Integrated Solution for Water Resources Information Management: A Case study of Athi River Catchment

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Integrated Solution for Water Resources Information Management
A Case study of Athi river catchment

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Abstract: ***The management of water resource has presented a major challenge to the various organizations mandated to manage this valuable resource. This has been due to the high rates of population growth and urbanization which has led to an increased demand for water for various uses which in turn puts a lot of stress on existing water sources. The main challenges include lack of well-defined processes of information flow from collection, storage and dissemination. We also have different storage formats hindering proper information sharing resulting to duplication. At present water resources information in Athi River Catchment is sent by use of emails and compact discs (cds) ones it's collected. It is then added into existing databases at the regional or headquarters offices.***

The main goal of the study was to come up with an integrated web-based system for water resources information management. This will provide a proper water information collection, storage and dissemination platform. The integrated system is composed of a spatial enabled and a centralized database to store data, a web based mapping component that provides tools for data updating and visualization and a website that hosts the mapping component and also provides additional information related to water resources use. Open Source and Geographical Information Systems (GIS) technologies were used to create the system. The system contained information on surface water, ground water, water quality, water pollution and water shed protection.

The system offered a solution to management of water resources information, by providing one shared integrated system hence reducing duplication and lowering maintenance cost. The system also offers a streamlined flow of information to all WRMA (Water resources management authority) offices which is mandated to manage Athi River Catchment hence ensuring there is well structured process of collecting, storing and disseminating of information. Adoption of the system will ensures we leverage advancement in GIS technology in management of our various resources.

Keywords: GIS, Information management, Open Source, Water resources.

1. Introduction

According to the Greek philosopher Pindar, the best of all things is water. This view is not surprising since the need for water, throughout human history, has always been appreciated. It is present everywhere, and without water, life, as it is known, will simply cease to exist [1]. Water has a unique place of all the planet's renewable resources. It is essential for sustaining all forms of life, food production, economic development, and for general wellbeing. It is impossible to substitute for most of its uses, difficult to de-pollute, expensive to transport, and it is truly a unique gift to mankind from nature [2]. Water is also one of the most manageable of the natural resources as it is capable of diversion, transport, storage, and recycling. The ability of developing countries to make more water available for domestic, agricultural, industrial and environmental uses will depend on better management of water [3]. In case of developing nations, proper management of water resources is hindered due to high rates of urbanization. This increases demand for drinking water putting stress on existing water sources. The mounting challenges posed by the changing demand for and supply of the resource highlights the importance of water in any development and growth agenda

Water resources management aims at optimizing the available natural water flows, including surface water and groundwater, to satisfy human needs. Climate change will increase the complexity of managing water resources, in some parts of the world, there will be more available water but in other parts, including the developing world, there will be less [3]. Kenya is classified as a water scarce country with only 647 cubic meters of renewable freshwater per capita. The same is characterized by high spatial and temporal variability and extremes of drought and floods [4] .This stresses the need for proper water resources management. All water resources in Kenya remain vested in the state. The Ministry of Water and Irrigation is tasked with the responsibility of creating institutions to manage water resources and provide water services. In 2002, the water sector reforms in Kenya culminated in the passing of the Water Act, gazetted in October 2002 [5]. The Water Act introduced new water management institutions to govern water and sanitation. The water reforms saw the introduction of the commercialization of water resources as part of the decentralization process and the participation of stakeholders in the management of national water resources. Policy and regulation responsibilities were separated. The devolution of responsibilities for water resources management and water services provision to local level functions has been the principal mechanism for improving accountability and transparency in the water and sanitation sector [6].

The Water Act provides a legal framework for the creation of water institutions and limits the Ministry's role to policy formulation; overseeing the implementation of the policies; and resource mobilization. The Ministry is also responsible for irrigation, drainage, and land reclamation. As a result of the provisions in the Water Act of 2002, the Water Resources Management Authority (WRMA) was created. Its mission is to manage, regulate and conserve all water resources in an effective and efficient manner by involving the stakeholders, guaranteeing sustained access to water and equitable allocation of water while ensuring environmental sustainability [5]. Other duties of the WRMA include: To ensure rational and equitable allocation of water resources, water quality monitoring, testing and surveillance to ensure compliance with drinking water standards and other standards for various water uses and effluent discharges into public sewers and the environment and mapping and publishing of key water catchment areas, groundwater resources and flood prone areas [6].

