public License (LGPL), and the Massachusetts Institute of Technology (MIT) License (Table 5).

The GPL is by far the most frequently used FOSS license. It allows using the program for your own purpose and allows copying and distributing the program as long as the GPL copyright notice is contained. The program and modified versions can be distributed only if the source code is attached or available. Also, the GPL allows modifying the source code and distributing these versions, provided the modifications are documented and the modified versions are licensed under the GPL. These restrictions prevent not contributing back to the community, but also bring problems if GPL-licensed software should be coupled with proprietary software.

To avoid these complications, the Lesser GPL has been introduced, which is a “weaker” version of the GPL. Here, the license terms are placed only on the program itself but not on other software that merely links with the program. The MIT License, also known as the X11 License, is a permissive FOSS license that grants the software end-user the right to deal in the software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and sell copies of the software. This license permits the reuse within proprietary software, provided all copies of the licensed software include a copy of the MIT License terms. Such proprietary software retains its proprietary nature. Thus, the MIT License is considered a more liberal software license than the GPL.

5.4 Project requirements concerning web map server

In order to serve the project’s needs, the following criteria were specified:

- The system must be capable of addressing at least the mandatory and important functionalities that were identified in sections 4.2 and 4.3;
- The system must support OGC standards to guarantee interoperability. We focus on the WMS-interface for producing web maps, since WFS and WCS are still prone to many bugs and errors;
- The system must be cross-platform on the client side, i.e., work on multiple operating systems such as Windows, Linux, and Mac OS X, to allow the widest accessibility;
- The system must be highly scalable to handle data growth and to meet an increasing number of end-users;
- The system must support the most commonly used spatial databases, such as PostgreSQL with PostGIS extension, MySQL Spatial, and Oracle Spatial;
- The presence of an active user and developer community is required, providing support through mailing lists, websites, online forums, and other forms of communication.

5.5 Major FOSS and proprietary web map servers

A range of proprietary and free and open source software has been developed to generate maps on the World Wide Web. In this report, we focus on four popular web map servers that are reliable and mature enough for a web mapping application: one proprietary server (ArcGIS Server 10.1) and three FOSS servers (MapServer 6.2.0, GeoServer 2.2.2, and Deegree 3.1.2). ArcGIS for Server is without a doubt the most commonly used proprietary software for web mapping applications. MapServer and GeoServer are the two most commonly FOSS servers used and widely supported by a large community. All four web map servers fulfill the above-mentioned project requirements (section 5.4). They support the OGC WMS standard, support PostGIS, and support a range of input and output formats. In combination with OpenLayers, an open source Ajax mapping library used for integrating WMS maps into web pages, they are capable of addressing the following functionalities:

- Visualize both raster and vector data;
- Overlay: turn on/off individual map layers to generate a user-defined map;
- Display map elements (legend, scale, grid, and locator map);
- Zoom/pan;
- Identify features on the map with an 'identify tool';
- Query the map's attribute data;
- Display the map full screen;
- Print/save the map.

We have chosen OpenLayers for building rich web-based geographic applications, as this library is already implemented in GeoServer and it constitutes the main open source alternative to the equivalent proprietary tools. Below, we provide a description of the main characteristics of the proposed web map servers and discuss the major advantages and disadvantages. An overview of their main characteristics is provided in Table 6.

5.5.1 ArcGIS for Server

ESRI's ArcGIS for Server is a proprietary Internet application service, used to extend the functionality of ArcGIS Desktop software to a browser environment. The latest version (ArcGIS for Server 10.1, released on June 11, 2012) runs on Windows and Linux, but not on Mac OS X (on the server side). Its main advantages and disadvantages, according to Di Pasquale et al. (2012) and Lienert et al. (2012), are:

Advantages:

- supports numerous OGC standards including WMS, WFS, WCS, SLD, and Filter Encoding;
- using ArcSDE, it handles spatial databases such as Oracle Spatial, IBM DB2, and PostGIS;
- data is delivered in different formats; raster (JPEG, PNG, or GIF, no additional client software is required) or vector (requires a Java plug-in on the client side, using ArcXML);
- offers a variety of geo-processing functionality;
- 3D output;
- tile caching;
- anti-aliasing;
- on-the-fly projection.

