Indian Journal of Science and Technology, *Vol 8(S3), 118–129, February 2015*
ISSN (Online) : 0974-5645
ISSN (Print) : 0974-6846
DOI: 10.17485/ijst/2015/v8iS3/60700

Sustainable Spatial Land Use Optimization through Non-dominated Sorting Genetic Algorithm-II (NSGA-II): (Case Study: Baboldasht District of Isfahan)

Mahmoud Mohammadi*, Mahin Nastaran and Alireza Sahebgharani

Department of Architecture and Urban Planning, Art University of Isfahan, Isfahan, Iran;
m.mohammadi@aui.acir, m.nastaran@aui.ac.ir, a_sahebgharani@yahoo.com

Abstract

A heuristic method named as non-dominated sorting genetic algorithm version two (NSGA-II) is developed for multi-objective land use allocation based on the concept of sustainable development which is the predominant notion of land use planning. Numerous plans are generated and optimized by NSGA-II according to land use allocation objectives: maximizing compactness, maximizing floor area ratio, maximizing compatibility, maximizing economic benefit and maximizing mix use. These objectives and constraints are formulated and combined through weighted sum method. This paper moves the previous studies forward in several aspects: 1) application of non-linear objective functions which represent the complexity of real word better than linear functions, 2) modification of NSGA-II operators to fit it for application in urban land use planning framework, and 3) adding density related objective functions which represent the concept of sustainable development more comprehensive. Application of NSGA-II in land use allocation of Baboldasht district, demonstrates effectiveness and the potential of this algorithm in development of planning support system through representation of optimal solutions with different preferences.

Keywords: Baboldasht District of Isfahan, Land Use, NSGA-II, Sustainable Spatial Optimization

1. Introduction

During the middle of the twentieth century, planning for development was based on the assumption that there is no restriction for utilization and consumption of natural resources[1]. After the 1950s, the period of recognizing environmental disasters and resource limitations, the concept of sustainable development emerged in the contradictory of development-oriented thoughts[2,3]. As World Commission on Environment and Development (WCED) stated in 1987, “sustainable development is a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development and institutional change all are in harmony”[4]. Land use is one of resources indicated in the definition of sustainable development. Sustainable land use allocation, allocation of various land uses to specific land units in geospatial context[5], is rudimentary goal of land use planning[6]. Moreover, the negative impacts of unbalanced land use allocation such as: environmental degradation[7], social and economical segregation[8] and dispersion of urban growth[9] emphasize on considering sustainability in the land use planning process.

Sustainable land use allocation contains social, economical and environmental dimensions which involve different objectives[10,11]. Moreover, optimality is one of the principles of sustainable land use planning[12]. These facts represent that sustainable land use allocation is a multi-objective optimization problem. Generally, there are two approaches for solving multi-objective optimization problems. The first and the second approaches are called Pareto-front-based[13] and weighted sum[14] methods respectively. Although diversity of generated solutions in Pareto-front-based methods is acceptable, they are not

*Author for correspondence

effective and efficient[5]. In contrast to Pareto-front-based methods, weighted sum methods, a prior knowledge oriented approach; generate effective and efficient solutions[15].

Land use optimization, a complex and multi-peak problem, deals with numerous variables and involves conflicting objectives and constraints[16–18]. These specifications put the land use optimization problem in the category of Non-deterministic Polynomial hard (NP-hard) problems[19]. In the case of land use optimization, application of heuristic methods is inevitable as existent exact methods are not capable of solving NP-hard problems[20].

Several heuristic algorithms such as genetic algorithm[13,17,21–27], simulated annealing[14,28,29], particle swarm algorithm[30] and ant colony algorithm[31] were developed to solve land use optimization problem. Although these methods do not generate an exact optimal solution, the generated solutions are meaningful and significant in many complex problems and case studies. In addition, plurality of studies attempted to solve land use optimization problem, presents the urgent need to develop an effective tool for supporting land use planning process.

There are important shortcomings in previous studies. First, however mix use, allocation of more than one land use to a specific area[32], is recommended in sustainable land use development, one and only one land use types allows locating in each geographical area in previous researches. Second, the pixel-based approach for land use allocation which is applied in previous studies is simple and unrealistic. Third, objective functions are linear whereas non-linear functions are better than linear function to represent complexities of the real world.