WRMA has divided the country into six catchment areas namely; Athi River, Ewaso ngiro, Tana River, Lake Victoria north, Lake Victoria south and Rift valley. Athi river Athi river catchment covers Nairobi, Makueni, Taita Taveta, Kwale and Mombasa counties, a part of Kiambu, Machakos, Kajiado and Kilifi counties. It is located in the southern part of Kenya. It borders with Tana Catchment Area in the north, with Rift Valley Catchment Area in the west, with Indian Ocean in the east, and with Tanzania in the south Figure 1.

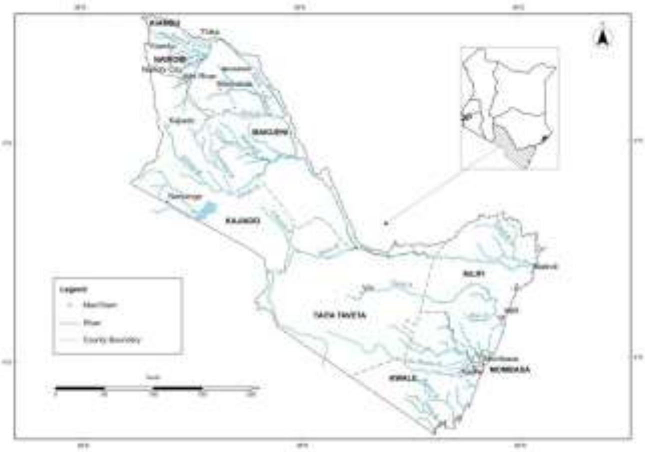

Figure 1: Location of Athi River Catchment Area showing counties administrative boundaries, major rivers and the major urban centers.

Total catchment area is 65,935 km2 which is11.4% of Kenya. According to the Census 2009, population in the catchment is 9.27 million, or about 24% of the total population of Kenya [5]. Athi River is the largest river in the Athi Catchment that flows from the southeast of Nairobi north-eastward in the most upstream area. Athi River turns its flow direction to the southeast in the north of Ol Doinyo Sapuk National Park and flows along the catchment boundary with Tana Catchment Area and drains into the Indian Ocean in the northern part of Malindi. The catchment area of Athi River is 37,750 km2, which account for about 57% of the Athi Catchment. There are two international rivers, namely, Namanga River and the Lake Amboseli (3,155 km2) and Lumi River that originates from the outskirt of Mt. Kilimanjaro in the territory of Tanzania and the Lake Jipe (2,804 km2). Other rivers flow into the Indian Ocean as well as Athi River, namely, Rare River (7,625 km2) at Kilifi, Mwachi (3,874 km2) and Pemba (4,760 km2) rivers at Mombasa, and Ramisi River (3,234 km2) in the south most of Kenya [5].

There are several springs near Chyulu Hills in the central part of the Athi Catchment such as Mzima Spring used for irrigation purpose and water supply for Mombasa city. As for crops in the Athi Catchment, beans are major crops in the western part, especially in the areas surrounding Kajiado County. Other crops are cotton in Machakos County in the east of Nairobi, cashew nuts and coconut in the coastal region of Kilifi and Mombasa. Banana is grown in the south most part of Athi Catchment in Kwale and Taita Taveta counties.

In the capital city Nairobi, there are various industries such as agricultural equipment, brewing and beverages, cement, chemicals and pharmaceuticals, coffee processing, construction material, electricity appliances, food processing, shoes, glass, leather, light industries, meat processing, painting material, paper industry, plastic product, printing, soap, steel, textile, timber and timber products, tobacco, tyre and car. In the suburbs of Nairobi, there are shoes and meat processing at Limuru, cement, brewing and beverages, meat processing and textile at Athi River and food processing and light industry at Machakos. In the downstream areas, textile industry at Voi and food processing at Malindi and Kilifi are famous. In the second largest city Mombasa, various kinds of industries are promoted such as brewing and beverages, cement, construction material, food processing, glass, light industry, meat processing, oil refinery, paper, plastic product, ship repair, soap, steel, textile, car, shoes.

