Web-based GIS-Hydrologic Modeling for Siting Water Harvesting Reservoirs

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Abstract. *Rainwater harvesting has been practiced at various scales in dry land and semiarid areas as a means to channel and store scarce rainfall for later on- farm or domestic use. The locations for water collecting structures are determined by a multitude of factors, often less than intuitive and involving compromise of interests. The Analytical Hierarchy Process (AHP) provides a systematic approach in conducting multi-criteria analysis and decision making. It allows for the comparison of alternatives based on the quantification of mostly qualitative characteristics of a given watershed/region. In this research, a Web-based GIS-hydrologic modeling system was designed to implement a spatial AHP process for selecting the most suitable and practical location for building water harvesting reservoirs. An on-line GIS digitizing tool helps user locate potential watershed, extract spatial data related to hydrologic characteristics as input for hydrologic model, which in turn produces needed runoff estimates from sub watersheds, together with land use and land cover data and experts opinions to produce a single Reservoir Suitability Index (RSI). Ranking of RSI allows for quick determination of suitable locations. The methodology was tested on a remote marginal watershed in Northeastern Lebanon. Major features and potential application of the Web-based tool are presented. The prototype technology is available at http://pasture.ecn.purdue.edu/~water/wh/.*

Introduction

Water availability is the main limiting factor in dry-land agriculture and economy throughout arid and semi-arid regions due to low annual rainfall depth and its often non-uniform temporal and spatial distribution. Water harvesting has been used since ancient times by people in dry areas to collect and supplement scarce water resources (Lavee et al., 1997). For agricultural production, rainfall collection has been practices mostly at local scale from deep percolation ditches (Abu-Zreig et al, 2000) to on-farm catchments (Carter and Miller, 1991; Li et al., 2004).

Siting of water collection structures depends on a multitude of factors, ranging from basic hydrologic characteristics of the local area (Giráldez et al., 1988; Abu-Awwad and Shatanawi, 1997) to the socio-economic interests of the government or local authorities, various interest groups and shareholders of a potential project (Srivastava, 1996).

A systematic approach to facilitate the siting of water harvesting reservoirs in dry areas was developed previously using the AHP concept and tested on a remote marginal watershed in

Northeastern Lebanon (El-Awar et al., 2000; Mohtar et al., 2003). The developed methodology locates and ranks potential sites for small water harvesting reservoirs based on a single composite RSI. The RSI for each potential site is calculated from a four-level decision hierarchy structure shown in Figure 1. Readers are recommended to refer to El-Awar et al. (2000) and Mohtar et al. (2003) for in-depth description of the AHP methodology.

The main obstacle for implementing this methodology is the intense efforts dealing with data collection, formatting and preparation for hydrologic modeling, and post processing for visualization with a desktop GIS. In this research, a Web-based GIS-modeling system is used to overcome much of these difficulties by streamlining the tasks involved in the calculation of RSI and the analysis thereafter. The proposed implementation of the AHP system is built on the foundation of an existing spatial decision support system (SDSS) (Engel et al., 2003). Although many standalone decision support systems (DSS) have been developed for several areas of watershed and water resource management, the complexity and focus on specific design tasks of many of these DSS has limited their applicability. The SDSS was developed by an interdisciplinary team and it is comprised of a modeling system (the Long-Term Hydrological Impact Assessment, L-THIA), a database system and a Web-based graphical user interface, and includes special features for users with limited hydrology knowledge. The SDSS employs Java-powered Web-GIS for Internet map browsing, online watershed delineation, and hydrologic spatial data extraction to prepare input data for the L-THIA model simulation. These enhancements assist and guide users in decision-making and increase users' comprehension of the effects of land use changes on water quantity and quality. The hydro-spatial AHP incorporates socio-economic selection criteria with the hydrologic and other physical conditions provided by the SDSS to form a decision matrix. The final calculated RSIs for potential reservoir sites after screening is displayed by the map server within user's web browser.

The focus of this paper is to present the structure of the Web-based reservoir siting system and the application of the system to a local watershed.

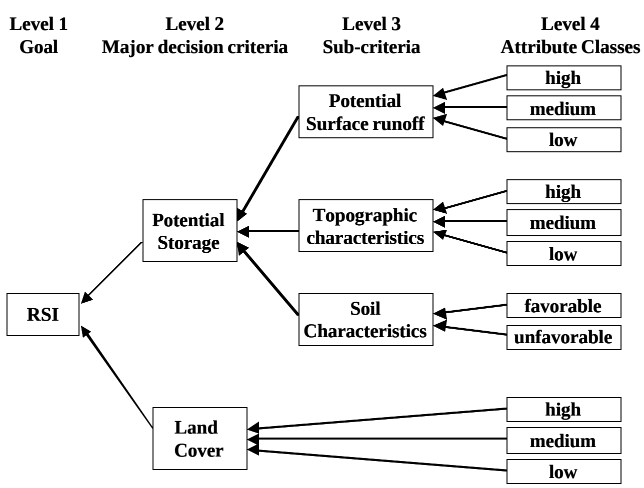

Figure 1. RSI calculation based on 4-level decision hierarchy structure. (Redrawn after El-Awar et al., 2000, figure 2)