Disadvantages:

- converters are needed for using non-ESRI data sources;
- depends on third party software products for being used as middleware.

5.5.2 MapServer

MapServer is free and open source software released under the Massachusetts Institute of Technology (MIT) License. The latest version of MapServer (version 6.2.0, released on November 14, 2012) is written in C/C++ and runs on all major platforms including Windows, Linux, Solaris, and Mac OS X. The "map file" (an ASCII text file) is the basic configuration file for data access and styling. Its main advantages and disadvantages, according to Di Pasquale et al. (2012) and Lienert et al. (2012), are:

Advantages:

- supports numerous OGC standards including WMS, WFS, WCS, SLD, and Filter Encoding;
- supports ESRI ArcSDE and Oracle Spatial;



- supports several input and output raster and vector data formats. More data formats are available through the Geospatial Data Abstraction Library (GDAL/OGR), the most widely used open source geospatial data access library that supports over 50 raster and 20 vector formats through GDAL and OGR, respectively;
- tile caching (MapCache);
- anti-aliasing;
- on-the-fly projection;
- scale dependent feature drawing and application execution;
- feature labeling including label collision mediation;
- fully customizable template driven output;
- use of TrueType fonts;
- map element automation (scalebar, locator map, and legend);
- thematic mapping using logical or regular expression-based classes;
- support for popular scripting and development environments, e.g., PHP, Python, Perl, Ruby, Java, and .NET;
- visualization of data in form of pie and bar charts;
- a large user and developer community.

Disadvantages:

- SLD is not fully supported.

5.5.3 GeoServer

GeoServer is free and open source software written in Java and is released under the GNU General Public License (GPL) version 2.0. The latest version of GeoServer (version 2.2.2, released on November 23, 2012) runs on all major platforms including Windows, Linux, and Mac OS X. GeoServer is built on Geotools, an open source Java GIS toolkit, and natively supports the integration with OpenLayers, an open source mapping library making map generation quick and easy. Its main advantages, according to Di Pasquale et al. (2012), Lienert et al. (2012), and Sarup & Shukla 2012) are:

Advantages:

- supports numerous OGC standards, including WMS, WFS, WCS, SLD, and Filter Encoding;
- can handle data from most common spatial databases (e.g., PostGIS, ESRI ArcSDE, MySQL, DB2);
- supports several file formats through GeoServer extensions and GDAL/OGR;
- tile caching (GeoWebCache);
- anti-aliasing;
- on-the-fly projection;
- has an integrated security concept for user management;
- Google Earth support for overlays using keyhole markup language (KML);
- a large user and developer community.

5.5.4 Deegree

The latest version of Deegree (version 3.1.2, released on February 25, 2012) is free and open source software written in Java that works on all major operating systems including Windows, Linux, Solaris, and Mac OS X. It is released under the GNU Lesser General Public License (LGPL). Its main advantages and disadvantages, according to Di Pasquale et al. (2012), are:

- supports several OGC standards, such as WMS, WFS, SLD, and Filter Encoding;
- supports PostGIS and Oracle Spatial;



- tile caching;
- anti-aliasing;
- scale dependent styling;
- high-quality and large-size print outputs through Web Map Print Service.

Disadvantages:

- does not support as many data formats as the other web servers discussed in this report;
- on-the-fly projection for WFS only;
- an active user community, although not as large as MapServer and GeoServer.