It is expected the urban population in the catchment will increase as the rural population decreases as the two major cities in the country that is Nairobi and Mombasa grow which are in this catchment hence compounding the current water supply problems. The catchment protection and conservation issues in Athi catchment area include: direct damage to water bodies this is a result of encroachment in recharge zones by destroying the wetland through cultivation, settlement, abstractions, livestock rearing and watering; Water use conflict due to inappropriate usage due to ground water over abstraction leading to reduced water levels; Ground water quality deterioration due to poor waste management and poor sanitation from human settlement; and climate change leading to long dry spells, resulting in long distances to watering points, water quality deterioration as a result of saline intrusion and water scarcity. Table 1, 2 and 3 lists the various watershed features that have been destroyed according to JICA study team on the development of National Water Master Plan 2030 [5].

Table 1: Deforested areas

Forest Name	Location (Sub-catchment)
Aberdare, uplands forest	Ndarugu SC,Ruiru SC,Kamiti SC,Thiririka SC
Kinare forest	3BC-Ruiru
Karura forest	3BC-Ruiru
Ngong hills forest	3AA-Mbagathi
Ngong Road forest	3AA-Mbagathi
Thogoto	3AA-Mbagathi-SC
Dagoretti forest	3AA-Mbagathi-SC
Iveti Hills	3EC-Thwake
Mbooni Hills	3EC-Thwake
Kilungu Hills	3EA

Table 2: Damaged springs

No.	Name of Spring/Sub-catchment	No.	Name of Spring/Sub-catchment
1	Jipe spring	11	Uumani spring
2	Kimana spring	12	Makindu spring
3	Msuni spring	13	Kiboko spring
4	Mzima spring/3G	14	Mtito Andei spring
5	Njoro Kubwa spring	15	Nthange spring
6	Nol Turesh spring	16	Simba spring
7	Rombo spring	17	Katanginim spring
8	Enduet spring	18	Mukuyuni spring
9	Kimana spring	19	Gitwe
10	Kikuyu spring	20	Thogoto

Table 3: Damaged wetlands

No.	Name of wetland/Sub-catchment	No.	Name of wetland/Sub-catchment
1	Onderi wetland/3BA	10	Lower Sabaki Estuary/3HA
2	Maguo/Ithangi wetland/3BA-Nairobi River	11	Lake Baratuma Malindi wetland
3	Irari wetland/3BC-Ruiru	12	Taita wetland
4	Theta wetland/3BD-Thiririka	13	
5	Nairobi Dam/3BA-Nairobi River	14	Kwale(Koromonjo) wetland
6	Kiserian wetland/3AA-Mbagathi	15	Muusini/Muselele wetland/3DB
7	Kiluw wetland/3F-Kibwezi	16	Kimana wetland/3F
8	Makindu wetland/3F-Kibwezi	17	Lake Jipe wetland/3F
9	Lake Jirore		wetland/3HD

WRMA has set up regional office in Machakos and sub-regional offices in Nairobi, Kibwezi, Mombasa, Kiambu and Oloitoktok. There are also several Water Resources User Associations (WRUAs) in distributed various parts of the catchment.

There were specific challenges facing management of water resources by WRMA in Athi river catchment that the study set out to address. One of the main challenge is having different systems in various local and regional offices that are used to store the water information, such as Access database and Excel spreadsheet which hampers the sharing of this information between these offices. There is also often conflicting information about the same water resources due to scattered database among different regional offices and organizations hence making it difficult to check for consistency of the information stored in the databases. The lack of proper tools to collect and store water related information is also another main problem which has led to some of relevant information not to be formally recorded [5].

There has also been inefficient use of Geographical Information Systems (GIS) in Athi river catchment WRMA offices. This is due to the lack of trained personnel as well as the challenge in use of the available database. Complicated interface of the existing server system is also an issue, as it is difficult for most of the staff that are not specialized in IT to adequately use it.

Another issue is shortage of manpower. It has only one ICT officer and one database administrator who currently have the responsibility of managing the entire water related database at the national scale. The data includes river monitoring, ground water, surface water, water quality and some meteorological data [5]. The database administrator is tasked to administer the database and also perform monitoring, supervision and checking the quality of data received from the six regional offices. He should also supply the needed information either internally or for a specific project being undertaken that require water related data. In addition to that he should provide the necessary maps in GIS format.

These challenges can be addressed by applying information technology to provide potential solutions to the problems of data accessibility. Current advances in computational speed, storage, World Wide Web and software provide great opportunities to develop decision and management support systems with the advantage of information dissemination for decision-makers.

