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Research paper

Assessment of open source GIS software for water resources management in developing countries

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Abstract

The European Commission is developing, under the responsibility of the Joint Research Centre and in close collaboration with international and national partners, the Water Knowledge Management Platform. This platform will integrate a dynamic management of different support tools and guidelines for the water management sector in developing countries. The support tools will be based on open source desktop GIS technologies in order to provide the final users in developing countries with a sustainable technology from both financial and technological points of view. In this study, a comprehensive list of several hundred open sources GIS software packages are put together by an extensive search and then screened to obtain a list of 31 packages for further consideration. Various criteria were developed to exclude 17 packages and the remaining 14 went through a series of installation and performance tests; firstly on a PC (Pentium (R), E5200 @ 2.50 GHZ, 1.98 Gb of RAM, Microsoft Windows XP Professional, Version 2002, Service Pack2). Several packages were dropped due to the general suitabilities and functionalities. Four packages (QGIS, gvSIG, MapWindow and openJUMP) performed well in map rendering of large file sizes (up to 125 Mb) and were further tested on a Pentium III computer. The QGIS package outperformed others in very poor computing conditions. The gvSIG and openJUMP packages performed reasonably well but their startup times were long, while MapWindow struggled. QGIS, gvSIG, openJUMP and MapWindow were recommended for the EU Water Knowledge Management Platform (WKMP).

Keywords: GIS; Open sources; Water resources management; Developing countries

1. Introduction

The Geographic Information Systems (GIS) has been developed for decades and commercial software packages have been successfully developed such as, for instance, ArcView and MapInfo. XML and Java have been developed to facilitate the development of the Internet as well as providing a coding standard in the software industries. GIS has been widely used in developing countries to manage water resources (Luijten et al., 2003; Andreas, 2007; Yagoub and Engel, 2009). Around 2000, the OpenGIS Consortium (OGC, http://www.opengeospatial.org/) was formed under W3C. The OGC has drawn nearly all prominent institutes and organizations in the sector to join, such as IBM, Microsoft, Oracle, ERSRI, MIT, and Stanford University amongst others. The OGC has then published the Geography Markup Language (GML), Web Map Service (WMS) and Web Feature Service (WFS) to provide standardised ways of manipulating the GIS data. The XML and Java languages are in the core of the OGC releases. Thus, it has also made the development of the GIS software much easier. Therefore, in the last few years, there has been a significant development in the area of free and open source geospatial software (Carrera-Hernandez and Gaskin, 2006; Fleagle and Gerlek, 2007). Research has flourished over the decades from vendor dependent software to open source software where researchers are paying increasing attention to maximize the

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value of their data so that resources can be utilised more efficiently (Shekar et al., 2001; Hartnett and Bertolotto, 2003; Morrison and Purves, 2002; Câmara and Onsrud, 2004; Purves et al., 2005). The term "open source" means that the source code is easily accessible (mostly under GNU license); the code can be modified, extended and/or distributed for non-commercial purposes benefiting the researchers, academics and other end users. Barton et al. (2002) have rightly pointed that developing countries and their donor partners policies should be reviewed for procurement of computer software, to ensure that options for using low-cost and/or open source software products are properly considered and their costs and benefits carefully evaluated. Other reasons for the adoption of open source in developing countries include avoiding being hostage to proprietary software (United Nations, 2004), and helping to set up an information economy (Weerawarana and Weeratunga, 2004).

This study looks into the open source GIS software (over 30 GIS softwares) and their potentiality to identify and shortlist the most suitable, user friendly, efficient software which could be used for analysis or designing a system applicable to water resources management for developing countries. Modelling and decision support for water management in developing countries are plagued with a number of related problems such as: lack of money, lack of expertise, inadequate training capacity, and dependence on experts from other countries (George and Leon, 2007).

As reported by Rajani et al. (2003), Ghosh et al. (2002) who studied the relevance of Free Libre Open Source Software (FLOSS) for developing countries, FLOSS has the potential to contribute to democratization, education, capacity building and research. In particular, FLOSS can foster poverty alleviation "if the adoption of FLOSS in developing countries is done wisely, it can help stimulate indigenous software industry and create local jobs" (e.g. in India, Madagascar). The developing countries have always been dependent on the transfer of technology ever since the beginning of technological progress. The trend of getting assistance through the transfer of technology has continued for the last 50 years as a result developing countries lagged behind in developing its own expertise, required knowledge and technological skills. Closed and licensed software market strategy is one of the barrages that keep developing countries in the vicious circle of poverty. FLOSS development towards a sustainable and long-term capacity building can break that circle.

Concerning the particular use of Open Source in hydroinformatics and in GIS applied to hydroinformatics, Harvey and Han (2002) affirm, in line with the principles of the Integrated Water Resource Management approach, that Open Source can have significant benefits for hydroinformatics, encouraging widespread interoperability and rapid development. This not only has technical and scientific advantages but also has huge potential for business market strategy and the community participative approach.

When presenting the different projects and their software, it is important to characterise the projects according to some unified criteria. The advantages and disadvantages will be analysed based on evaluation criteria established in this study. For this project, easy installation and running on personal computers are needed to allow users to display, query, update, and analyze data about geographic locations and the information linked to those locations. Only desktop GIS packages have been considered. This study discusses, in brief, the major features of each open source GIS software and then compares them in a tabular format based on the evaluation criteria. As the development of open source GIS has evolved over the last several years and still continuing to emerge, it is not easy to find a particular software package which will to meet all the requirements such as cross-platform operation system, map rendering, analytical and computational speed, functionality, data acceptability in wider range of formats and user friendliness. Therefore, each criterion is assessed using a weighting method of pair wise comparison and the final score is obtained by summing up all the criteria for a particular software package and ranked accordingly.

2. Development of assessing criteria and information collection

2.1. Major considerations in development of assessing criteria

2.1.1. EU SWRM guideline and Water Knowledge Management Platform (WKMP)

The EU's guidelines entitled "Towards sustainable water resources management: a strategic approach" (hereinafter "the guidelines") were a good reflection of recent developments in Integrated Water Resources Management (IWRM), presenting a strategic approach to planning and managing activities relating to water resources, encompassing the drawing up of national policies, the use of services and the implementation of specialised projects and programmes. It has been identified that the guidelines are intended for all those involved in the development cooperation of water management and its use, including public entities and the private sector. The guidelines form part of the broader context of approaches adopted by the Member States of the European Union, the partner countries and other contributing parties. The EC–AIDCO has decided to update the guidelines by creating a Water Knowledge Management Platform (WKMP), with the intention of a wider collaboration and supporting relevant works within the EU as well as in developing countries.

