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Small reservoir siting 'from scratch': merging GIS-based and participatory approaches in a multi-criteria analysis

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ABSTRACT

1. Introduction

Adaptation measures are key to help communities to face natural hazards, including drought and water scarcity, in the face of climate change. As part of a research project involving the Department of Civil and Environmental Engineering at the University of Florence and the Consorzio di Bonifica 3 Medio Valdarno, we examine how the construction of small reservoirs in a rural area with multiple and competing water uses can help increase the resilience of the local water infrastructure. A reservoir is an engineering work that can occupy a portion of territory originally dedicated to other uses (e.g., agricultural areas, woodlands) or have an impact on territorial elements, for example on areas with protected landscape or existing infrastructures. On the other hand, a reservoir can offer several benefits both from a water resource perspective (availability of summer water reserve, flood mitigation, downstream groundwater recharge) and from a socio-ecological perspective (maintenance of ecological flows in the summer period, energy production, and recreational purpose). The construction of a new reservoir must consider these and many other criteria, often incommensurable, to qualify the sustainability of the planned measure. The aim of the work is to complement the GIS morphological analysis with a participatory approach to select and weight the siting characteristics in a Multi-Criteria Decision Making (MCDM) analysis for the identification of the most appropriate reservoir siting. The working hypothesis is that no prior siting study exist in the given area of interest, while in-depth site analysis prior to actual project implementation needs to be focused on a limited number of optimal sites.

2. Method and case study

The methodology is structured around three main phases: (i) the development and application of an algorithm which performs a geomorphological and geospatial analysis, (ii) the involvement of stakeholders, (iii) the MCDM approach for the best reservoir siting. The method is summarized in Fig. 1.

2.1. Geomorphological and spatial analysis

One of the most common siting methods for dams and reservoirs is based on GIS analysis, which can include many different types of variables, such as topography, hydrology, and geology (Wang et al., 2021). In this work we developed an algorithm which, based on Digital Terrain Model, for each assigned dam height automatically finds all possible reservoirs and the optimal dam orientation.

2.2. Stakeholders' involvement

A group of stakeholders with different expertise and interests has been involved since the beginning of the process, first to identify the criteria to be used in the analysis of the potential impacts of a new reservoir, second, to weight the criteria. The criteria refer to the (i) impacts of potentially submerged items within the reservoir surface, i.e., structures, infrastructures, population, economic activities, landscape, cultural heritage, environmentally protected areas, natural hazards; and to the (ii) benefits of the reservoir, i.e., resource storage, energy production, ecological support, flood hazard reduction. Weights are obtained through an online survey built as a pair-wise comparison between criteria with a rating scale, to quantify the relative importance of each criterion. The questions asked to the participants are prioritized based on the Swiss tournament method, which maximizes the occurrence of all criteria among the respondents. Weights are assigned to the criteria with the AHP method (Saaty, 1990).

2.3. Reservoir site ranking

GIS analysis is again applied to evaluate the attributes of each site according to the criteria selected by the stakeholders. A payoff matrix containing all siting alternatives and their representative attributes is built and the Simple Additive Weighting (SAW) technique is applied to rank the alternatives.

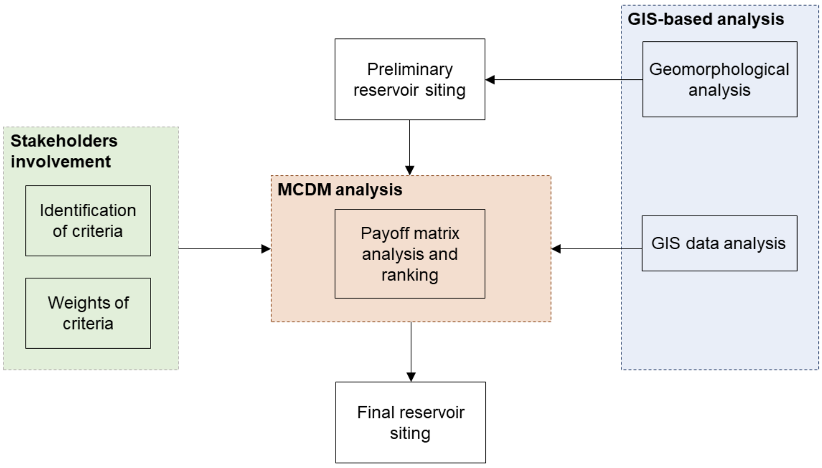

Fig. 1. Scheme of the methodology for the reservoir siting based on GIS analysis, stakeholders' involvement and MCDM analysis.

2.4. Study area

The method is applied to the Pesa river catchment (surface area 330 km^2, mean annual precipitation ca. 800 mm) located in Chianti area of Tuscany (central Italy) to identify the sites of potential new small reservoirs with prescribed constraints (dam height lower than 12 m and volume lower than 10^6 m^3). Climate change projections foresee a significant reduction of summer precipitation in the area (Spano et al., 2020) which are crucial for agricultural and civil water uses. The panel of stakeholders involved includes majors of the main municipalities, water utilities managers, hydraulic engineers, ecologists, academic researchers, and members of civil society for a total of 25 people.

3. Results

The geomorphological analysis identified and ranked approximately 180 potential reservoir sites. The answers to the paired-comparison survey were more than 2000 and the most important criteria were to minimize the impacts on (i) landslides, (ii) flood risk downstream, (iii) river ecology, (iv) resident population. Based on the SAW analysis and on new consultations with stakeholders, the 5 reservoirs which obtained the best scores have been identified for an in-depth feasibility study and preliminary engineering design.

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