A Comparative study of Multi-objective Optimization techniques for GIS-based resources allocation problem in Disaster management

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Abstract

In spatial context, resources allocation is defined as the distribution of available resources to different demand locations. However, optimal resources allocation remains a problem to various actors. This explains the need for appropriate analysis techniques to ensure efficient resources allocation .Most analysis of efficient resource distribution request to deal with more than two conflicting factors, such as environment, economic cost, time, distance costs, and landscape. This research aims at comparing the four most known nature inspired meta-heuristic algorithms from the class of Evolutionary Algorithms (EA) and Swarm Intelligence optimization algorithms (SI). These algorithms are the most used to find optimal locations for spatial planning. The resulting models may differ from one algorithm to another depending on their optimization competencies. These algorithms are compared based on their performance and modelling complexity depending on the expected context for their use, evacuation planning. Among the tested algorithms, NSGA-II shows potential to provide optimal solutions whereas AMOSA can give a wide range of best results. MOABC has the potential to be easily adapted in different context depending on its ability for hybridization.
Key words: Disaster Management, resources allocation, multi-objective optimization, GIS, MODA.

1. Introduction

Spatial decision problems are faced in many forms in the real world. A decision maker has a role to play in all involved complex senarios in problem solving and decision making. And appropriate tools and techniques are of capital importance in supporting the decision maker.

Resources allocation is among the spatial decision problems that are faced in all phases of disater management life cycle (mitigation, preparedness, response and recovery). Most of spatial decision problems in disaster management involve a large set of possible alternatives and a set of conflicting objectives with spatial constraints. Although, Geographic Information System (GIS) is known as a powerful tool to support decision making; it has limitation on solving such real word problems with multiple conflicting objectives. Over the last twenty decades, research proved a potential benefits of using integration of GIS and Multi-Objective Decision Analysis (GIS_MODA) techniques in many GIS-based research areas including disaster management (Caunhye et al., 2012).

Among the used techniques, evolutionary algorithms (i.e. Genetic algorithm, NSGA-II) are the most integrated with GIS to tackle decision problems with spatial context (Malczewski 2004, Saadatseresht et al., 2009). Recently, the swarm intelligence algorithms have been also involved in few applications of disaster management. The MODA techniques showed the good impact of performance and can provide trustworthy results rather than classic methods (Malczewski, 1999; Ehrgott och Figueira, 2010; Malczewski & Rinner, 2015). However, less have involved swarm intelligence algorithms and almost none has evaluated the performance of four meta-heuristics algorithms to solve a spatial optimization problem (Song och Chen 2018).

This research aims to investigate on the performance of four natural-inspired Evolutionary and Swarm Intelligence algorithms; including Non-dominated Sorted Genetic Algorithm-II (NSGA-II), Standard Particle Swarm Optimization (SPSO), Archive Multi-Objective Simulated Annealing (AMOSA) and Multi-Objective Artificial Bee Colony (MOABC). These four algorithm will be tested on evacuation planning application. The study area is a part of City of Kigali, in the country of Rwanda, Central-East Africa (Fig 1).

2. Methodology

A GIS-based multi-objective optimization method (GIS-MOD) define a real world problem in terms of a model that includes a set of number of decision variables, a set of objective functions to be optimized and parameters that represent a set of constraints subjected to decision variables. Spatially, constraints and decision variables of the problem must have spatial characteristics (i.e. location, connectivity, and distance, and direction, shape of area and perimeter of boundaries.

Mostly in urban area with dense population like Kigali city, the evacuation plan requires to allocate people from the locations where they are (working places or residential zones) to a limited number of safe areas, which have a total carrying capacity lower than the population that needs to be evacuated.

To handle this problem, there are two main objectives to address. Those include to optimize how people are distributed into the safe places; and to optimize the total displacement (meters per person) required to evacuate the dangerous areas.. Those objectives are conflicting each other thus they must be optimized simultaneously to provide decision maker a traded off solutions to the problem.

