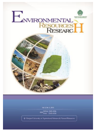

Environmental Resources Research

Vol. 4, No. 2, 2016

GUASNR

LAGA: Software for Landscape Allocation Using Genetic Algorithm

H.R. Kamyab[1*], A.R. Salmanmahiny[2], M. Shahraini[3]

[1]PhD Graduate, Faculty of Fisheries and Environmental Sciences, Gorgan University of Agricultural Science & Natural Resource,Golestan, Iran.

[2]Associate Professor, Faculty of Fisheries and Environmental Sciences, Gorgan University of Agricultural Science & Natural Resource, Golestan, Iran.

[3]Assistant Professor, Collage of Engineering & Technological, Golestan University, Golestan, Iran.

Received: August 2016 ; Accepted: September 2016

Abstract

In this paper, Landscape Allocation using Genetic Algorithm (LAGA) is introduced as aspatial multi-objective land use optimization software. The software helps in searching for optimal land use when multiple objectives suchassuitability, area, cohesion, and edge density indices are simultaneously involved. LAGA is flexible and easy to use for optimizing the spatial configurations of land use. LAGA uses a steady-state genetic algorithm with one-point crossover and flip-mutation as genetic operators. A major novelty is that spatial changes are performed according to patch topology that allows changes of different landscape elements to integrate simultaneously; this improves the speed and performance of the process. Another feature of this software is that exclusion areas (i.e. cities, roads and water bodies) can be locked or unlocked in the optimization process. The program reads and writes maps in Arc ASCII raster format which is supported by many GIS (e.g. ArcGIS/ArcView, GRASS, and IDRISI). LAGA has been applied to Gorgan Township as a case study to find optimum land use. The results suggest that LAGA can be a useful tool for land use planning.

Keywords:Genetic algorithm, Land use allocation optimization, Landscape metrics, LAGA software

*Corresponding author; kamyab.hr@gmail.com

1. Introduction

Land use optimization is a method of resource allocation defined as the process by which different activities or land uses are allocated to specific units of land area (Cao *et al*., 2011). There is an increasing demand for tools that support the planning process and specially land allocation. One of the most complex tasks in this process is optimally allocating land use categories to spatial units, resulting in a land use zoning map (Porta *et al*., 2013). In recent decades, a higher demand for optimized land use allocation has been emerged, but despite all efforts, few user-friendly software packages have been developed for the implementation of the process. Perhaps the most important available tool to allocate land use is Multi-Objective land allocation (MOLA) in Idrisi software that allocates land use based on the suitability and contiguity (in the Terrset version).

This paper presents the software for Landscape Allocation using Genetic Algorithm (LAGA). This software integrates the C++ library for genetic algorithms GALib (Wall, 1996) to optimize land use allocation spatial structure based on landscape parameters and land suitability. The step we have taken is to make it user friendly by providing a user interface and allowing the use of GIS raster data structure. Theoretically, the LAGA software can be used for any regional land use optimized allocation. The ultimate goal of the software is land use optimization through maximization of the suitability, improvement of landscape parameters, and minimization of area condition violation.

Like most programs dealing with complex spatial optimization problems (however, for very few of them, a user-friendly software has been developed for the intended purpose), LAGA uses genetic heuristic search algorithm for land allocation process. This optimization algorithm approaches a global optimum solution in an iterative directed search (Goldberg, 1989). It has been applied to land use allocation optimization problems and has proven to be effective in earlier studies (Stewart *et al*., 2004; Cao *et al*., 2011, 2012; Porta *et al*., 2013; Stewart and Janssen, 2014; Liu *et al*., 2015). The method is based on the principles of natural evolution and uses terms such as genes and individuals and operators as selection, crossover, and mutation (Porta *et al*., 2013). In biological evolution, genetic algorithm is an effective way to transform a population of chromosomes to a new population through a natural selection process involving factors such as mutation and crossover. Additionally, the use of GA for global optimization offers the ability of parallelization in the optimization process (Seppelt and Voinov, 2002).

LAGA utilizes a steady-state genetic algorithm with one-point crossover and flip-mutation as genetic operators and usestheLUPOLib package developed by Holzkamper *et al*. (2006) in its core. The objective function is specified so that it solves land use planning problem while maximizing the set criterion. One innovative feature is that changes are performed based on a user-defined patch topology. Structure and pattern of the patches in LAGA is flexible and changeable according to user requirements. Land use for each patch is changeable and if the area is not in one of the patches (in other words, the area is not included in the patch extraction process), its land use will be preserved.