There are a number of Water Knowledge Management Platforms based in the EU as well as all over the world. Advances in information technology and rapid changes in IT provisions for the water sector bring new opportunities for improving and enhancing the role of water knowledge management in the sector. The updating of the EC guidelines is one of many processes that would offer an opportunity for greater collaboration in Water Knowledge Management.

2.1.2. Open source GIS

Open source software is becoming popular and increasingly more reliable than in the past. Considering the resource limitations faced by most developing countries, the utilisation of open source software is to be considered in the development of the WKMP. In addition to the cost issue, the inter-

operability is the major challenge faced by possible collaborations between organizations.

One of the major EU legislations in the water sector is the Water Framework Directive in which river basins have been defined as the basic unit for water management. Therefore, spatially distributed information such as water quantity and quality, water supply and collection networks, soil, vegetation and crops etc need to be gathered, processed and modelled for decision making. Geographic Information Systems (GIS) are effective in supporting the management and modelling of spatially distributed information. As an international standard for the development of a new generation of GIS, the OpenGIS standard has been developed in the past decade driven by the OpenGIS consortium under the W3C, primarily for the purpose of addressing the inter-operability issue (Gardels, 1993). The XML has been adopted as the main language to present spatially distributed geographic and related information.

There are also efforts being made through EU projects, and a list of potential open source GIS tools have been published on the internet such as GeOxgene, Batik, Cascadoss, GeoAPI, GeoTools, JTC, openJUMP, OJB and PostGIS. The advantages and disadvantages of those GIS tools need to be analysed.

2.1.3. Open source operation system and cross-platform

As we are looking for Open source GIS, the issue of open source operation system (OS) would naturally be brought up. Linux is a well-known open source OS and is getting more popular; however MS windows are still the dominant. Probably in the near future, support for both Windows and Linux would be necessary.

In recent years, cross-platform has been adopted by more developers as a basic requirement for software development. Cross-platform refers to software that can be made to work on multi-platforms, such as, the UNIX systems including Linux, Windows and Mac OS. Cross-platform has been achieved in various ways. There are several platforms or programming languages used in the development of open source GIS, like Python and Eclipse in Java programming and .NET framework in the Windows environment. In most open source GIS projects, efforts have been made to achieve cross-platform interoperability so that they can run on Linux.

2.2. Assessment criteria and procedures

The main objective of this study is to select a few open source GIS software packages for the WKMP. The flow diagram (Fig. 1) below shows the assessment criteria and procedures.

After the preliminary selection process, the top candidates will be analysed in greater depth by considering more technical issues such as the detailed system integrations, matching of software versions between the database, operation systems, programming languages and user interface, graphic functions and internet connections, security and different level of authorisations etc. The benefits and costs will need to be analysed to strike a balance. Some compromises may be needed since no system would be perfect in every single aspect. If the main requirements are satisfied, the two top candidate systems can then be recommended for the WKMP, and may need further modifications.

2.3. Information sources for open sources GIS

2.3.1. Websites on the Internet

Information of open sources GIS have been collected from all possible sources on the Internet. Several very useful links are:-

i. Open source GIS (http://opensourcegis.org/): This site attempts to build a complete index of Open source/free GIS related software projects. The definition of GIS has been kept loose to encompass a broad range of projects which deal with spatial data. This site stands on the sturdy shoulders of other projects, most notably OSRS, FreeGIS.org, Metalab Linux Archive, and FreshMeat.net. A list of over 250 GIS related software packages is provided.
ii. Freegis (http://freegis.org/): This site organise software, geodata projects etc according to the OS, language features. More than 300 relevant softwares were collected.
iii. SourceForge (http://web.sourceforge.com/): This is a site for all sorts of open source softwares. It helps to maintain and provide codes for downloads.
iv. OSGeo (http://www.osgeo.org/): This is the website of *The Open Source Geospatial Foundation* that has been created to support and build the highest-quality open source geospatial software. A list of very popular software packages are listed as OSGeo projects in the OSGeo website.

Web mapping	Desktop applications	Geospatial libraries	Metadata catalog
deegree	GRASS GIS	FDO	GeoNetwork
Mapbender	OSSIM	GDAL/OGR	
MapBuilder	Quantum GIS	GEOS	
MapGuide	gvSIG	GeoTools	
MapServer			
OpenLayers			

v. GISwiki (http://en.giswiki.net/wiki/Category:Software): GISwiki lists both commercial and open source softwares.
vii. Cascadoss (http://www.cascadoss.eu/en/index.php): Cascadoss is a European project and a list of open source GIS has been compared at (http://www.cascadoss.eu/en/index.php?option=com_content&task=view&id=14&Itemid=14).

viii. Wikipedia provides a list of open source GIS software packages (http://en.wikipedia.org/wiki/List_of_GIS_software) and comparisons of some packages were given at (http://en.wikipedia.org/wiki/Comparison_of_GIS_software). It is noted that both commercial and open source softwares have been included.

Links for open source GIS from the above sites were used to search for more information in the present study. Often some developers for open source GIS may only have support for a limited time to their projects. Some software packages

