A software for optimal information based downsizing/upsizing of existing monitoring networks.

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Abstract: Using reliable stochastic or deterministic methods, it is possible to rearrange an existing network by eliminating, adding or moving monitoring locations producing the optimal arrangement among any possible. In this paper, some spatial optimization methods have been selected as more effective among those reported in literature and implemented into a software M-Sanos able to carry out a complete redesign of an existing monitoring network. Both stochastic and deterministic methods have been embedded in the software with the option of choosing, case by case, the most suitable with regard to the available information. Finally, an application to the existing regional groundwater level monitoring network of the aquifer of Tavoliere located in Apulia (south Italy) is presented.

Keywords: Environmental monitoring, Spatial simulated annealing, Kriging.

1. Introduction

With the growth of public environmental awareness and the contemporary improvement in national and EU legislation regarding the environment, monitoring has assumed great importance in the frame of all those managerial activities related to environmental protection and safeguarding. The recent technical and scientific literature has produced a huge amount of papers related to the Optimal Monitoring Network Redesign (OMNR) (Barca et al., 2008; Wu, 2004). Typical OMNR problems consist in adding, removing or moving one or more measurement point in the monitoring network. Scientific literature often refers to these cases as upsizing, downsizing and relocation. In general, the OMNR is an optimization problem solvable through the quantitative formulation of one or more objective functions (OF), whose minimization can be achieved iteratively through various network configurations that meet specific conditions of theoretical and practical nature. The choice of the OF strongly depends on the goals and the information available. Among the iterative optimization methods, one of the most cited in the literature is the so-called Spatial Simulated Annealing (SSA) (Kirkpatrick et al., 1983; Van Groenigen et al., 2000). Many of the methods developed for OMNR require a huge computational effort, consequently, some authors developed software able to perform this task which, however, generally deals only with one of the possible aspects of OMNR (Hu and Wang, 2010; Naoum and Tsanis, 2004; Jimênez et al., 2005; Van Groenigen and Stein, 1998; Passarella et al., 2003).

This paper presents a software developed in MATLAB able to solve any OMNR problem. It allows one to use several approaches (deterministic, stochastic, mixed), techniques (SSA, Greedy deletion) and OF (kriging variance estimation, geometric parameters). A case study based on the downsizing of the groundwater level monitoring network of the Apulia Region located in the aquifer of Tavoliere (Southern Italy) is presented. Three piezometric stations have been removed from the existing monitoring network, made of 30 measurement stations.

2. Materials and Methods

The proposed software is fundamentally made by a Network Downsizing Module and a Network Upsizing Module, which allows one to solve 3 different OMNR related problems: (i) removing points from an existing monitoring network; (ii) adding new points to the monitoring network; (iii) moving points from the existing location to another one as a combination of (i) and (ii). The proposed software provides suitable techniques able to produce reliable optimal solutions to different OMNR problems once the goals have been focused and the available information has been evaluated. The backbone of the software is the Spatial Simulated Annealing (SSA).

Other three modules complete the software architecture: an Input Module, an Output Module and an optional Variography Module (Optional). The input module has been designed in order to support the user in this phase which is strongly dependent from the problem, the goals and the available data. An optional variography module has been added to the software capable of performing a best fit of a model to the experimental variogram. Once the input phase has been completed the software starts running, showing, real time, the evolution of the current transitory optimal configurations. The output of the software consists in a list of the coordinates of the redesigned monitoring network together with some statistics and plots representative of the convergence rate of the method. The software has been named M-SANOS (MATLAB SANOS) in order to honour the well known software SANOS (Spatial ANnealing for Optimal Sampling) proposed by Van Groenigen and Stein (1998) which is the first approach to OMNR based on SSA. Starting from SANOS, new options have been implemented in M-SANOS, as the downsizing module, new OFs and heuristics. Several study cases have been implemented in order to test the software reliability and efficiency. As an example, a case study referred to the downsizing of the groundwater levels monitoring network, consisting of 30 piezometers, and located in the aquifer of Tavoliere in the Apulia Region (Italy) is presented. The study area extends over 1275 km^2 and it corresponds to the largest alluvial plain of southern Italy (fig.1). The simulation concerned the elimination of three wells from the original configuration.

3. Results

The Mean KEV (kriging estimation variance) has been used as OF for the case study simulation to reach the goal of increasing the accuracy for kriging estimations to be carried out at unsampled points over the monitored area. Figure 1 shows the study area and the starting monitoring network. A gaussian variogram model has been fitted to the experimental data. After about 1300 iterations, the method converged to the optimal configuration characterized by a correspondent value of the OF of 0.433. Figure 2 shows the resulting configuration; the three empty dots are those removed by the optimization method, while Figure 3 shows the behaviour of the correspondent value of the OF (*fitness value*) vs. the iterations and the final configuration.