In genetic algorithms, each land use layer is introduced as an individual (chromosome) of the population. Each patch in the layers can be considered as a gene. The two processes of crossover and mutation are used to escape from local solutions to an overall solution. The process of evolution is based on the objective value by each layer of land use at each stage of the process. In general, the steps for using genetic algorithms in LAGA software can be shown as Figure 1.

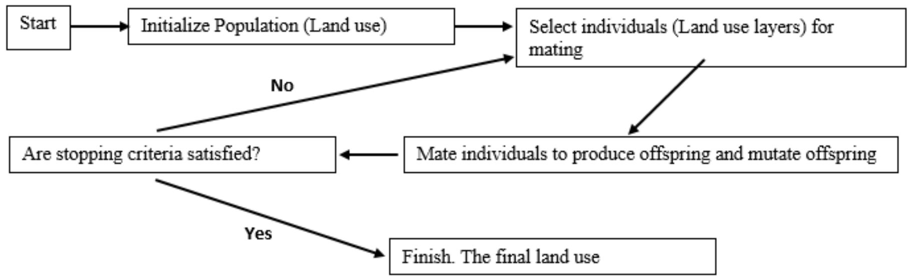

Figure 1. Overview of Genetic Algorithm approach for land use planning in LAGA

1. LAGA Software Structure

LAGA Software is based on C/C++ library for the spatial optimization of spatial land-use patterns. It integrates the GALib (Wall, 1996) C++ library for genetic algorithms and provides an interface between the genetic algorithm and land use planning through a spatially explicit landscape approach. LAGA includes functions for reading and writing raster maps, the definition of the landscape representation, and algorithms for deriving a user-defined patch topology for calculating landscape metrics, query functions (Holzkamper et al., 2006), and a function for applying land allocation at the landscape level. Cell structure turns into a patch structure to reduce the computation time in optimization. Patch units are identified by unique ID's. There is an ability to extract patches (genes) from current land-uses as well as a user-defined facility in LAGA. The objective function in LAGA is set such that land use allocation for each region maximizes suitability and landscape structure. The first version of the LAGA software is presented to optimize the land use allocation based on suitability, area, and landscape metrics (Figure 2).

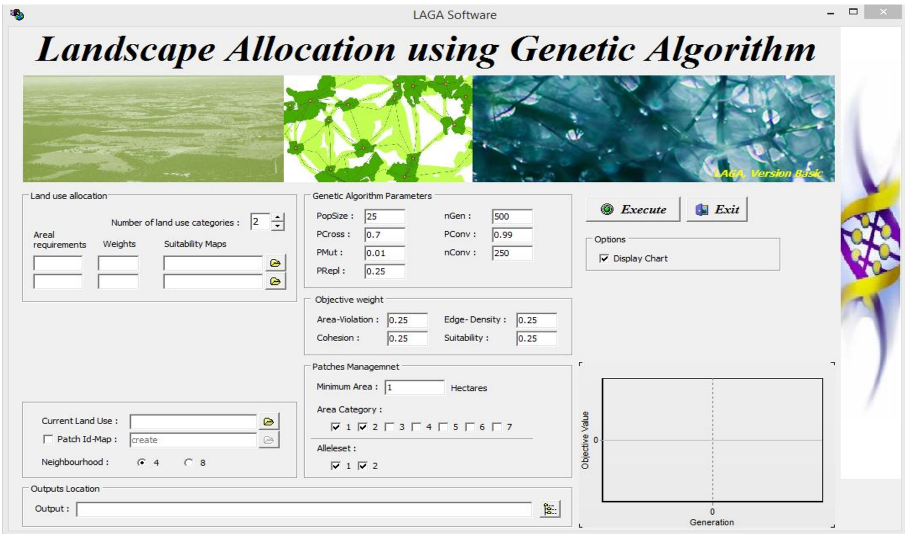

Figure 2. Structure of LAGA software

2. Application of LAGA

Application of LAGA entails taking six steps which are explained in the following sentences. A case study of (Gorgan Township) is also presented to investigate the performance of the software. Gorgan is located in the north eastern part of Iran close to the Caspian Sea (Figure 3). The city is the capital of the Golestan Province which is limited to 54° 10'-54° 45' E and 36° 44'- 36° 58' N with a surface area of around 1316 KM^2.