In order to fulfill the rules of natural inspired algorithm, the defined objective functions are formulated into two equations.

a) Function to minimize distance (distance):

$$f_{distance} = \sum_{j=1}^{n} \sum_{i=1}^{m} d_{ij} p_{ij} \quad \ldots\ldots\ldots\ldots(1)$$

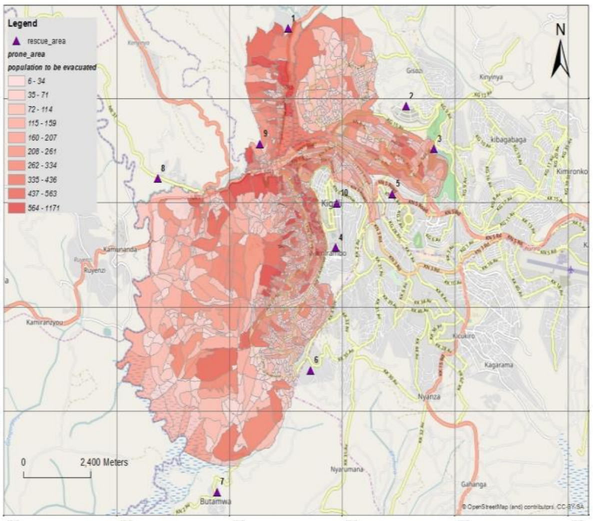
b) Function to minimize capacity of safe area (capacity overload):

$$f_{capacity} = \sum_{j=1}^{n} abs \frac{\sum_{i=1}^{m} p_{ij}}{c_j} - 1 \quad \ldots\ldots(2)$$

Where: m represent number of decision variables (point of origin) of people; n is the number of safe areas, d_{ij} is the distance between the i^{th} point of origin and the j^{th} safe area; p_{ij} is the population in the i^{th} point of origin being evacuated to the j^{th} safe area; and c_j is the capacity of the j^{th} safe area for receiving people.

In order to investigate on the performance of the four selected algorithms (NSGA-II, SPSO, AMOSA, and MOABC), Pareto front Size and effectiveness of the optimisation were key considered metrics. However, cost function and modelling complexity were among considered criteria. Algorithms that shown a low cost of function and low time to perform (modelling complexity) were consider to be better performing than others. It is recognized that there are other parameters which can impact the performance of these algorithms but evaluated parameters are recognised to be key factors for algorithm performance evaluation.

Figure 1 : Map of study area for evacuation planning



Source: By the author, 2018

3. Preliminary results

The performance evaluation of the four selected algorithms (NSGA-II, SPSO, AMOSA, MOABC) using the above-mentioned criteria revealed the high potential for NSGA-II to provide optimal models whereas MOABC shows high potential for hybridization. SPSO has near level of hybridization to MOABC whereas AMOSA shows the potential to provide a wide range of results which can give enough options to decision makers. In regards to evacuation planning in the Rwandan context, hybrids of these tested algorithms can provide effective options for decision makers. Figure 2 shows Pareto front of each evaluated algorithm and table 1 shows summarized results on the performances of each algorithm based on evaluated criteria (Annex I).

Conclusion

All tested algorithm have their strengths and weaknesses. For disaster management in the Rwandan context, where an optimal resources allocation can be ensured through a proper evacuation planning. Tested algorithms can contribute in developing a hybrid algorithm that has the competencies to provide large results with optimal locations. A hybrid of MSGA-II and MAOBC can be among the best options to explore for developing as suitable evacuation plan for disaster management in Rwanda. However, possibilities for other hybrids can be explored depending on dynamics in evacuation planning factors.

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Annex I

Table 1: Summary results of algorithms performance

Parameter	First Pareto front size	Minimum $F_{capacity}$	Minimum $F_{Distance}$	Execution time
MOABC	11	33.93894	1142195406	00:16:52
NSGA-II	18	38.7723	108231280	00:30:47
AMOSA	42	17.51963	976334680.7	00:02:43
SPSO	6	36.34922	1114143378	00:14:34

Source: By the author, 2018

Figure 2: First Pareto front presentation.

Source: By the author, 2018.