5.5.5 Which map server to choose?

Reviewing previous studies, discussion forums and the websites of the proposed map servers, it was deemed that the functionality between the four systems was quite similar and they would all provide the level of functionality required for the project. However, each of these four systems comes with its advantages and disadvantages. An important decision to make is whether proprietary or free and open source software should be used. Esri's ArcGIS for Server is without a doubt the most popular proprietary software used to generate web maps. This map server provides a high-quality graphical user interface and GIS functionality, but has the disadvantage of being costly and non-customizable. When the needs are to simply serve map data on the web, this can be accomplished using free and open source software. This places a higher demand on developer skills, but avoids high license fees and provides full, permanent control over software development. Open source software not only has the advantage of low cost, but also provides an enterprise or organization the ability to provide a fully open source web mapping application with unrestricted use, i.e., the possibility of using the software on any computer one desires but also without any restriction to the number of installations. MapServer and GeoServer both support WMS, WFS, WCS, SLD, and Filter encoding and form a robust platform for web mapping that will provide the level of functionality required for the project. Since they implement more OGC standards than Deegree, they show greater adherence to OGC standards and, consequently, higher future viability. Moreover, MapServer and GeoServer are more mature systems, support more file formats, provide high-quality user documentation, and have a larger user and developer community than Deegree. Both MapServer and GeoServer have proven their value in web mapping applications. Since GeoServer provides a graphical user interface, it is easier and quicker to load data into WMS compared to MapServer. Additionally, GeoServer fully supports SLD for styling and, unlike MapServer, supports several SLD extensions to create cartographic symbolization. The quality of output of web maps in GeoServer is also higher. MapServer, on the other hand, is easier to combine with proprietary software because of its MIT License. Based on the literature, forums, and own experience, it is deemed that both MapServer and GeoServer are evenly matched.

	Client/Server side	Identified Requirement	ESRI ArcGIS Server	GeoServer	MapServer	Deegree
Website			www.esri.com	www.geoserver.org	www.mapserver.org	www.deegree.org
Latest version			10.1 (June 11, 2012)	2.2.2 (Nov 23, 2012)	6.2.0 (Nov 14, 2012)	3.1.2 (Feb 25, 2012)
License type			Proprietary	GPL v.2.0	MIT License	LGPL
Written in				Java	C/C++	Java
Operating systems	Server	Accessibility	Windows, Linux	Windows, Linux, Mac OSX	Windows, Linux, Mac OSX, Solaris	Windows, Linux, Mac OSX, Solaris
Supported services	Server	WMS/WFS/WCS	WMS 1.0.0, 1.1.0, 1.1.1 & 1.3.0; WFS 1.0.0 & 1.1.0; WCS 1.0.0, 1.1.0 & 1.1.1	WMS 1.0, 1.1.1 & 1.3.0; WFS 1.0.0, 1.1.0 & 2.0; WCS 1.0.0, 1.1.0 & 1.1.1.1	WMS 1.0.0, 1.1.0, 1.1.1 & 1.3.0; WFS 1.0.0 & 1.1.0; WCS 1.0.0, 1.1.0, 2.0.0 & 2.0.1	WMS 1.1.1, 1.3.0; WFS 1.0.0, 1.1.0 & 2.0.0
Support for SLD	Server	Raster/Vector visualisation	Yes (SLD 1.0)	Yes (SLD 1.0, SLD 1.1.0), with extensions	Yes (SLD 1.0.0), without extensions	Yes (SLD 1.0.0, SLD 1.1.0), with extensions
Support for FE	Client/Server	Attribute query	Yes	Yes (FE 1.0 & 1.1)	Yes (FE 1.0.0)	Yes (FE 1.0 & 1.1)
On-the-fly projection	Server	Raster/Vector visualisation	Yes	Yes	Yes	No
Tile caching	Server	Raster visualisation	Yes	Yes	Yes	Yes
Anti-aliasing	Server	Vector visualisation	Yes	Yes	Yes	Yes