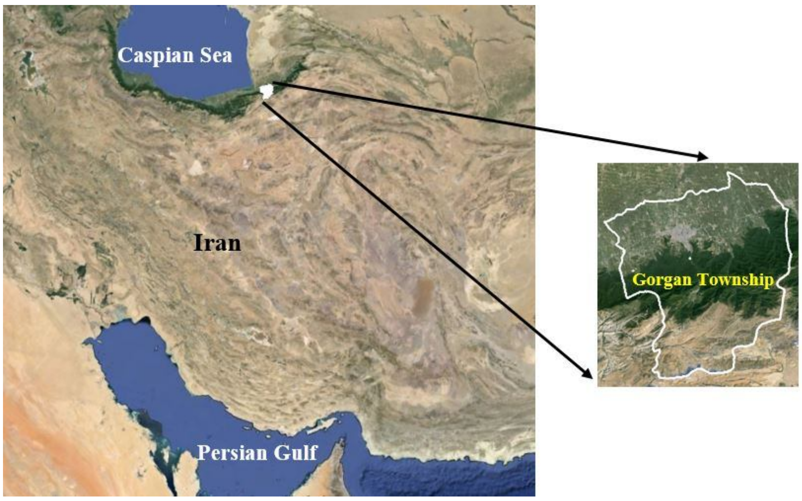

Figure 3. Study area

2.1. Land Use Allocation

In this step, areal requirement, weight, and suitability layer for each land use category are assigned. Table 1 shows areal requirements and weights for allocation to each land use for Gorgan Township.

Table 1. Areal requirement (Hectares) and weighting

Land use	Current area	New area in LAGA	Change	Weight
1. Development	4395.5	500	+500	0.25
2. Forest	35259.3	34259.3	-1000	0.25
3. Rangeland	15297	16797	+1500	0.25
4. Agriculture	48656.6	47656.6	-1000	0.25
5. Water bodies	1036.2	0	0	0
6. Road	3278.9	0	0	0
7. Protected area	50059.5	0	0	0
Changeable(1,2,3,4 above)	99212.9	0	0	0
Non- Changeable(5,6,7 above)	58770.1	0	0	0

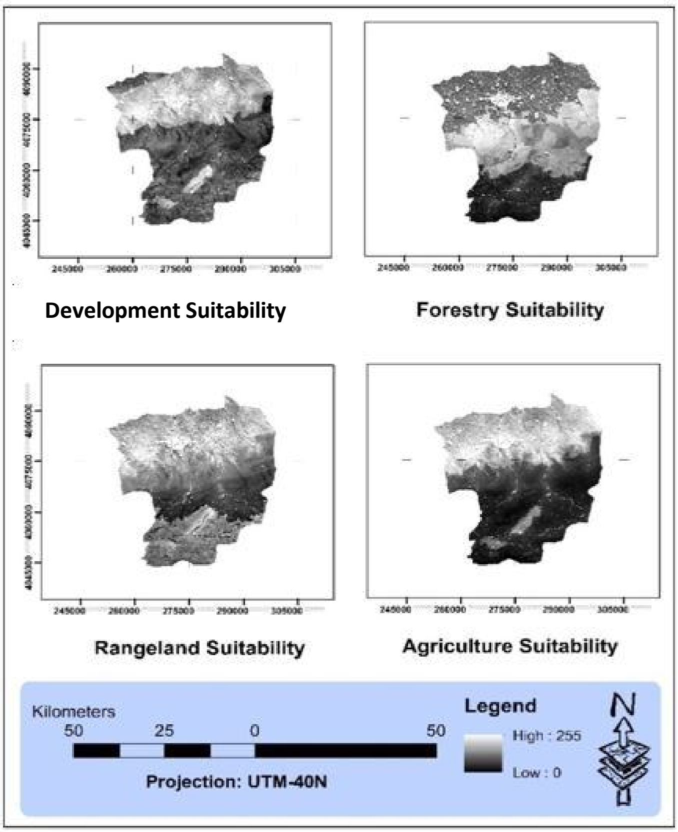

Figure 4. Suitability layers created through MCE approach(Gorgan Township)

Suitability layers can be created using a suitable method such as multi-criteria evaluation (MCE) approach. To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Land-use suitability assessment (LSA) is one of the key processes of land-use planning (Yu *et al*., 2011). Due to the large number of factors involved in decision making, LSA can be identified as a multi-criteria evaluation (MCE) approach. The most important task of LSA is to classify specific areas of land in terms of their suitability for defined uses (FAO, 1993).