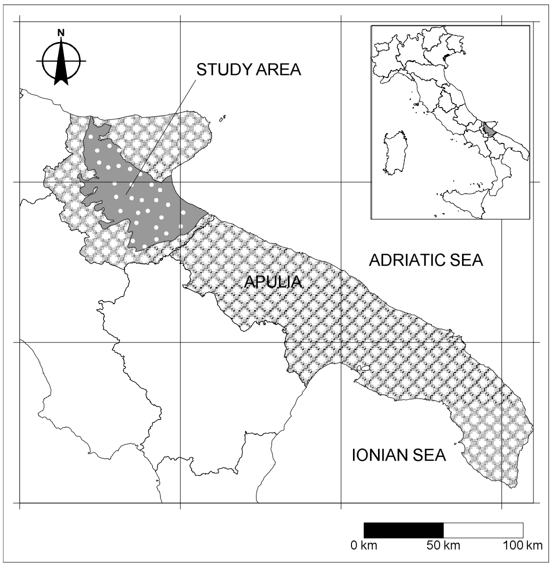

Figure 1: Study area.

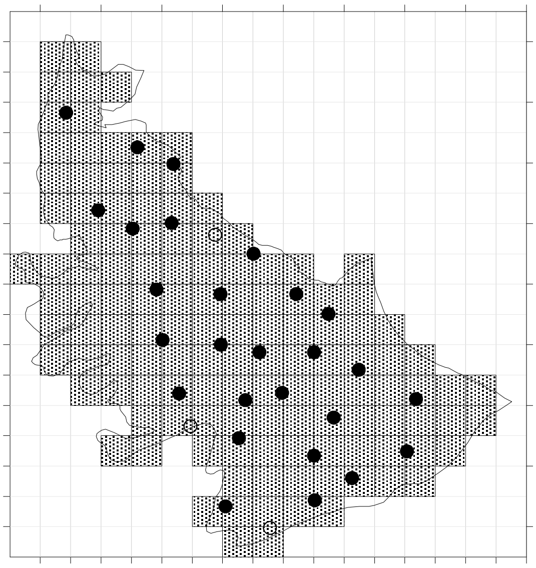

Figure 2: Results of the simulation: greyed background = simulation grid; empty dots = removed monitoring points.

In order to evaluate the effectiveness of the method applied, the optimal network configurations has been verified through complete enumeration. In practice, all the possible $\binom{30}{3}$ = 4060 configurations have been generated and the minimum value of the OF has been evaluated. This value corresponds exactly to the *fitness value* of the optimal configuration resulting from the simulation. Figure 4 shows the values of the OF (mean KEV) for all the possible configurations of the monitoring network in descending order. It confirms that the minimum value, corresponding the global optimum, is just 0.433.

4. Concluding remarks

A software for optimal monitoring network redesign (OMNR) has been presented able to add and/or remove measurement points from an existing network. It allows one to use stochastic and deterministic approaches and to select among different objective functions (OF) covering the main desired goals of optimization. The software works in MATLAB environment and it is provided of different computational modules embedded within a graphical user interface. A case study has been presented related to the downsizing of the groundwater level monitoring network of the aquifer of Tavoliere in Apulia (South Italy). Nevertheless, many other validation tests have been performed in order to assess the software reliability and efficiency. All these tests provided excellent results. Further developments of the software have already been scheduled in order both to add new objective functions and improve the user interface.

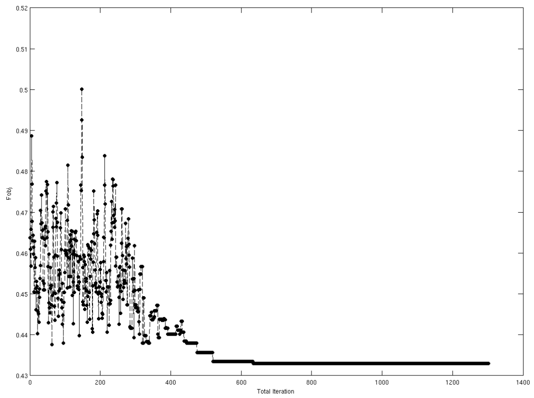

Figure 3: Behaviour of the current transitory optimal energy (*fitness value*).

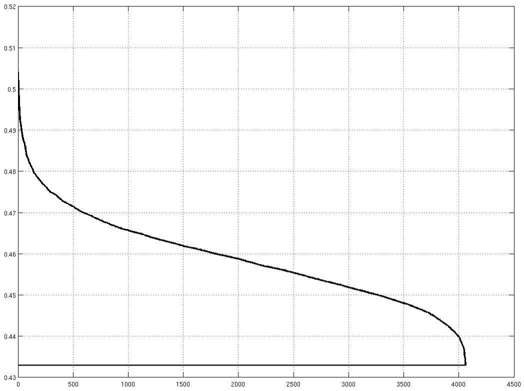

Figure 4: Values of the objective function (mean KEV) for all the 4060 possible configurations of the monitoring network.

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