Table 2: Overview of proprietary and free and open source software map servers

	Client/Server side	Identified Requirement	ESRI ArcGIS Server	GeoServer	MapServer	Deegree
Supported vector data formats	Server	Data input	Shapefile	Shapefile and many others through extensions (GML, VPF) and OGR	Shapefile, Inline, and others through OGR	Shapefile, GML
Supported raster data formats	Server	Data input	TIFF, GeoTIFF, JPEG, GIF, PNG	ArcGrid, ImageMosaic, GTOP030, GeoTIFF, TIFF, WorldImages and others through extensions (e.g., Oracle Georaster, JDBC, Custom JDBC Access, Postgis Raster, ImagePyramid, Image Mosaic) and GDAL	TIFF/GeoTIFF, JPEG, GIF, PNG, Erdas.LAN/GIS and others through GDAL	GeoTIFF
Supported spatial databases	Server	Data input	PostGIS, Oracle Spatial, DB2, Informix Dynamic Server, Microsoft SQL Server, Microsoft SQL Server Express, Netezza, Microsoft SQL Azure	PostGIS, and others through extensions (DB2, H2, ArcSDE, Microsoft SQL Server, MySQL, Oracle Spatial, Teradata) and OGR	ArcSDE, Oracle Spatial and others through OGR	PostGIS, Oracle Spatial
Supported image formats	Client	Data output	JPEG, PNG, PNG8, GIF, PDF, EPS, SVG, CSV	KML, KMZ, JPEG, GIF, SVG, TIFF, TIFF8, GeoTIFF, GeoTIFF8, PNG, PNG8, BMP, ArcGrid, OpenLayers, PDF, AtomPub, GeoRSS, GeoJSON, CSV, GML2, GML3, Shapefile	PNG, GIF, JPEG, TIFF/GeoTIFF, Erdas.LAN/GIS, SCG, PDF, KML, GML2, GML3, Shapefile and others through GDAL/OGR	TIFF/GeoTIFF, GIF, PNG, JPEG, BMP, GML2
Active user/developer community	Server	Maintenance support	Yes. Standard support included with purchase of a software product license	Yes	Yes	Yes

Table 2 (continued): Overview of proprietary and free and open source software map server

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ANNEX 1 – Glossary of terms

- AJAX – A web development technique used for creating interactive web applications. It allows creating web pages that dynamically update without forcing a page to reload;
- Aliasing: the jagged appearance of curves and diagonal lines in a raster image. Aliasing becomes more apparent as the size of the raster pixels is increased or the resolution of the image is decreased;
- API – An interface that allows two independent computer programs to communicate with each other;
- Architecture – The internal design of an application or software package; the way software or hardware components are organized into a functioning unit;
- ArcSDE – Is part of the ArcGIS platform and is the data server between ArcGIS and relational databases;
- Attribute – Nonspatial information about a geographic feature in a GIS, usually stored in a table and linked to the feature by a unique identifier;
- Base layer – A data layer in a GIS to which all other layers are geometrically referenced;
- Buffer – A zone around a map feature measured in units of distance or time;
- C/C++ – Programming languages;
- Cache – A temporary storage area for frequently accessed data;
- Client – A computer or application that remotely accesses a service on another computer (known as a server) using a network;
- Desktop GIS – Mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations;
- ESRI – Company that provides mapping software;
- Feature – A representation of a real-world object on a map;
- Filter Encoding – an XML encoding for expressing filters for spatial queries in order to select a subset of features based upon specific attributes;
- GeoTools – An open source Java library that provides tools for geospatial data;
- GML – The XML grammar defined by the Open Geospatial Consortium to express geographical features;
- HTML – The predominant markup language for web pages;
- HTTP – A text-based protocol that is commonly used for transferring information across the Internet;
- Identify – A tool that, when applied to a feature (by clicking it), opens a window showing that feature's attributes;
- Java – Programming language;
- JavaScript – Scripting language often used for Internet applications;
- KML – An XML-based language for describing three-dimensional geospatial data and its display in application programs. KML is comparable to GML;
- Label – descriptive text placed on or near features
- Loose coupling – a relatively unstructured relationship between two software components or programs that work together to process data;
- OpenLayers – open source software to put a dynamic map on a web page;
- Overlay – The process of superimposing layers of geographic data that cover the same area to study the relationship between them;
- Pan – To shift a map image relative to the display window without changing the viewing scale;
- Plug-in – A small software application that extends the functionality of a web browser;