Many methodologies have been proposed in this respect; weighted averaging (Malczewski, 1999) is the most common and basic approach where continuous criteria (factors) are standardized to a common numeric range (0-255) and then combined by means of a weighted average (Eastman, 2012). The result is a continuous mapping of suitability. Figure 4 shows suitability layers for each land use. It is important to note that these layers must be in ASCII format for LAGA. Value range for these layers are 0-255; higher value means more suitability.

2.2. Genetic Algorithm Parameters

These steps allow the user to control the genetic algorithm parameters. Table 2 describes parameters and their default value.

Table 2. GA parameters and their default values in LAGA

Parameters	DefaultValue	Description
PopSize	25	population size
PCross	0.7	crossover probability
PMut	0.01	mutation probability
PRepl	0.25	replacement probability
nGen	500	maximum number of generations
PConv	0.99	convergence criterion
nConv	250	convergence parameter

The large number of possible modifications not only offers great opportunities to optimize performance, but also makes the finding of robust and optimal GA configurations difficult (Pereira *et al*., 2005). Hardly any general rule exists to guide parameter adjustment. In this paper, parameter configuration was derived based on similar previous applications (Seppelt and Voinov, 2002; Venema *et al*., 2005)

2.3. Objectives Weights

The objective function for land allocation have four sub-objectives including suitability, area violation, cohesion, and edge density indices (Equation 1).

Equation 1:

$$Objective\ Function = \boldsymbol{Maximize}[\,Weight1 * \sum_{LUs} Suitability + Weight2 * \sum_{LUs} Cohesion + Weight3 * \left(1 - \sum_{LUs} Area\ Penalty\right) + Weight4 * \left(1 - \sum_{LUs} Edge\ Density\right)]$$

Suitability is extracted from layers generated through MCE approach. Landscape metrics are calculated according to McGarigal *et al.* (2002). Patch cohesion index measures the physical connectedness of the corresponding patch types. Cohesion index increases as the class type becomes more clumped or aggregated in its distribution; hence, more physically connected. Edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size. In this step, different or equal weights can be assigned to each of sub-objectives. Table 3 shows the assigned weights for these sub-objectives.

Table 3.Objective weighting

object	weight
Area-Violation	0.35
Edge-Density	0.1
Cohesion	0.2
Suitability	0.35

Assigning weight to each of these sub-objectives has a direct impact on the output results. More weight to suitability or landscape metrics improves these in the optimized land use at the cost of lowering other sub-objectives.

2.4. Patch Management

Because LAGA is patch-based software, area units can be defined in two ways. ID-maps that identify decision units for the optimization can either be derived from land use map by LAGA or read in as preprocessed ASCII raster-files (e.g. to exclude protected areas from changes). The first method is used here. A land use map is needed as input in Arc ASCII raster-format.

The following sources were used to create land use map:

- ✓ Landsat ETM+ remote sensing data,
- ✓ Classified data from MODIS sensor, and
- ✓ NDVI data from SPOT and MODIS.

We created a final land use map using maximum likelihood (MAXLIKE) classification method. Kappa index for land use was 90% (Figure 5).