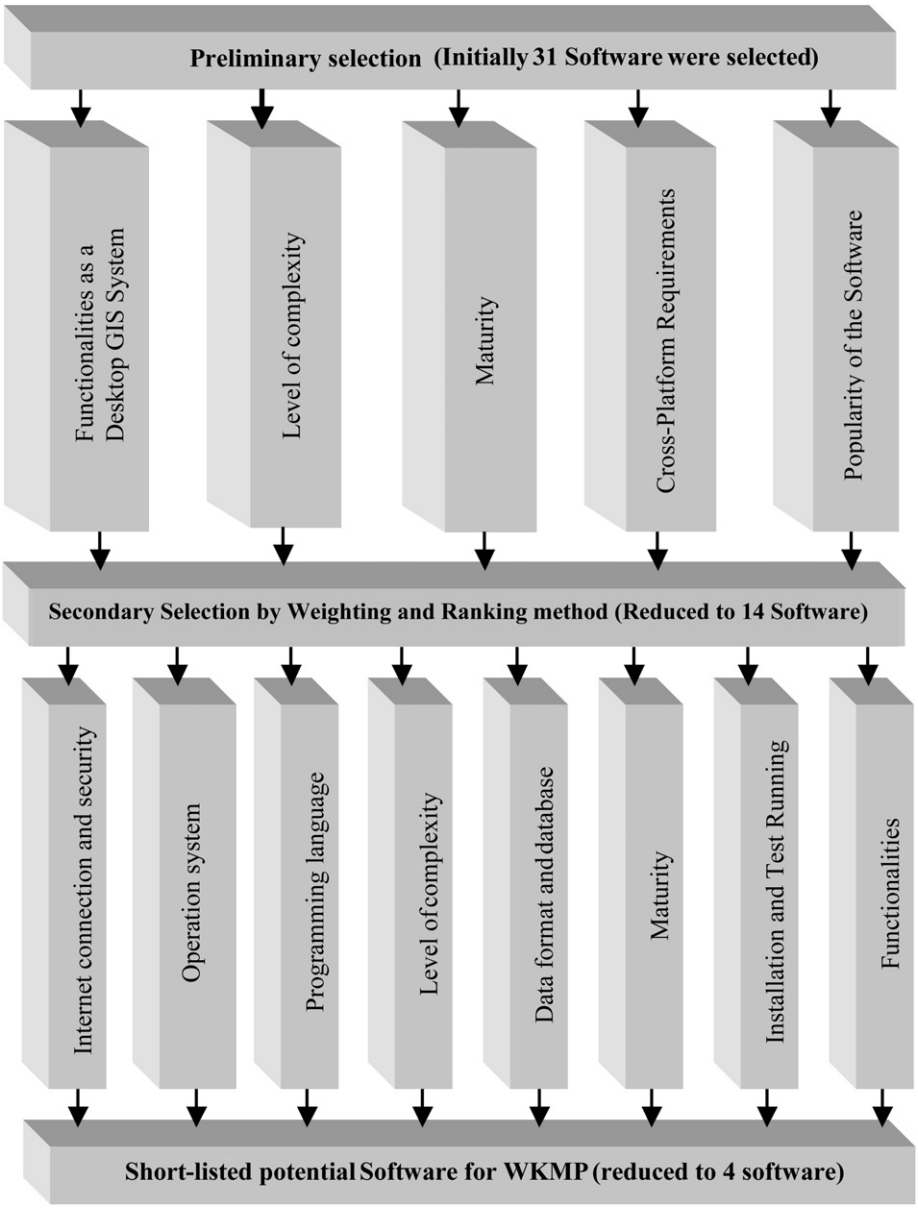

Fig. 1. The flow diagram with the assessment criteria and procedures.

are placed at several websites with different versions. All of these create difficulties in searching for information on the web for open source GIS package.

3. Assessment of open source GIS software

3.1. Screening of open sources GIS software packages

Through various extensive searches, several hundreds of GIS relevant software packages were found. An initial screening was based on two criterions: (a) general purpose DeskTop GIS applications and (b) currently active, which means that updates occurred in the last couple of years. For example, a number of web-GIS packages were excluded, such as, MapServer, OpenLayer, PrimaGIS etc. A list of 31 open sources GIS software packages has been put together as serious candidates to be considered for this study. The name, version of release, date of downloading, developer and homepage are shown in the following (Table 1a).

Information on the operating system and the programming language has been collected for all the software in Table 1a, and comments are also made in Table 1b. It has been noticed that there are broadly two types of open source GIS softwares. The first type was developed in the past with a relatively long history like SavGIS and ILWIS. They were developed for internal use in the early days and then they have decided to make it open to the public as the openGIS became the new trend of development. The second type was developed recently to catch up on opportunities offered by the openGIS standardizations in the GIS field. As the GIS development became much simpler than before, it had promoted the development of open source GIS and a number of projects are still undergoing. The list to be

Table 1a
List of Desk GIS candidate software.

Name	Release	Developer	Homepage
Apache Batik	V1.6 downloaded on 17-10-2008	Apache	http://xmlgraphics.apache.org/batik/
DIVA GIS	V6.0.3 downloaded on 11-09-2008	CIP (International Potato Center, Peru)	http://research.cip.cgiar.org/confluence/display/divagis/Home
Deegree	V2.1 downloaded on 10-12-2008	lat/lon, Germany	http://www.deegree.org/
Fmaps	V0.0.2 downloaded on 14-09-2008	Fmaps team	http://sourceforge.net/projects/fmaps/
FWTools	V2.0.6 downloaded on 16-10-2008	Private	http://fwtools.maptools.org/
GeOxygene	V1.3 downloaded on 21-09-2008	GeOxygene Team	http://oxygene-project.sourceforge.net/
GeoServer	V1.6.4 downloaded on 03-11-2008	Geoserver team	http://geoserver.org/display/GEOS/Welcome
Generic mapping tools	V4.3.1 downloaded on 19-07-2008	Univ of Hawaii	http://gmt.soest.hawaii.edu/
GRASS GIS	V.6.2.3 downloaded on 07-07-2008	GRASS Development Team	http://grass.itc.it/
gvSIG	V1.1.2 downloaded on 23-08-2008	Iver, Generalitat Valencia, Universidad Jaume I, Prodevelop	http://www.gvsig.gva.es
HidroSIG	V.3.1.1 downloaded on 18-06-2008	University of Colombia, Sede Medellin	http://cancerbero.unalmed.edu.co/~hidrosig/ingles/index.php
ILWIS	V3-04-02 downloaded on 22-08-2008	52° North	http://52north.org/index.php?
KOSMO	V1.2 downloaded on 22-08-2008	SAIG S.L.	http://www.opengis.es/
JTS Topology Suite	V1.8.0 downloaded on 01-07-2008	VIVID SOLUTIONS	http://www.vividsolutions.com/jts/jtshome.htm
Mapnik	V.0.5.1 downloaded on 03-09-2008	BerliOS Developer	http://mapnik.org/
MapWindow GIS	V4.5SR downloaded on 25-07-2008	MapWindow Open Source Team	http://www.mapwindow.org
mezoGIS	V.0.1.5 downloaded on 19-07-2008	Private, frozen now	http://www.mezogis.org/
monoGIS	V0.7 downloaded on 15-08-2008	MonGIS team	http://www.monogis.org/
NRDB	V.2.3 downloaded on 18-07-2008	Private	http://www.nrdb.co.uk/
OpenJUMP	V1.2 downloaded on 14-08-2008	OpenJUMP Team	www.openjump.org
OpenMap	V4.6.4 downloaded on 21-06-2008	BBN Technologies	http://openmap.bbn.com/
OSSIM	V1.7.9 downloaded on 19-09-2008	OSSIM team	http://www.ossim.org/OSSIM/OSSIMHome.html
PostGIS	V.1.3.3 downloaded on 22-09-2008	Refractions Research	http://postgis.refractions.net/
Quantum GIS	V0.11.0 downloaded on 23-07-2008	QGIS Development Team	http://www.qgis.org
SAGA GIS	V2.0.3 downloaded on 21-08-2008	Univ of Goettingen	http://www.saga-gis.uni-goettingen.de/
SAMT	V.2.8.1 downloaded on 11-08-2008	Institute of Landscape Systems Analysis (ZALF)	http://www.zalf.de/home_samt-lsa/
SavGIS	V2.1.5.0 downloaded on 16-07-2008	lRD (Development Research French Institute)	http://www.savgis.org
SharpMap	V0.9 downloaded on 14-08-2008	SharpMap Team	http://www.codeplex.com/SharpMap
TerraView	V.3.2.0 downloaded on 21-08-2008	DPI of INPE	http://www.dpi.inpe.br/terraview/index.php
Thuban	V.1.2.1 downloaded on 09-08-2008	Thuban Team	http://thuban.intevation.org/
uDig	V1.1-RC14 downloaded on 13-07-2008	Refractions Research	http://udig.refractions.net