- PostGIS - Extends the PostgreSQL relational database so it can store, query, and manipulate spatial data;
- Query - A request to select features or records from a database;
- Scalable - The ability to grow in size or complexity without showing negative effects;
- Shapefile - ESRI software; a vector data storage format for storing the location, shape, and attributes of geographic features;
- Server - A computer that performs a service to one or more computers or applications (known as clients);
- SLD - an XML schema for describing the appearance (symbolization and coloring) of map layers;
- Tight coupling - A high or complex degree of interconnections between the components within a program or between programs;
- URL - The address of an Internet resource;
- WCS - An Open Geospatial Consortium standard web service for exchanging geospatial data. Coverage refers to continuous spatial data, such as aerial photography, land cover and elevation data;
- WFS - An Open Geospatial Consortium standard for serving geographic features in GML;
- WMS - An Open Geospatial Consortium standard for serving georeferenced map images over the Internet that are generated by a map server;
- XML - A flexible markup language for creating special-purpose markup languages. Its primary purpose is to facilitate sharing of data across different systems;
- Zoom - To display a larger or smaller region of an on-screen map or image.

ANNEX 2 – Acronyms and abbreviations

- AJAX – Asynchronous JavaScript and XML
- API – Application Programmer Interface
- APOC – African Program for Onchocerciasis Control
- BCG – Bacille Calmette-Guérin
- CDTI – Community-Directed Treatment with Ivermectin
- FE – Filter Encoding
- FOSS – Free and Open Source Software
- FSF – Free Software Foundation
- GAHI – Global Atlas of Helminth Infections
- GDAL – Geospatial Data Abstraction Library
- GIF – Graphics Interchange Format
- GML – Geography Markup Language
- GPL – General Public License
- GPS – Global Positioning System
- HAT – atlas of Human African Trypanosomiasis
- HTML – HyperText Markup Language
- ICTC – International Coalition for Trachoma Control
- ITHI map – International Travel and Health Interactive map
- ITI – International Trachoma Initiative
- IVM – Ivermectin
- JPEG – Joint Photographic Experts Group
- JRF – Joint Reporting Form
- KML – Keyhole Markup Language
- KVP – Key-Value Pairs
- LF – lymphatic filariasis
- LGPL – Lesser General Public License
- MARA – Mapping Malaria Risk in Africa
- MDA – Mass Drug Administration
- MIT – Massachusetts Institute of Technology
- NTD – Neglected Tropical Diseases
- OGC – Open Geospatial Consortium
- OSI – Open Source Initiative
- PC – Preventive Chemotherapy
- PCT – Preventive Chemotherapy and Transmission control databank
- PNG – Portable Network Graphics
- RAPLOA – Rapid Mapping of co-infection with Loa-loa
- REMO – Rapid Epidemiological Mapping of Onchocerciasis
- SAFE – Surgery, Antibiotics, Facial cleanliness, and Environmental improvement
- SBD – School-Based Deworming
- SE – Symbology Encoding
- SLD – Styled Layer Descriptor
- SOAP – Simple Object Access Protocol
- STH – Soil-Transmitted Helminthiasis
- SVG – Scalable Vector Graphics
- TIGER – Topologically Integrated Geographic Encoding and Referencing
- URL – Uniform Resource Locator
- WCS – Web Coverage Service
- WebCGM – Web Computer Graphics Metafile
- WFS – Web Feature Service
- WMS – Web Map Service
- XML – eXtensible Markup Language

Methodology for reviewing information systems

- Google search: mapping other NTDs
- Identify key publications describing systems:
- Start at <http://www.thiswormyworld.org/publications>
- Look for publications page on each site
- Select key-refs based on abstracts in PubMed <http://www.ncbi.nlm.nih.gov/pubmed/>
- Establish quantifiable criteria to analyze information systems:
- Data content
- Data quality
- Functionalities
- IT solutions
- Conduct analysis

Methodology for reviewing IT solutions

To achieve this platform, we seek to develop a database-enabled, spatially explicit web framework. Possible features should include: map navigation, such as zooming, panning, and querying map objects; geoprocessing such as generating buffers and performing spatial overlays and analysis; map creation such as drawing of points, lines and polygons on-screen which can then be printed, emailed or downloaded.