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The Web-based hydro-spatial AHP

The previously developed hydro-spatial AHP (El-Awar et al., 2000, and Mohtar et al. 2003) comprises the following major steps: 1) identify the selection criteria; 2) use GIS and hydrologic model to extract/calculate corresponding data layers; 3) develop a decision hierarchy structure such as the one shown in Figure 1; 4) assign user preference for each of the decision criteria for the calculation of the Relative Weight (RW); 5) calculate the composite decision criterion, i.e. RSI, for all potential sites; 6) rank of the sites based on their RSI values. Steps 1, 2, 5, and 6 rely on the previously developed SDSS (Engel et al., 2003) with its online watershed delineation, database connection/data extraction, hydrologic modeling, and data layer intersection capabilities. The overall schematic web-based hydro-spatial AHP procedure is shown in Figure 2.

The Web interface starts from the target watershed delineation, which in turn determines the area for which spatial data including soil map, land use map and other hydrologic data are extracted via the Web-GIS system (powered by MapServer). During preliminary development, a watershed in the State of Indiana, USA, was used for development of the methodology, hence, bypassing the user initiated watershed selection steps. This is mainly due to data availability considerations. Users first access the system main page via URL: http://pasture.ecn.purdue.edu/~water/wh/. The first button on the left will lead to Web-GIS engine (Figure 2) to delineate watershed and extract and compute data layers. Then user click the "Calculate RSI" button in the interface to initiate the suitability index derivation process, which starts from assigning user preference for the major and sub-criteria in the decision hierarchy (Figure 1). Once user preferences are assigned, the user clicks the "Calculate decision matrix" button to calculate the actual RW for each criteria. The final step is to click the "Continue RSI map/layer calculation" button to call upon Web-GIS engine to calculate the RSI for potential sites and display results in user browser. A detailed description of the Web-GIS (MapServer) interface was given by Choi et al., (2003).

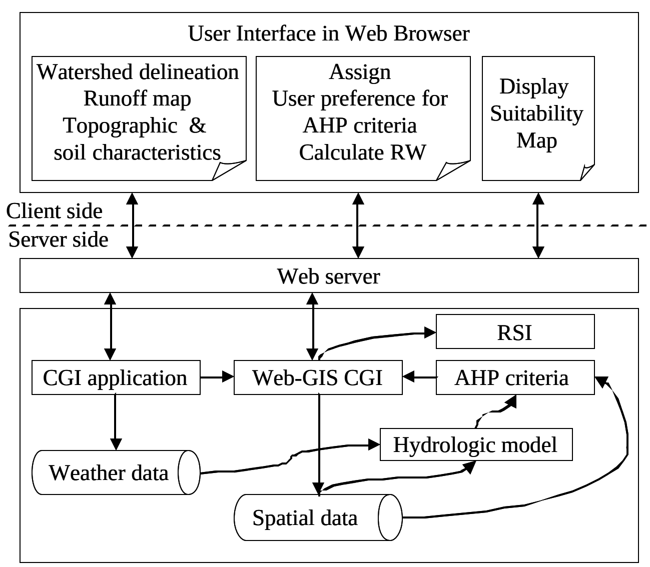

Figure 2. Schematic of Web-based Hydro-spatial AHP system for siting water harvesting reservoir

In this research, the L-THIA model was used to calculate the surface runoff used as one of the decision criteria. L-THIA estimates long-term average annual runoff for different land use types in a watershed based on long-term climate, soils and land use data for that area. It also provides comparative impact assessments of land use change in terms of annual average non-point source pollution loadings by multiplying event mean concentration (EMC) data with daily direct runoff. The EMC data were introduced to estimate non-point source (NPS) pollution loading from non-urban and urban areas. The L-THIA model was written in the "C" programming language, and an executable L-THIA program was created to run over the Web via Common Gateway Interface (CGI). L-THIA is the core hydrologic model within a locally developed web-based Spatial Decision Support System (SDSS) (Engel et al., 2003). For watershed management purpose, it has been chosen as it can be readily run through a network environment with readily available data considering connection speed, and model execution time and data requirements.

Currently, work is underway to further improve the Web-based AHP procedure on a number of issues. Foremost is the watershed delineation process carried out by the Web-GIS engine that requires a number of potential sites to be first selected. Algorithms are being explored to conduct more intuitive watershed delineation with minimum user knowledge of the target watershed. Secondly, the HEC-1 model is being explored to replace the current hydrologic model (L-THIA) for estimating surface runoff based on different distribution of potential water harvesting reservoirs across a target watershed. Thirdly, data are being assembled for the Oued Oum Zessar watershed in southern Tunisia to study the socio-economic impact from various distribution patterns of water harvesting reservoirs.

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