Geographic Information Systems (GIS) have had a profound effect on water resource management. Various GIS tools are now commonly used for data preparation and developing water resource management systems. There have been various systems developed in different parts of the world using geospatial technologies. They vary in terms of the approaches adopted and also on the capabilities of the resulting systems. Integrated GIS-based water resources information and assessment system was built for the state of Georgia in the USA to be used as a guide in managing water resources in a sustainable manner to support the state's economy, to protect public health and natural systems, and to enhance the quality of life for all citizens [7].Web-based GIS and spatial decision support system for watershed management and a GIS-based water resources information system provided a web-based SDSS (Spatial Decision Support System) framework in terms of system components and data flow. The SDSS uses web-GIS for watershed delineation, map interfaces and data preparation routines, a hydrologic model for hydrologic/water quality impact analysis and web communication programs for Internet-based system operation [8].

This project explored how GIS technologies can be applied in managing water resources in various water catchment regions in the country. The project describes a conceptual web-based framework in terms of system components for the development of a web based water management system using web-GIS for water resources data collection, storage, mapping, visualization, analysis and map outputs.

To address these challenges the broad objective of the research project was to develop an integrated solution for water resources information management. The system would be used to address the problem of information management being experienced by Water Resources Management Authority (WRMA) offices in Athi river catchment. This will provide proper water information collection, storage, dissemination, improved access and decision making for sustainable management of water resources.

To be able to achieve the overall main objective, the study in particular set out to establish a centralized spatial enabled database for use by all WRMA offices within the catchment. The study also set out to avail a web-based mapping interface. The interface would enable the users to update the data, visualize the data and utilize other capabilities in the system including outputting maps. Also to achieve its main goal a general website was created to host the mapping interface and also be used to relay additional water resources information.

To realize the objectives, the study focused on investigating and analyzing how water resources are managed in the Athi river catchment. This involved identifying the various stake holders and their responsibilities in the process. One of the major players in the water resources management was found to be the Water Resources Management Authority (WRMA) whose primary role is monitoring and assessment of water resources.

The organization was found to be facing major challenges in managing water resources information. The research then focused on addressing these problems by developing a web based water resources management information system. The system was developed using various open source technologies and geospatial softwares.

2. Methodology

The approach taken to achieve the set objectives involved carrying several steps: user need evaluation and data collection, data processing, system development and system implementation Figure 2.

The first phase involved the collection of relevant data as per system user need evaluation. The data was obtained from various organizations dealing with management of water resources. The data was in different formats depending on the type of data and the source or organization from which the data was obtained as shown in Table 4.

The data collected was then converted to the desired formats. The spatial data was linked to respective non spatial data. To process the data, Quantum GIS software was used. The processed data was then imported into PostgreSQL database. The data stored in the database was then used in system development. System development involved designing the database, building the web-based mapping application using Mapserver, designing a website using Joomla and integrating all this to makeup the system.

The last step of the methodology was testing the system on a local area network. This was done to evaluate the various features of the prototype against the user needs evaluation and the various refinement needed on the prototype were done.

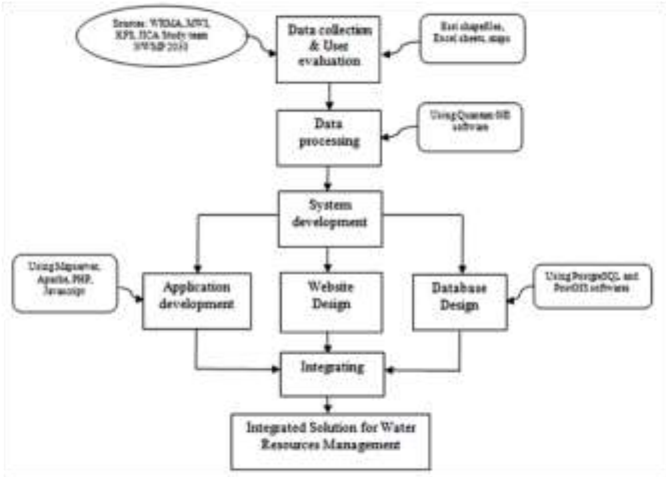

Figure 2: workflow diagram

Table 4: Data type, format and source

Data	Type	Format	Source
Rainfall, surface and ground water monitoring stations	primary	Microsoft Excel sheet	WRMA and MWI
Rivers	primary	Esri Shapefile, Maps	WRMA and JICA study team
Dams	primary	Microsoft Excel sheet	WRMA and MWI
Forest	primary	Esri Shapefile	KFS
Wetlands	primary	Esri Shapefile	MWI
Floodplains	primary	Esri Shapefile	MWI
Major pipeline	primary	Esri Shapefile	WRMA and JICA study team
County, district and division water resources	secondary	Microsoft Excel sheet, Microsoft Word	WRMA, MWI and JICA study team