At this stage, we do not privilege a particular design or approach and various alternatives will be explored, with a strong emphasis on assessment of technical and operational appropriateness and practical feasibility. An example of one possible option is an open source, object-relational PostgreSQL database (<http://www.postgresql.org>) with a PostGIS spatial extension (<http://postgis.refractions.net>). This coupling allows a queryable database to be linked to the spatial operators and functions of a GIS platform, and in turn, can be linked to an open source interactive mapping application, such as MapServer (<http://mapserver.org>), MapFish (<http://mapfish.org>), Mapstraction (<http://mapstraction.com>) or OpenLayers (<http://www.openlayers.org>). Such an integrated system enables regular audited and authenticated updates from team members via the web and facilitates a queryable database on the website allowing public dissemination of the mapped products. Other possible features include: a Google maps interface to view the underlying data and modeling products; a dynamic interface which permit querying of multiple themes (e.g. geographic and demographic) which can generate customized output in multiple formats. We would also explore how the platform can be linked to the Electronic Data Gathering and Evaluation (EDGE) system developed by the Lymphatic Filariasis Support Center in Atlanta.

A technical report of design options will be prepared with assistance of developers with expertise in open source frameworks.

ANNEX 4 – Baseline tool requirements

NTD data platform

Activity 1.6 – Develop open access NTD data platform → create a web-based, interactive data platform that will enable users to access and process information in new ways, and more specifically:

1. Provide essential open access information source:
 - a. Link to current major mapping platforms and in particular WHO's PCT databank and WHO-AFRO's real-time NTD mapping tool
 - b. Provide regular updates and rapid data access
 - c. Include use of 'semantic web' to explain epidemiological concepts and content
 - d. Enable data gaps identification for evidence-based survey and research investment planning
2. Provide essential input data for a spatial planning tool.
3. OUTPUT = MILESTONE 2: Open access data platform (no specific timing).

Spatial planning tool

Activity 1.7 – Develop a spatial planning tool for SBD and NTD control:

1. Such a tool should:
 - a. Enable the planning and management of program activities according to location and place.
 - b. Enable the integration of available survey data with other information: e.g. economic data (FGAT), disease transmission model predictions.
2. Such a tool should include the following functions:
 - a. Determine the overall burden of STH and other NTDs;
 - b. Identify and prioritize areas requiring MDA;
 - c. Estimate drug needs and financial resources;
 - d. Identify potential areas for co-implementation of control activities;
 - e. Predict likely benefits of interventions;
 - f. Estimate duration of MDA required to achieve program goals and;
 - g. Help define overall strategy.
3. Such a tool should fulfill the following essential criteria:
 - a. The tool must be capable of reliably identifying treatment areas and estimating drug requirement associated with different policy options and resources.
 - b. Different scenarios should be readily compared and stored for future reference.
 - c. The tool must be simple and intuitive to use, with limited training required by users to apply the tool effectively, and where minimal input requirements are placed on the user.

- d. There must be transparency of data resources and calculations in order to enhance confidence in outputs.
 - e. The tool must contain relevant epidemiological, demographic and geographic information, although users should be able to utilize their own data, where available.
 - f. As available information may be insufficient, uncertainty becomes part of the decision making process, and this uncertainty should be able to be quantified.
 - g. The tool should be in open access software format (or linked to Microsoft Excel) and so accessible to as wide an audience as possible.
 - h. The tool should be accessible through standard internet connection, as a web-based tool, or as a stand-alone application.
4. OUTPUT = MILESTONE 3: prototype spatial planning tool developed by 3rd project year.