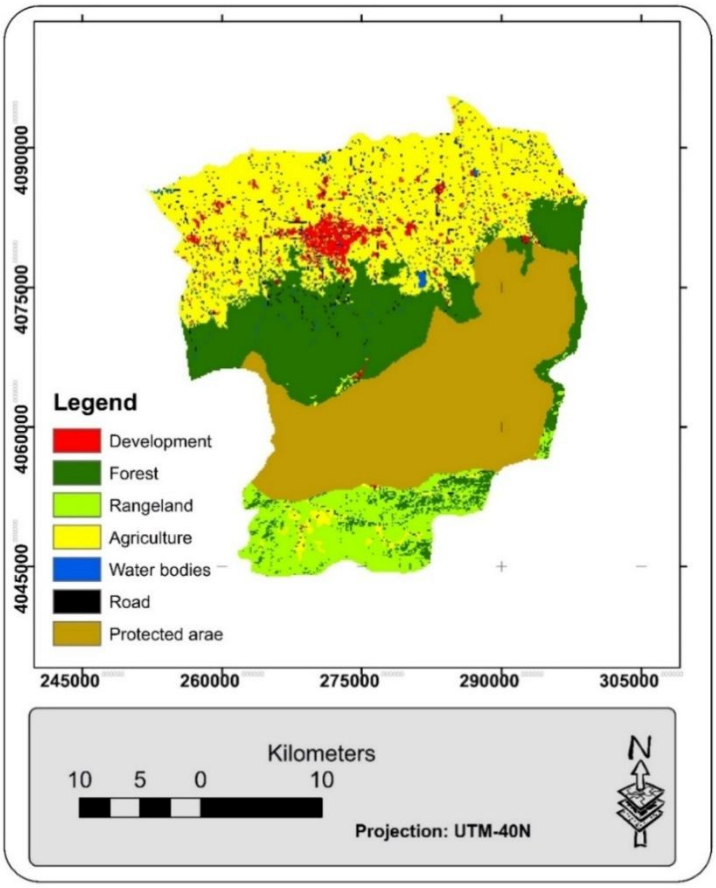

Figure 5. Land use map (Gorgan Township)

Land use in designated patches (of areas) is changeable, whereas the remaining landscape persists. Developed areas, roads, water sources, and protected areas are not included in the patch extraction process, so they are not touched during the optimization process.

2.5. Output Location Definition

In this step, output data location generated by the LAGA can be introduced. The main productions of this step include an optimized land use layer according to the parameters entered in pervious steps and an area unit layer extracted from the land use (if patch area is defined independently). Figure 6 shows the optimized land use based on genetic algorithm parameters and the current land use in Gorgan Township.

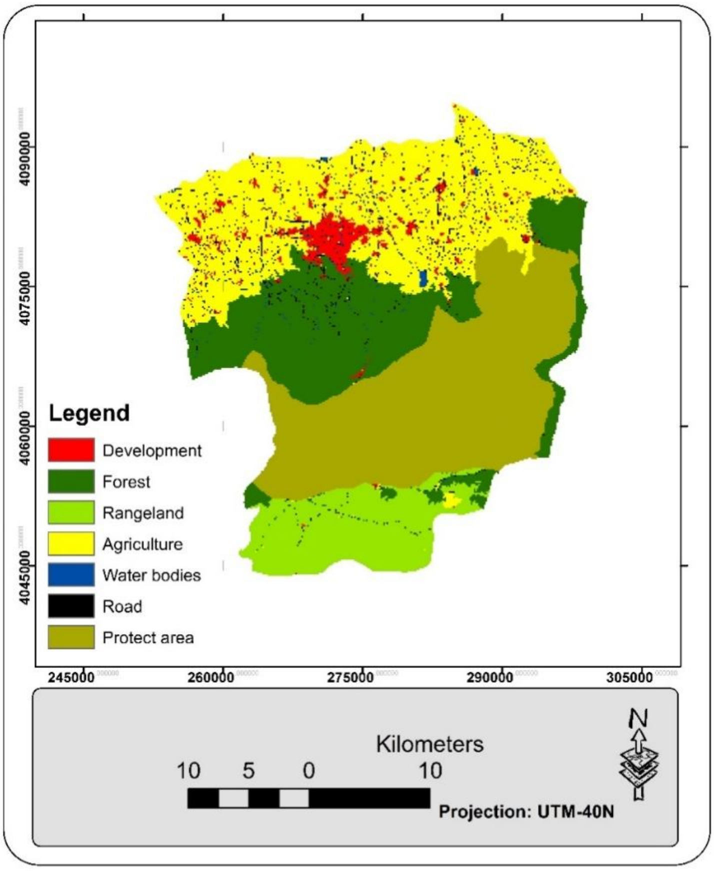

Figure 6. Optimized land use for Gorgan Township

2.6. Execution and the Results

The optimization chart in LAGA shows the objective function values versus the number of generations. This chart has an ascending trend (Figure 7) which is good as the objective function has been defined for maximization.