discussed here only reflects a snapshot at the current time, and the picture may change remarkably in the future.

As the aim of the project is for Desktop applications in the water resources fields for developing countries, a preliminary screening has been done to pick up the most suitable ones that are balanced, with easy to use and sufficient GIS functions. The following observations were made to the listed open source GIS in Table 1b.

3.1.1. Sufficient functionalities as a desktop GIS system

Some packages only served as tools or libraries so that they would not be shortlisted.

a. GMT
b. OpenMap
c. Apache Batik (for handling SVG)
d. Mapink (for map presentation)
e. MezoGIS (improve postGIS's SQL workflows)

Some packages like Thuban and OpenEV have relatively simple functions.

Level of complexity

i. The most powerful GRASS software was not selected as it may be more complex.
ii. OSSIM is very large (600 Mb to 1 Gb download for a full version)

Maturity

Some packages may have great potential in the future but are currently still in the early or middle part of their developmental stages such as:-

a. GeOxygene
b. MonoGIS.

3.1.2. Cross-platforms requirement

Some packages only work on either Windows or Unix; so they may be excluded from further consideration if cross-platform become a compulsory requirement.

Table 1b
Operation system, programming language and comments to open source GIS.

Name	Operating System	Programing language	Comments
Apache Batik	Windows, Linux	Java 1.3	Limited to SVG functions
DIVA GIS	Windows only	Java with Eclipse	Java, Eclipse RCP like uDig, but only for Window so far
Deegree	Windows only	Java 1.5, tomcat 5.5	For Server/client web applications
Fmaps	Linux and Gnome	C	For Unix only
FWTools	Windows, Linux	Java, python	A comprehensive package, too complex
GeOxygene	Independent	Java	In the middle of development
GeoServer	Mac, Unix, and Windows	Java 1.4	For web-GIS, installation difficulties
Generic mapping tools	Windows, Linux, mac	C/C++	Tools only
GRASS GIS	Unix (Linux,) Window	C	Large and complex
gvSIG	Windows, Linux, Mac OS	Java	Good computing resources management
HidroSIG	Windows and Linux	Java	Latest release in 2005, working language and installation instruction in Spanish
ILWIS	Windows only	MS Visual 6	to be converted to Java, unstable
KOSMO	Windows, Mac OS X, Linux	Java	From the JUMP project
JTS Topology Suite	Windows, Linux	Java	OGC Simple features specification for SQL
Mapnik	Windows, Linux, Mac OS	C++, python	Tool kits only for making pretty maps
MapWindow GIS	Windows only	.NET(VB,C++,C#),. Net framework 2.0	Rich functions in water resources
mezoGIS	Linux and Windows	Python	Python programming language, improve postGIS's SQL workflow
monoGIS	Linux and Windows	OGR/GDAL (C++), Shapelib (C), Net Topology Suite (.NET, C#), Geotools.	Powerful, but in early development stage
NRDB	Windows only	C++	More for database, simple map functions
OpenJUMP	Windows, Mac OS X, Linux	Java	Easy to use
OpenMap	Windows, Linux, Mac OS	Java	Insufficient functionalities
OSSIM	Windows, Linux, Mac OS	C++	For remote sensing mainly
PostGIS	Windows, Linux, Mac OS	C	Support spatial database
Quantum GIS	Linux, MS Windows, Mac OS X, POSIX	C++	Powerful system
SAGA GIS	Windows and Linux	C++	Advanced analyses functions
SAMT	Unix	?	Too specific landscape modelling tools, too complex to install
SavGIS	Windows only	?	Old fashion
SharpMap	Windows only	C#,.NET, meno, Ermaper ECW SDK	CLR (common language runtime), .NET or Meno
Thuban	Linux, Windows and Mac OS	Python	Simple functions
uDig	Windows (not window2000), Mac OS X, Linux	Java with Eclipse	Good openGIS implementation

a. DIVA GIS (Windows only)
b. Deegree (Windows only)
c. FMaps (Unix and Gnome)
d. ILWIS (Windows only)
e. MapWindow GIS (Windows only)
f. NRDB (Windows only)
g. SAMT (Unix only)
h. SavGIS (Windows only)
i. SharpMap (Windows only)

Some of the single platform softwares like SavGIS and ILWIS may be due to historical reasons.

The above criteria were used to eliminate a number of software. However, the following criteria are used for selecting the various candidates to the shortlist.

3.1.3. Popularity of the software

For various reasons, there are some software packages which have drawn more attention to the user community, and they may be used more widely and developed further in the future. Some names mentioned in the OSGeo homepage for DeskTop GIS are:-

GRASS GIS,
OSSIM,
Quantum GIS,
gvSIG

In the European CASACDOSS project, the following software packages were compared:

GRASS
OSSIM
OpenEV
gvSIG
SAGA GIS
FMaps
QGIS
Thuban

Table 2
Installation of 14 open source GIS.