In this way, the current research is momentous in several reasons: 1) consideration of mix uses in land use allocation process, 2) transformation of pixel-based results into parcels located in the study area, 3) consideration of Floor Area Ratio (F.A.R) as objective function, 4) modification of conventional NSGA-II operators and 5) application of non-linear instead of linear functions.

In this paper, firstly, the objective functions are introduced and formulated. Secondly, the NSGA-II, modified crossover and mutation operators, is explained. Finally, the proposed algorithm is applied to the Baboldasht district of Isfahan, and the results and conclusions are represented.

2. Materials and Method

2.1 Selection of Objectives

As mentioned before, land use allocation with respect to sustainable development involves social, economical and environmental features. Balling et al.[13] considered maximizing economic development, minimizing traffic congestion, minimizing tax and fees and maximizing conservation of historical and cultural sites as sustainable land use optimization objectives[13]. Leccese and McCormic[33], emphasized on infill development, environmental protection, compactness and local geography to achieve sustainable land use plans[33]. Economic forest cover, soil loss and water quality are indicated by Wang et al.[34]. Zielinska L et al. introduced infill development, compatibility of adjacent land uses and defensible redevelopment[9]. Sante et al. focused on maximization of suitability and maximization of compactness[29]. Chandramouli et al. considered maximization of public amenities for improvement of sustainability[26]. Chang and Ko, focused on maximization of economic development, minimization of environmental pollution, maximization of employment opportunity and minimization of Carbon dioxide emissions[18].

These studies indicated that economic benefit plays an important role in sustainable land use allocation. In addition, compactness and compatibility of land uses with geospatial context are noted by scholars in spatial-physical point of view. Moreover, both social and environmental factors are considered as driving forces in terms of sustainable development. As Jenks and Jones discussed, maximizing accessibility, compactness, compatibility and mix use and providing required land uses improve social equity, enrichment of human relationship and economic benefit[35]. This means that augment of these factors promotes social and economic benefits which are the main aspects of sustainable land use development. In addition, above factors besides of maximizing compatibility increase environmental benefit. It must also be noted that these dimensions are interrelated[36], for instance reduction of energy consumption which relates to environmental dimension, increases economic benefit over the time.

Based on the characteristics of sustainable land use allocation, selected objectives for land use optimization problem are as follow:

f1: Maximization of F.A.R
f2: Maximization of Mix Use
f3: Maximization of Compactness

f4: Maximization of Compatibility

f5: Maximization of Commercial land use area

As the geological aspects such as: slope, elevation, etc, are appropriate for land use development in the study area[37], suitability function is not regarded in this research.

Subject to:

Supply land use per capita demand.

Consider the thresholds of heights determined by local government (municipality).

2.2 Formulation of Objective Functions and Constraints

2.2.1 Notations

i=1,2,…,n; The number of cells included in the study area.

j=1,2,…,m; Type of land uses.

F; The number of floors allocated to each cell.

A; Area of each cell.

x_{ij}; The number of land uses allocated to each cell. In other words, this variable represents the land use *j*, allocated to cell *i*. It must also be noted that this is not a binary variable and it is able to adopt integer values such as *1,2,3,…,k*.

C_i; The number of adjacent land uses the same as land use type of cell *i*.

Co_{ip}; Value of compatibility between land use located in cell *i* and land use located in cell *p*.

l; The number of adjacent land uses around cell *i*.

P_k^{min}; Minimum of area demand for the land use type *k*.

P_k^{max}; Maximum of area demand for the land use type *k*.

P_k; Area demand for the land use type *k*.

P_k'; Area of land use *k* in a generated plan.

h; The number of objective functions.

w_s; Weight of objective function *s*.

$x_i^{commercial}$; Represents that the commercial land use allocated in cell *i* or not.

β_i; The area of plot *i* in which the commercial land use is allocated.