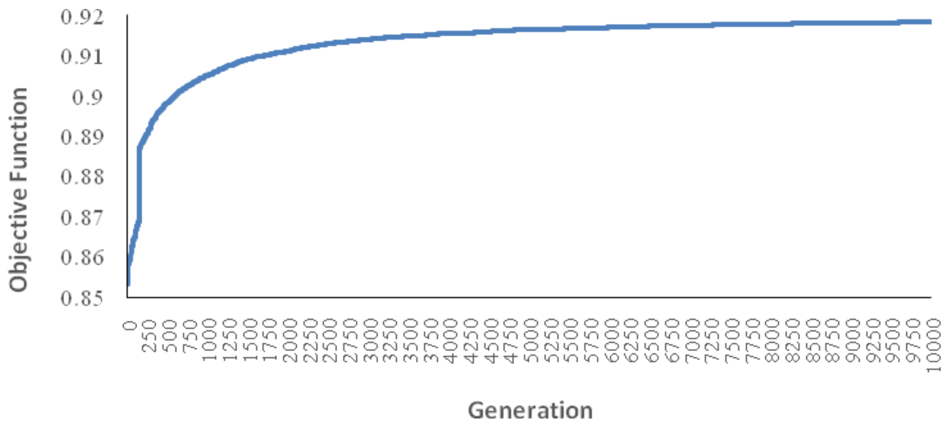

Figure 7. Objective function scores versus number of generations

2.6.1. Comparison of the Optimized and Current Land Use

The optimized land use layer shows changes compared to the current land use. As stated before, the objective function was based on four objectives including suitability, area violation, cohesion, and edge density indices. Therefore, the results generated through the genetic algorithm optimization are analyzed and compared with the current land use in terms of these four objectives to provide a better understanding of the results of the optimization approach (Table 4).

Table 4. Comparison of three objectives between the current and the optimized land use (LU)

Indices / Land use	Suitability		Cohesion index		Edge density index	
	Current LU	Optimized LU	Current LU	Optimized LU	Current LU	Optimized LU
Development	168	167.8	89.5236	89.7237	1.3797	1.2714
Forestry	179	180.9	99.2291	99.4863	4.1409	2.6198
Rangeland	170	171	99.1817	99.2233	2.9246	1.7226
Agriculture	203	204.9	99.4029	99.4737	4.6666	3.5272

The suitability has slightly increased after the optimization. While suitability of the land uses increased using genetic algorithms optimization, landscape metrics also improved. Using the optimization approach improved landscape indices for all land uses. Cohesion index was also increased; however, the edge density index decreased.

The measure of success is slightly different for area parameter. In optimization approaches such as genetic algorithm, the goal is achieving near-optimal solutions. Therefore, exact achieving of the area defined by user is probably not possible. The objective function in LAGA software does not try to achieve the exact area set as goal. By defining a penalty function in LAGA, the higher is the area violation, the lesser the chance to continue evolution in genetic algorithm becomes. Table 5 shows the achieved area for each land use after optimization.

Table 5. Area(Hectares)comparison after optimization.

Land use	Current area	New area in LAGA	Defined change by user	Area after optimization	Change	Goal achievement (%)
Development	4395.5	500	500	4755.2	359.7	71.94
Forestry	35259.3	34259.3	-1000	34130.9	-1128	88.62
Rangeland	15297	16797	1500	17244	1947	77.04
Agriculture	48656.6	47656.6	-1000	47478.5	-1178	84.88

There is a violation in optimized land use layer. The violation can be controlled using change in weight assignment to objectives in LAGA. More weight leads to more cost for area violation in optimization. Most violations were related to the developed land use which achieved 71.9% of expected area.

3. Conclusion and Discussion

The optimization problem addressed in LAGA encompasses a very complex combinatorial problem. The case study dealt with the optimum allocation of multiple land-use options with respect to suitability, area violation, cohesion, and edge density indices for Gorgan Township. In LAGA, a genetic algorithm (GA) was applied for optimization, a heuristic method, which approaches a global optimum solution based on a concept that adopts the principle of genetic evolution (Goldberg, 1989). Genetic algorithms can be more powerful if the solution surface has many local optima as is the case in land use planning problems.