Name	Prerequisites	Download file size (Mb)	Installation
DIVA GIS V6.03.0	Java and Eclipse	120	Suitable for both XP and Vista
FWTools	Java, Python	20.3	Suitable for both XP and Vista
GeoServer	Need JAVA JDK1.4 or newer	36.7	Easy to install but not run on both Vista and XP
GeOxygene	Java	10.6	Problems in installation
GRASS GIS	Python	44.3	Suitable for XP
gvSIG	VJM1.05.12,JAI 1.1,JAI image I/O 1.0 (16 + 6 + 10 Mb)	69.4	Easy, need to install 3 Java programmes. Suitable for XP, but cannot read image files in Vista
HidroGIS	Jre1.4.2	155	Installation instruction in Spanish, hard to guess
ILWIS	No	13.5	Run directly
MapWindow GIS	No need for JAVA; Net framework 2.0 is needed for XP (can be downloaded during the installation)	34.1	Easy and suitable for XP
OpenJUMP	JRE1.5.0 (happy with the jre1.05.12 for gvSIG)	11	Easy
QGIS V0.11.0	Python 2.5.2 (10.7 Mb)	73	Can not be installed in Vista; Suitable for XP
SAGA GIS	No	7.4	Run directly
SavGIS	No	10.5	Easy
uDig	jre1.05.12 + a special uDig SDK kit including Java and Eclipse, 79.7 Mb (not Java SDK)	85.4	Easy

OpenMap
uDig
JUMP
Kosmo

3.2. Installation and test running of potential candidates open sources GIS

Based on the above considerations, the following 14 open source GIS packages shown in Table 2 were downloaded. Subsequently they were installed firstly on a PC (Pentium (R), Dual-Core CPU, E5200 @ 2.50 GHZ, 1.98 Gb of RAM, Microsoft Windows XP Professional, Version 2002, Service Pack2). A relatively new Sony laptop computer with MS Windows Vista has also been used to test the Vista compliance. The prerequisites and outcome of the installations are presented in Table 2.

The selected 14 softwares were evaluated based on the weight and scale as given in Table 3 and the total score was obtained (Table 4) using the following formula:

$$\sum_{i=1}^{8}(C_i W_i S_i) \times 100$$

where, C_i = criteria, W_i = weight for that particular criteria, S_i = scale factor or performance factor for that particular criteria.

3.3. Assessment of the performance of open source GIS

It was observed that gvSIG cannot open image files in Vista and QGIS cannot be installed at all on Vista. It is hoped that the problems with Vista will be sorted in future releases.

Table 3
Selection criteria using weighted method based on the pair wise comparison.

Selection criteria	Weight (W)	Performance scale (poor–average–good) (S)	Remarks
Internet connection and security (C1)	0.125	Scale (0–0.5–1)	Twice as important than Operating System and programming language as it is expected WKMP will be Internet based and therefore should be well secured.
Operation System (C2)	0.063	Scale (0–0.5–1)	Users are less bothered about the operating system.
Programming language (C3)	0.063	Scale (0–0.5–1)	Given less priority as its final users are not expected do any programming or write any codes.
Level of complexity (C4)	0.125	Scale (0–0.5–1)	As important as Internet and security as less complexity means more user friendliness.
Data format and database (C5)	0.125	Scale (0–0.5–1)	As important as user friendliness as wider data access means more dissemination of information for WKMP.
Maturity (C6)	0.125	Scale (0 − 0.5 − 1)	As important as data format and database capacity as matured and well developed software are less likely to face any obstacles than those software still in its development phase.
Installation and test running (C7)	0.25	Scale (0–0.5–1)	Top priority given as easy installation and speed indicate wider acceptability.
Functionalities (C8)	0.125	Scale (0–0.5–1)	As important as data format and database as functionalities should be well defined and easy to operate.

Table 4
Evaluation of the software based on weighting and ranking.

Name of software	$C_1W_1S_1$	$C_2W_2S_2$	$C_3W_3S_3$	$C_4W_4S_4$	$C_5W_5S_5$	$C_6W_6S_6$	$C_7W_7S_7$	$C_8W_8S_8$	Total Score × 100	Rank
DIVA GIS	0.063	0.125	0.063	0	0.063	0	0.125	0.063	50.2	10
FWTools	0.125	0.125	0.063	0	0	0.063	0.125	0.063	56.4	8
GeOxygene	0.125	0.063	0.032	0.125	0	0.063	0.063	0.063	53.4	9
GeoServer	0.125	0.063	0.032	0.125	0.125	0.063	0.063	0.063	65.9	6
GRASS GIS	0.125	0.063	0.063	0.063	0	0.063	0.125	0.063	56.5	7
gvSIG	0.125	0.125	0.032	0.063	0.063	0.063	0.25	0.032	75.3	3
HidroSIG	0.125	0.063	0.033	0	0.063	0	0.125	0.063	47.2	11
ILWIS	0.063	0	0.033	0	0	0	0.125	0.063	28.4	14
MapWindow GIS	0.063	0.125	0.063	0	0.125	0.063	0.25	0.063	75.2	4
OpenJUMP	0.125	0.063	0.032	0.063	0.125	0.063	0.25	0.063	78.4	2
QGIS	0.125	0.125	0.063	0.063	0.063	0.063	0.25	0.063	81.5	1
SAGA GIS	0.125	0.125	0.032	0.063	0	0.063	0	0.063	47.1	12
SavGIS	0.063	0	0	0	0	0.063	0.125	0.063	31.4	13
uDig	0.125	0.063	0.063	0.125	0.063	0.125	0.063	0.063	69.0	5

Therefore, further running tests were conducted detailed comparisons were then recoded in Table 5.

Data format and database

Amongst the software packages in Table 5, SAGA GIS and SavGIS can only recognise limited data formats. They also do not have compliance with the openGIS standards. However, the rest of them used the latest libraries, and so they could support the majority of popular data formats.

From the above test results on Pentium (R, Dual-Core CPU), PC, as mentioned in previous sections, the startup times of QGIS was around 9 s. The rest of the packages took 15 s to 1 min to startup. Because handling large size images may be one of the most resource demanding jobs in GIS, two large image files in TIF format (47.7 Mb and 125 Mb) were used to test the GIS map rendering functions such as reading, panning and zooming. The SAGA GIS software cannot read the TIF format image. The uDig and the new version (6.03) DIVA GIS packages were very poor in handling large files. As indicated in Table 6, the uDig took a hundred times longer to get the data read in the 47.7 Mb image, and every single step in rendering the image would take approximately 300–400 s. The DIVA GIS's performances were similar to the uDig, probably due to the fact that both of them used the Geotools image library. On the other hand, the uDig and DIVA GIS packages have a unique friendly feature that enable layers to be added to the map by dragging the file and dropping it into the map window. In contrast, the gvSIG, MapWindow, openJUMP and QGIS performed satisfactorily in opening and rendering large size images. Conclusions drawn from the running tests are recoded in the Table 4 during the evaluation process.

3.4. Systematic assessments to the top 4 candidates

After the weighting and ranking process, only the top 4 candidate software were further considered:

i. C/C++ software packages: QGIS and MapWindow GIS
ii. Java software packages: gvSIG and openJUMP

The general features for the above open source GIS softwares are documented in Table 7. It is observed that gvSIG, openJUMP, MapWindow GIS and QGIS are all satisfactory in

Table 5
Database compatibility and data format for different GIS softwares.