information			
Catchment water resources information	secondary	Microsoft Excel sheet, Microsoft Word	WRMA, MWI and JICA study team

Several Open Source tools and technologies were used to develop the system. Mapserver for windows (ms4w) was used as the server on the localhost. Apache Web Server was primarily used to serve both static content and dynamic Web pages on the localhost. PHP script and Java scripts used to create web pages, application dynamic content, tools and functionalities. To create the database PostgreSQL and PostGIS were used. Quantum GIS was used to process the data and create the digital map.

3. Results and discussion

The result was an integrated system of managing water resources in the Athi river catchment. The system is centralized and hence accessible to all regional and sub-regional offices within the catchment and other stakeholders as shown by the prototype system model Figure 3.

Figure 3: Prototype system model

The resulting System had three main components. First component was the spatial enabled database which was single and centralized for use by all. Several tables where created in the database and grouped into surface water, ground water, water shed conservation and administrative groups. The surface water group contained rivers, dams, surface stations, rain stations, major pipes and water transfer scheme tables. The ground water group contained boreholes and monitoring boreholes tables. The water shed conservation group had forests, wetlands, flood plains and deforested areas tables. The administrative group contained WRMA main catchments, sub regional management regions, counties, roads and major town’s tables.

The other component was the main website. It hosted the mapping user application which was embedded on it. It also contained other information related to water resources management such us detailing the various functions of WRMA, describing other services provided by WRMA and also providing the instruction to various users on how to use the system. The other major importance feature on this component was the login section. By entering the various details required the user can access the mapping interface as illustrated by Figure 4.

Figure 4: Website welcome page showing the login section

The mapping component had various mapping features to aid the user in map viewing and navigation that included: Zoom to full extent ; this tool was used to view the whole map at the default minimum scale, Back and forward ; these tools allowed one to move back or forward to previous zoom level and hence help to locate point of interest on the map, Zoom in and out ; these are tools to allow one to increase or reduce the scale of the map so as to ease in locating features of interest, Pan ; this tool aid in navigating on the map and Clear selection ; tool used to make the map fresh again by removing selection made earlier. Figure 5 shows the main interface of the mapping component.

Figure 5: Mapping interface showing map viewer section, various tools and map layers

On the mapping component also we had various capabilities that were added according to evaluation of user needs.

Data retrieval capability enables the user to obtain the information associated to various water resources and other features on the map. User is able to use the identify tool or the select tool to extract specific data related to a given feature. The identify tool is used on a single feature while select tool is used when one wants to retrieve information of several features at same time Figures 6 and 7.

Figure 6: Using 'identify tool' on a dam to get the associated information

Figure 7: Using 'select feature tool' on dams to get the associated information

Data visualization capability is also enabled on the system. The user is able to visualize the data against a Google maps (street, physical and satellite) background as shown in Figure 8. This capability allows the users to better identify the location of various water resources features without the need of going physically on the ground to locate the features. Using this capability the users can also be able to determine if the various feature for example the monitoring stations are located at the most optimal location or may require relocation. Also the users can be able to tell the condition of various water resources features without the need to carry out a field assessment by viewing them against the Google satellite images background.

Figure 8: Visualizing the location of a monitoring borehole

To use the printing map and downloading map capability, the user zooms into his area of interest the map at the required scale. Then using the print tool on the tool bar he can be able to print or download the map. The user is given an option to view the map in either image or HTML format Figure 9.

Figure 9: Printing and downloading map options

Data export capability is only available to system administrators and other high level users. To export the data one has to login into the database web interface, select the table and then choose download option and export into Microsoft Office Excel format Figure 10.