2.2.2 Functions

f_1: Floor area ratio is the total square meters of a building divided by the total square meters of the lot the building is located on. This value represents intensity of urban development. Generally, the greater the F.A.R is, the less the land conversion on an area occurs. The F.A.R objective is calculated as follows:

$$\max f_1 = \frac{\sum_{i=1}^{n} F_i \times A_i}{\sum_{i=1}^{n} A_i}$$

f_2: By definition of mix use indicated in previous section, the more the land uses allocated in a cell, the more the mix use attained. To represent this objective, the below function is defined:

$$\max f_2 = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij}$$

f_3: In land use planning, direct economic benefit is achieved from commercial and industrial land uses. Because of the pollutions and high incompatibility of industrial land type with residential land uses[6], the industrial land uses should not allocate in district level. Therefore, the more area of commercial land use is allocated, the more economic benefit is achieved. The economic benefit function is as below:

$$\max f_4 = \sum_{i=1}^{n} \beta_i \times x_i^{commercial}$$

f_4: Land uses are preferred to be located in the neighborhood of the same land uses[30]. In addition, compactness is important in two points of view: 1) reduction of pressure of dispersed pattern of development and 2) prevention of wasting valuable land resources[39]. In this paper, a counter is defined for enumeration of same land uses located in adjacency of the cell *i*. This notion is modeled by the following equation:

$$\max f_4 = \sum_{i=1}^{n} C_i$$

f_5: Compatibility is the value which represents impact of coexisted land uses[40]. The more the compatibility between every two land uses is, the higher the level of sustainable development attain. Value of compatibility is calculated through compatibility matrix. This matrix could be obtained from experts through the Delphi method[5,30]. The Delphi method which consists of two main steps is a continuous and iterative process. The first step includes questionnaire design, responses analysis and draft compatibility matrix preparation. The second step comprises of preliminary matrix prepared in previous step distribution, results re-evaluation and compatibility matrix modification (for more information see [41,42]). The compatibility function could be calculated as follows:

$$\max f_5 = \sum_{i=1}^{n}\sum_{p=1}^{I} Co_{ip}$$

2.2.3 Constraints

Per capita demand, required amount of area for each land use type, is considered as the constraint of optimization problem in this study. There is no certain value for per capita, but it could be limited in a minimum and maximum range which determine by urban planners. This constraint could be represented by the following conditions:

$$P_k^{\min} \le P_k \le P_k^{\max}$$

2.2.4 Combination of Objective Functions

In this study, weighted sum method (indicated in [43]) is applied for combination of objective functions. This method is represented in below equation:

$$f_{total} = \sum_{s=1}^{h} w_s \times f_s$$

As there are five objective functions, the extended form of combined objectives is as following model:

$$f_{total} = w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4 + w_5 f_5$$

It must also be noted that values of all objective functions are normalized before combination through the following equation:

$$f_{normalized} = 1 - \frac{f_{\max} - f}{f_{\max}}$$

2.3 Development of Land Use Optimization Model

2.3.1 Brief Review of NSGA-II Algorithm

NSGA-II algorithm, proposed by Deb et al. consists of three main components (Figure 1)[44]. These components are non-dominated sorting, crowding distance and operators of NSGA-II algorithm.

Non-dominated sorting: vector $u=(u_1,u_2,\ldots,u_k)$ dominates vector $v=(v_1,v_2,\ldots,v_k)$ if and only if u is partially less than v. This concept could be represented as below:

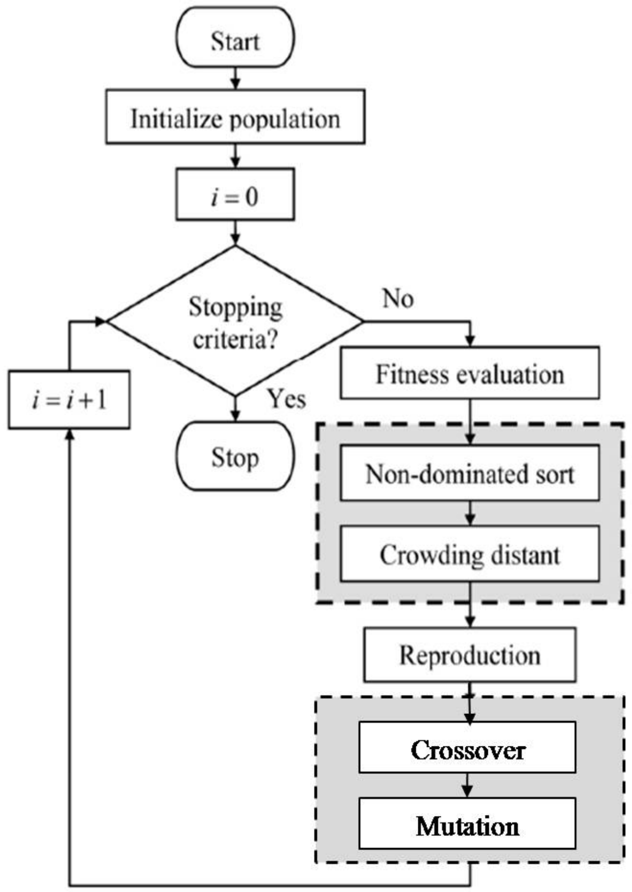

Figure 1. General framework of NSGA-II.

$$\forall_i \in \{1,..,k\}, u_i \le v_i \wedge \exists i \in u_i \le v_i$$

In other words, solution x_1 dominates solution x_2 if x_1 not worse than x_2 in none of objective functions and be better than x_2 at least in one objective function.

Crowding distance: the aim of crowding distance is to estimate density of solutions surrounding a specific solution in population. For point i, crowding distance is the estimated size of the largest cuboid enclosing the point i without any other point in the population being part of this[27] (Figure 2).

Crowding distance could be mathematically expressed as below equations:

$$d_i^1 = \frac{f_1(x_{i+1}) - f_1(x_{i-1})}{f_1^{\max} - f_1^{\min}}$$

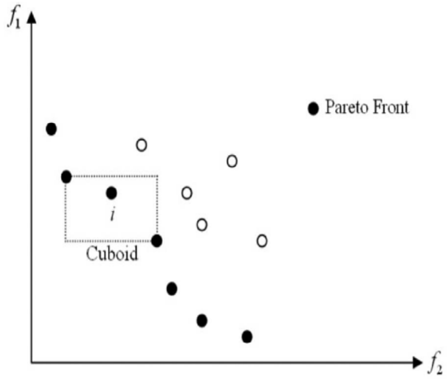

Figure 2. Crowding distance calculation15.

$$d_i^2 = \frac{f_2(x_{i+1}) - f_2(x_{i-1})}{f_2^{max} - f_2^{min}}$$

$$d_i = d_i^1 + d_i^2$$

Where x_i is the solution i, d_i^1 is the crowding distance of solution i in the first objective function, d_i^2 is the crowding distance of solution i in the second objective function and d_i is the value of crowding distance of solution i.

NSGA-II Operators: Two basic operators which the performance of NSGA-II is depending on them are crossover and mutation. In crossover operator, two chromosomes are selected and randomly exchanged to yield a better population. There are various crossover operators such as: one point crossover (Figure 3), two point crossover, etc.

Mutation is another operator of NSGA-II for maintaining the diversity of solutions. Mutation alters one or more gene values in chromosome from its initial state (Figure 4). The achieved solution, after application of mutation operator, may completely differ from previous solution.

These operators must be modified and adapted with the structure of land use problem. Modified operators are described in the next part of the paper.

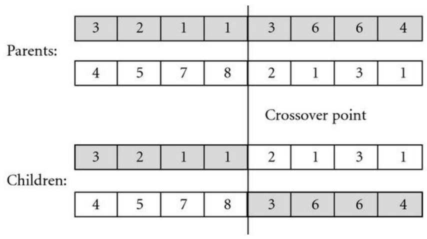

Figure 3. Crossover operator.

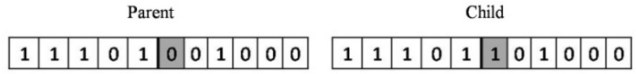

Figure 4. Mutation operator.

In short, at first, the population (initial solutions) is created. To generate initial solutions, two approaches could be identified: the first is Monte Carlo approach in which the initial solutions are satisfied all of constraints, the second is approaches which convert constrained problem to unconstrained problem by definition of penalty function or Lagrange multipliers. At second, the objective functions are calculated for each solution and combined through weighted sum method. At third, the number of dominations is calculated for all solutions through non-dominated sorting method. At fourth, crowding distance is computed for each solution. At fifth, solutions are ranked based on the results of non-dominated sorting and crowding distance steps. Finally, the fitter solutions are selected, and the next generation is created by application of crossover and mutation operators. This process is repeated until the stopping criterion is met.