Name	OpenGIS	Database	Data format
Diva GIS	WMS, WFS	Yes	Shp, grd, tif, ipg, sid, arc
gvSIG	WMS, WCS,WFS (ArcIMS)	Yes	shp, gml, dxf, dwg, dgn, geoBD, WFS, WMS, WCS, ArcIMS
MapWindow GIS	WMS, WFS	Access, ArcXML	shp, bgd, bil, asc, ESRI grid, img,ESRI FLT, ddf, aux, dhm, bt, bmp, ecw, map, sid, LF2, kap, wmf
OpenJUMP	WMS	Yes	ESRI (shp), ecw, gml, xml, fme, jml, wkt, txt, WMS, database query
QGIS	WMS	PostGreSQL/PostGIS	ESRI (shp), mapinfo (mif), cadd, ddf, gml, tif, img, dem, asc, dt0
SAGA GIS	No	Via ODBC	ESRI E00, GPX, GDAL, DXF, SBF, ODBC
FWTools	WMS	MySQL	VPF (i.e. VMAP, VITD), RPF (i.e. CADRG, CIB), and ADRG
GeoServer	WMS, WFS	PostGreSQL/PostGIS, Oracle	VPF, MapInfo, and Cascading WFS, MrSID, ECW, JPEG2000, DTED, Erdas Imagine, and NITF
HidroSIG	WMS, WFS	MySQL	ESRI (shp), dxf, jpeg, tiff, gif, bmp
GeOxygene	WMS, WFS	Oracle and PostGreSQL/PostGIS	ESRI (shp), dxf, jpeg, tiff, gif, bmp
SavGIS	WMS, WFS	SavGIS databases (called SavBase, proprietary format)	ESRI (shp), dxf, tiff, gif, bmp
ILWIS	WMS, WFS	PostGreSQL/PostGIS	ESRI (shp), dxf, jpeg, tiff, gif, bmp
GRASS GIS	WMS, WFS	MySQL, PostGreSQL/PostGIS, SQLite	ESRI (shp), dxf, TINs, jpeg, tiff, gif, bmp
uDig	WMS, WFS	ArcSDE,DB2,Oracle, ArcSDE, PostGIS	ArcSDE, DB2, Map Graphic, Oracle Spatial, PostGIS, WFS, WMS

Table 6
Performance of open source GIS.

Name	Reading 125 Mb tif image (second)	Panning a 125 Mb image	Time for zooming (second)	Conclusion
Diva GIS	V6.03 is very slow as uDig	Took a long time	Long	Not acceptable for large size images
gvSIG	2	Easy	<1	
MapWindow GIS	9	Easy	1	
OpenJUMP	2	Easy	<1	
ILIWS	4	Easy	<1	
HidroSIG	5	Easy	<1	
SavGIS	3	Easy	<1	
GeOxygene	11	Took longer time	Long	
GeoServer	13	Took Longer time	Long	
GRASS GIS	4	Easy	<1	
FWTools	3	Easy	<1	
QGIS	2	Easy	<1	
SAGA GIS	Cannot read.tif			Too few image formats
uDig	125 Mb is too big to handle, read a 47.7 Mb tif image in 317s	Took more than 350 s for a simple navigation function or zooming on a 47.7 Mb image	359s	Not acceptable for large size images

terms of their ease of installation, user friendliness, efficiency, capability and wider accessibility of data in different formats.

3.4.1. Functionality

Furthermore, as shown in Table 8, these software packages were studied in detail including their read and write access (Vector and Raster Data), database link, OGC compatibility, thematic mapping, GPS support, scripting functionality, coordinate projection, watershed, terrain and 3D analysis. In the final shortlist, there are two C/C++ language GIS packages, namely QGIS and MapWindows. The QGIS can run on multi-platforms, and it is adequately powerful and easier to use than GRASS. MapWindow GIS can only run in MS Windows. Its advantages lie in the rich water-related functions. In the two Java GIS packages, gvSIG is very easy to use and also powerful. The OpenJUMP software is very useful too but it has less functionality than the gvSIG. Therefore, gvSIG appears to be relatively more suitable than the openJUMP.

Considering that a wide number of users in developing countries use computers having less computing powers, further tests were conducted on a Pentium III PC to reach the final decision of recommending the top software packages.

3.4.2. Further installation and running tests on a Pentium III PC

The top 4 open source GIS packages in the shortlist were further tested in a laptop computer with Pentium III 450 MHz, 328 Mb RAM, MS Windows 2000, Service Pack 4.

Python 2.4 was installed prior to the installation of QGIS. Java running environment was also pre-installed for the openJUMP package. In general, the installations of QGIS and openJUMP were quite straightforward and the lengths of time taken were acceptable, that is, within several minutes. The gvSIG required two more Java libraries, in addition to the Java running environment, and the installation took approximately 20 min. The MapWindow requires Windows Installer 3.0 and .NET Framework 2.0, which took more than 30 min to be

Table 7
General features of the top 4 candidate softwares.

Functionality	gvSIG	MapWindow	OpenJUMP	QGIS
Working language	Multilingual (CA, DE, EN, ES, EU, FR, …)	CA, DA, DE, EN, ES, EU, FR, GL, IT, PT, Nederlands, Norsk, Suomi	Only English (may be translated but complex)	At least: English
Manual language	English, Spanish and Italian	English (Spanish for ActiveX).	German, French, English	English, German and Italian
Capacity, efficiency and reliability	High	Very rich water-related plug-ins	Medium, includes plug-ins and standard GIS data visualization features	High, efficient and reliable
GIS Data interoperability via openGIS	Yes	Yes	Yes	Yes
Cross-Platform	Yes	No. Supports Windows platform only	Yes	Yes
Easy to use and to be effective	Yes	Yes	Yes	Yes
Demand for computing resources	Medium	High	Medium	Low

Table 8
Showing detail of shortlisted potential open source GIS software.