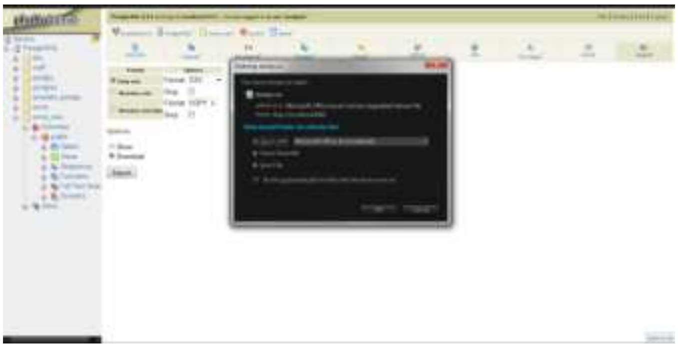

Figure 10: Exporting data into Microsoft Office Excel format

Search feature tool provides the find specific feature capability. Using this tool the user can search for specific feature information from the database. The user can either use input that 'belong to', 'begins with' or 'exactly matches' the label of the feature Figure 11.

Figure 11: Search results for a borehole

The users can also be able to edit the data in system directly on the mapping interface. By using the edit tool the user can add point, line or polygon. He can also be able to edit the attributes of a given feature Figure 12.

Figure 12: Using the feature edit tool to add a point

The users can also be able to carry out length and area measurement on the map using the length and area measurement tools respectively. The length can be measured in various units that include; feet, yard, inches, meters and kilometers. The area can also be measured in square feet, square yards, square meters, square kilometers and square miles Figure 13.

Figure 13: Measuring the length of a pipeline

4. Conclusion

The study leads to the development of an integrated solution for the management of water resources in the Athi river catchment. The system offered a solution to management of water resources information, by providing one shared database hence reducing duplication and lowering maintenance cost. It also offered a mapping interface that ensures WRMA leverages advancement in GIS technology in its service delivery. The system also offers a streamlined flow of information by having one system accessible to all WRMA offices hence ensuring there is well structured process of collecting, storing and disseminating information. From the study one can draw conclusions that Web-based GIS is a prospective application in GIS and represents an important advancement over the traditional desktop GIS. Its application eliminates duplication and inconsistency and makes location information conveniently and intuitively accessible across organizations, at a lower cost per user. Internet provides a medium for processing geo-related information and spatial information to users at an amount larger than traditional GIS.

The study lays the foundation of proper management of the water resources. It aids in realization of the social strategy under The Kenya Vision 2030 in developing water and sanitation sector which is one of the key social sector. This project can be extended to create a nationwide water resources management system that can provide services for a wide range of users, starting with government institutions and ending with private individuals.

Further improvements of the system could be made to include more water resources information and also capabilities improved to carry out analysis using the available data. Also the systems functionality can be improved such that it supports all of the procedures that are involved in the water resources management like allocation of water use licenses.

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References

[1] Asit K. Biswas, "Integrated Water Resources Management: A Reassement: A Water Forum Contribution," *Water International.*, vol. 29, Number 2, June 2004. pp. 248–256

[2] Rakesh Kumar, R.D. Singh and K.D. Sharma, "Water resources of India," *Journal of the Current\Science.*, vol. 89, Number 5, September 10.

[3] World Bank, "Sustaining water for all in changing climate", World Bank, 2010. Available:http://water.worldbank.org/publications/sustaining-water-all-changing-climate-world-bank-group-implementation-progress-report

[4] United Nations. "Kenya National Water Development Report: A Case Study of Kenya". United Nations.2006.Available: http://unesdoc.unesco.org /images/0014/001488/148866e.pdf

[5] Kenya Government, "Interim report: The Project on Development of National Water Master Plan 2030"Japan international Cooperation Agency, Nippon Koei Co., Ltd. Nairobi. 2011

[6] Hilda Moraa, Albert Otieno and Anne Salim, "Water Governance in Kenya: Ensuring Accessibility, Service delivery and Citizen Participation". iHubResearch, Nairobi, July 2012

[7] Yi Zhang, Wei Zeng and Menghong Wen, " Integrated GIS-based Water Resources Information and Assessment System" , paper presented at the 2009 Georgia Water Resources Conference, held April 27–29, at The University of Georgia. 2009.

[8] Jin-Yong Choi, Bernard A. Engel and Richard L. Farnsworth, "Web-based GIS and spatial decision support system for watershed management" .*Journal of HydroInformatics*.2005.

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