In GA, there is the possibility of many modifications that affect the optimization process. For example, different settings of GA parameters (GA-population size, crossover probability, mutation probability, and convergence criterion/number of generations) can be applied to enhance the optimization performance. The precise optimum parameter configuration will always be specific to the optimization problem. Actually, choice of the most authors for genetic algorithm parameters are based on guidance from other studies (Moore *et al*., 2000) or preliminary experiences (Venema *et al*., 2005). Our results indicate that the genetic algorithm performed well in optimizing land use patterns with respect to the multiple spatial objectives. The algorithm converged after a moderate number of iterations and the variance of optimization results between different optimization runs was close to each other.

Figure 8 shows a total of 10 different iterations with the same parameters using genetic algorithm in LAGA. Due to the nature of random search in GA, changes in the first generations are relatively high. However, after a number of iterations and the increase in the number of generations, the algorithm's results converge more and get closer to each other.

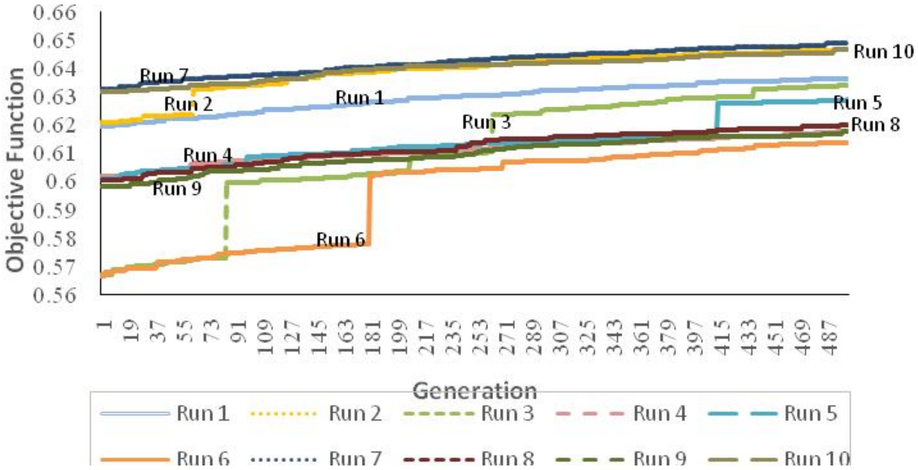

Figure 8. Variations of objective functions after 10 runs

In other words, the variance of the objective function in various runs is reduced with the evolution of the genetic algorithm (Figure 9).

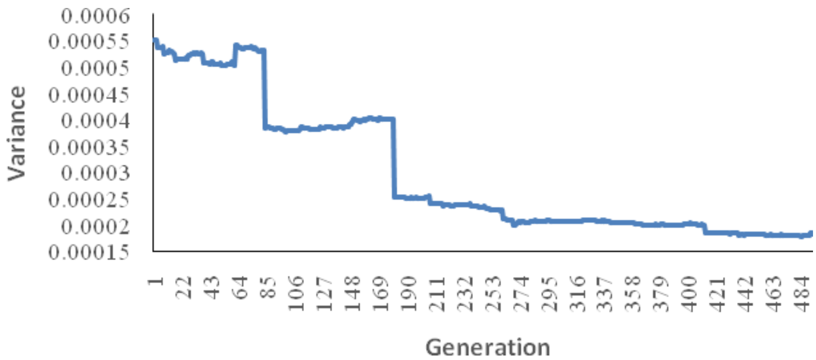

Figure 9. Variance of the objective function over the runs

Spatial optimization, as it was performed with the developed optimization framework in LAGA, has much potential to support land use planning decisions. LAGA Software provides a user-friendly structure to define various parameters and thus facilitates land use allocation in spatial planning. The structure of the LAGA is very simple and land use allocation process parameters can be easily controlled. Instead of using cell-based approach, the patch-based approach is used in LAGA which reduces the complexity of the land use allocation and increases its applicability in real situations. The outcomes of the LAGA demonstrate the great value of spatial land-use optimization for supporting spatial planning decisions based on landscape structure. Potential users of land use planning cannot be necessarily familiar with the concepts of optimization using GA, but LAGA provides a user-friendly environment to facilitate user-adjustments for specific spatial allocation problems. However, some limitations may still prevent the application of LAGA for practical planning problems; one of the main limitations is the size of the area considered in LAGA.

Further scientific applications of LAGA could integrate different objective functions and different management options. Not only land-use planning, but also hydrological, ecological or economic functions could be considered. However, the parallel processing of the method should be considered first to resolve the size limitation and the number of objective functions when using LAGA.

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