Functionality		gvSIG	OpenJUMP	MapWindow GIS	QGIS
Vector data	**Read**	SHP, DXF, DGN, DWG, GML	Shp, FME GML, JML, WKT, MIF(p), DXF(p)	At least: SHP, DXF (P), CSV(P), Waypoint+(P)	At least: SHP, GML, TAB, CADA, DAF, MIF
	Write	SHP, DXF, GML	Shp, FME GML, JML, WKT, MIF(p), DXF (p).SVG	At least: SHP	At least: SHP, GML, TAB, CADA,DAF, MIF
Raster data	**Read**	ECW, MrSID, JPEG,jpg, jp2, TIF, geoTIFF, PNG, GIF, img, bmp, jpeg2000	tif, GeoTIFF, png, jpg, ecw(p), mrSID(p)	At least: JPEG, GeoTIFF, ECW, ArcInfo GRID; all GDAL supported	At least: IMG, ASC, DAF, DT0, DEM, AIG, GRASS
	Write	ECW, MrSID, JPEG,jpg, jp2, TIF, geoTIFF, jpeg2000	png, jpg	At least: JPEG, GeoTIFF, ArcInfo GRID; all GDAL supported	At least: Png, jpg
Database links (R: read, W: write)	PostGIS	R,W	R, W(p)	R + W(p)	R,W
	ArcSDE		R(p)	No	
	Oracle	R,W	R(p)	No	
OGC Compliant/supported OGC standards		WMS, WFS, WCS, CSW, Filter, WFS-G	SFS, WMS, GML, WFS(p)	WMS (P), WFS (P)	WMS, WFS(p)
Thematic mapping (e.g. Bar Chart • Graduated Symbol • Individual Value • Pie Chart • Label • Ranges • Dot Density)		Yes (simple)	Yes (p)	Only labels; others in development	Yes
Developer API		No	Yes	Yes	Yes
Scripting functionality		Jython	Beanshell Jython(p)	C#,B.Net	Python
Coordinate transformations/projections		Yes	Yes(p)	Yes	Yes
Data creation and Editing (The creation of new 2D graphics including lines, polylines and freehand lines. Area tools include areas, multiareas, ellipses, circles, and rectangles. Point tools include points, multi-points, and shapes. Also, familiar CAD−like precision tools such as snap and typed coordinate input.)		yes	Yes	Yes	Yes
GPS support		no	No	Yes	Yes
Topology creation and editing (Creation of link,node, chain and polygon topology)		yes (lines)	Yes (limited)	TIN creation per API; viewing/creation via plug-in	Yes
Advanced data creation & editing (including item snapping, creating offsets, line generalisation, trimming, rotating, etc.)		yes	Yes (except offsets)	Yes (except generalisation)	Yes
Advanced thematic mapping (including Thiessen polygon analysis, grid analysis, contour mapping and flow-line generation.)		Yes	Thiessen polygons (for specific cases)	Yes (contour and flowline generation)	Yes
Creation of 3D views & terrains (Creation of triangulated irregular networks (TINs) and digital terrain models (DTMs), relief shading and surface draping of raster images and vector data for 3D visualization purposes. Includes support for constrained Delaunay triangulation, allowing TINs to be created from a collection of surveyed elevations, with optional breaklines and bounding areas.)		Yes	No	Yes (3D plug-in, TIN for API only, hillshade)	Yes
Viewshed and terrain analysis (provides line-of-sight calculations used to determine all areas on DTM data that are visible from a chosen location, plus slope, aspect, and gradient grid analysis.)		Yes	No	Yes (watershed analysis and terrain analysis)	Yes

(p) = functionality provided via external plug-in.

installed. The installation of MapWindow itself was also very slow and it took approximately another 30 min, probably due to the installation of sample projects with large image files. The performance results of the top 4 software on the Pentium III PC are listed below in Table 9.

This Pentium III PC is widely regarded as a standard computer for developing countries. PCs with such configurations do not represent conditions of high computing resource. The QGIS performed comfortably under this condition. It started up in 35 seconds, which is acceptable. It opened a large (125 Mb) image in 4 seconds and only took one to two seconds to pan and zoom the image. Therefore, it has to be ranked as the number one among the 4 packages in the tests.

The startup times of gvSIG and openJUMP were 345 s and 560 s respectively, which were far too slow to tolerate. However, both performed comfortably in handling a large (125 Mb) image, including opening, panning and zooming, but openJUMP was slightly faster.

MapWindow's startup time of 90 s was long. It also took a very long time to open a large image (125 Mb) and failed to get the panning function working properly. However, the zooming function worked fine. It appears that MapWindow had struggled.

In summary, the QGIS outperformed the rest, followed by the OpenJUMP and the gvSIG. One apparent disadvantage of the OpenJUMP and gvSIG is that the starting up time is quite long, perhaps due to the Java language. The performances of MapWindow in reading and rendering maps were poor. However, its starting up time is short, probably due to the nature of the C/C++ programming which has already been demonstrated by QGIS too.

An important lesson learned from this exercise is that the perceived hardware constraint in developing countries may not be a real big issue, at least for relatively simple GIS applications. At the beginning of this project, constraints in both hardware and software supports in developing countries were of serious concerns. After running the test above, it was felt that computing hardware in developing countries should be adequate for simple GIS application, such as, in WKMP. As it has been shown, any GHz and 500 Mb RAM computers can comfortably handle most GIS map rendering and processing tasks, up to an image size of 100 Mb. We should focus more on the possible constraints in software support in developing countries and pay more attention to provide truly user-friendly interfaces.

3.4.3. Water resources management related functionalities

Table 8 has already presented different important characteristics such as contour mapping and flowline generation under Advanced Thematic Mapping, creation of TINS, DTM, calculating slope, aspect and gradient under Viewshed and Terrain Analysis.

What would be particularly interesting to the water resources management community are the plug-in packages specifically created for them. QGIS has a long list of user contributed plug-in that include "GHYDRAULIC" for water supply network. GRASS has a build-in finite difference groundwater flow model "MODFLOW". As mentioned earlier, QGIS can also access GRASS functionalities. The first author's research team at Liverpool has developed a plug-in for the risk assessment of soil and land contaminations. MapWindow GIS offers "Stream-Flow-Analysis" and "Water-Quality-Analysis" plug-in packages. Users can generate plug-in codes for the GIS packages and it is expected that more functionalities will be created in the near future.

4. Discussion and conclusions

The purpose of this study is to choose suitable open source GIS software packages for potential WKMP users in developing countries. Amongst a list of criteria, relatively easy installation with greater computing speed have been emphasised. A Pentium III PC was used for installation and test running. Furthermore, the capability of rendering large size images has been chosen as an important indicator.

QGIS performed extremely well under the existing conditions and its functionalities are adequate for most general applications in water resources management. Its functionalities may be enhanced by linking to GRASS. Based on balanced consideration of all discussions made above, a conclusion can be drawn that QGIS is obviously the top choice for the WKMP.

openJUMP has performed satisfactorily under the existing computing conditions but does not perform as good as QGIS. However, it has very rich water-related functionalities and the list of plug-ins is still increasing. openJUMP is also recommended for the WKMP.

Both gvSIG and MapWindow GIS offered balanced performance in efficiencies and functionalities at an acceptable level. The gvSIG and MapWindow GIS scored almost same and therefore both of them are recommended to WKMP.

Furthermore, amongst the rest of the open source GIS packages, if the uDig and GeoServer packages can improve their map rendering functions, they are potentially very user-friendly software packages. A number of GIS software packages are still in their developmental processes; hence, it is

Table 9
Performance of top 4 open source GIS on a Pentium III PC in Windows 2000.

Name	Time to startup the program (second)	Reading 125 Mb TIF image (second)	Time to settle after panning a 125 Mb image (second)	Time for zooming (second)	Rank
QGIS	35	4	1	2	1
OpenJUMP	345	17	1	4	2
gvSIG	560	16	3	8	3
MapWindow GIS	90	225	Could not pan over the image	2	4

Table 10
A ranking list of open sources GIS obtained in the CASCADOSS Project. Retrieved from "http://www.mapwindow.org/wiki/index.php/MapWindow:Overview".

Market + Tech+ Economic		
Type	Software	Total score (%)
GIS/RS app.	GRASS	81
	gvSIG	70
	OSSIM	69
	OpenEV	66
	SAGA GIS	62
	FMaps	34
GIS app.	QuantumGIS	82
	Thuban	74
	OpenMap	67
	uDig	64
	JUMP	62
	Kosmo	57

expected that some interesting packages would be released in the near future.

This recommendation of QGIS and gvSIG is consistent with the conclusion of the CASCADOSS Project. They have scored a list of open source GIS software in three headings: Market Potential, Technical Potential and Economical Potential. The adding up of the three headings has produced a ranking list as shown in Table 10, in which GRASS is the number one package, followed by QGIS and gvSIG. As the WKMP is for developing countries, GRASS GIS though ranked seven was not recommended in the present study because it was not as easy to use as the QGIS and the gvSIG packages.

As has been emphasised from the beginning, this study can only provide a snapshot in an area that is moving quickly. A similar review is recommended every 2–3 years. An important issue is the change of version. For example, as DIVA GIS developed from version 5.2 to 6.03, the software became more powerful in many aspects; however, the speed of map rendering has been significantly reduced to an unacceptable level. Unfortunately, if the WKMP is going to rely on open source GIS software in the community, this version change problem would be an issue forever.

References

Andreas, M., 2007. Strategy for groundwater management in developing countries: a case study in Northern Costa Rica. Journal of Hydrology 334 (1–2), 109–124.

Barton, J., Alexander, D., Correa, C., Mashelkar, R., Samuels, G., Thomas, S., 2002. Integrating Intellectual Property Rights and Development Policy. UK Department for International Development, Commission on Intellectual Property Rights, London.

Câmara, G., Onsrud, H., 2004. Open-source geographic information systems software: myths and realities. In: Esanu, J.M., Uhlir, P.F. (Eds.), Open Access and the Public Domain in Digital Data and Information for Science: Proceedings of an International Symposium. National Research Council, U.S. National Committee for CODATA, Washington, DC, pp. 127–133.

Carrera-Hernandez, J.J., Gaskin, S.J., 2006. The groundwater modeling tool for GRASS (GMTG): open source groundwater flow modeling. Computers & Geosciences 32, 339–351.

Cascadoss Project (http://www.cascadoss.eu/en/index.php) http://www.cascadoss.eu/en/index.php?option=com_content&task=view&id14&Itemid=14

Fleagle, M., Gerlek, M.P., 2007. LizardTech: why we use and support free and open source software. OSGeo Journal 2, 3–6.

Freegis (http://freegis.org/).

Gardels, K., 1993. Defining Open GIS: an introduction to the Open Geodata Interoperability Specifications (OGIS). GRASSClippings. The Journal of Open GIS 7 (2), 7–13.

George, C., Leon, L.F., 2007. WaterBase: SWAT in an open source GIS. The Open Hydrology Journal 1, 19–24.

Ghosh, R.A., Glott, R., Kreiger, B., Robles, G., 2002. The Free/Libre and Open Source Software Survey and Study—FLOSS Final Report. International Institute of Infonomics, University of Maastricht, Maastricht, The Netherlands.

GISwiki (http://en.giswiki.net/wiki/Category:Software).

Harvey, H., Han, D., 2002. Discussion of the relevance of Open Source to hydroinformatics. Journal of Hydroinformatics 4 (4), 219–234.

Hartnett, P., Bertolotto, M., 2003. Developing interoperable web-based geospatial Digital. GIRSUK 2003: Session 5b: pp. 185–188.

Luijten, J.C., Knapp, E.B., Sanz, S.I., Jones, J.W., 2003. A role for GIS-based simulation for empowering local stakeholders in water resources negotiations in developing countries: case studies for two rural hillside watersheds in Honduras and Colombia. Water Policy 5, 213–236.

Morrison, K.W., Purves, R.S., 2002. Customizable landscape visualizations. Implementation, application and testing of a web-based tool. Computers, Environment and Urban Systems 26, 163–183.

OSGeo (http://www.osgeo.org/).

Open Source GIS, http://opensourcegis.org/.

Purves, R.S., Medyckyj-Scott, D.J., Mackaness, W.A., 2005. The e-MapScholar project-an example of interoperability in GIScience education. Computers & Geosciences 31, 189–198.

Rajani, N., Rekola, J., Mielonen, T., 2003. Free as in education: significance of the free/libre and open source software for developing countries. In: World Summit on the Information Society.

Shekhar, S., Vatsavai, R.R., Sahay, N., Burk, T.E., Lime, S., 2001. WMS and GML based interoperable web mapping system. *Proceedings of the ninth ACM international symposium on Advances in geographic information systems*. Atlanta, Georgia, USA. 2001, pp 106–111.

SourceForge (http://web.sourceforge.com/).

United Nations, 2004. Road Maps Towards an Information Society in Latin America and the Caribbean (No. LC/G.2195/Rev.1-P). United Nations Economic Commission for Latin America and the Caribbean, Santiago, Chile.

Weerawarana, S., Weeratunga, J., 2004. Open source in developing countries (no. SIDA3460en). Sida 2004, Department for Infrastructure and Economic Cooperation, Stockholm.

Wikipedia (http://en.wikipedia.org/wiki/List_of_GIS_software) and (http://en.wikipedia.org/wiki/Comparison_of_GIS_software).

Yagoub, M.M., Engel, B., 2009. Remote sensing and geographic information systems in developing countries: case of the United Arab Emirates (UAE). The Journal of Terrestrial Observation 1 (2), 69–88.