2.3.2 Specification of NSGA-II Based Land Use Optimization Model

Setting operators: Land use types should be encoded in the form of chromosomes before initializing NSGA-II algorithm. A chromosome is a grid each part of which is called gene. The position of each cell (gene) represents a unit, and land use types determine by specific values. In this paper, each cell is a gene and the value of each gene is the code (value) of land use types.

After determination of method for encoding chromosomes, the initial population which means random solution should be generated. This step plays an important role in efficiency of algorithm and quality of solutions. Therefore, one hundred randomly solutions which satisfy constrains are generated as initial solutions (parents).

To select parents for performing crossover and mutation operators, the fitness function as described in before section is calculated for each generated solution. Then, the solutions are sorted based on the fitness function value, and according to the fact that for maximization objectives, the greater the value of the fitness function, the better the solution, the parents are selected.

The conventional crossover operators such as single point crossover method are not appropriate for land use optimization problem due to the fact that usual operators do not generate solutions which have the acceptable compactness quality[5]. Therefore, in this study this operator is modified as below:

1. Generate two random numbers in range of 1 and the number of cells in the study area as crossover point.
2. Check the land use type of crossover points in the generated solution.
3. If the values of the cells are not equal at the crossover point, swap the plot values (Figure 5).

After performing crossover operator, the combined objective function value is calculated for each offspring. Then, the fitter solutions go to the mutation step.

Changing value of genes in a solution randomly is called mutation. Mutation plays an important role in better convergence and performance of NSGA-II[45]. The mutation process is related to encoding process of the optimization problem[46]. In this paper, a patch based mutation is considered. Path based mutation could be performing through the following steps:

1. Determine the shape of the mutation window (in this study, a square shape which consists of nine cells is considered).
2. Determine the land use type of mutation window (i.e. commercial, residential, etc).
3. Choose the location of mutation window randomly by generating a random number between 1 and the total number of plots, as the center of mutation window.
4. Change the land use type of the solution according to the land use type of mutation window (Figure 6).

As the constraints may remain unsatisfied after the mutation process, another mutation operator is added to mutation operator. In this operator, at first, the satisfaction of each constraint is checked. Then, if the area of a land use type does not locate in the constraint range, the

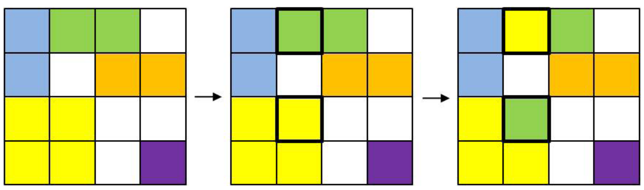

Figure 5. Crossover operator applied in the land use allocation problem.

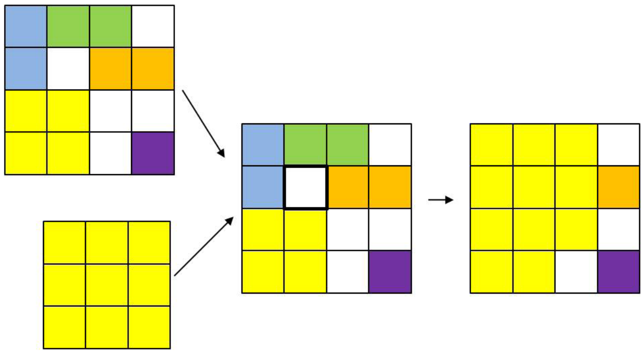

Figure 6. Mutation operator applied in the land use allocation problem.

operator chooses a random location and allocates required land uses to direct solution to become feasible.

Initial population: To generate initial population, a code was defined for each land use type (Table 1) and initial population generated randomly.

The encoding method means that for each cell, a land use code (an integer value between 1 and 12) is selected and assigned. It must also be remembered that the urban scale land uses not assign and current state of them pre-

Table 1. Codes assigned to land use types

Level of land use	Land use type	Code
Local scale	Residential (Low density with 1 floor)	1
	Residential (Medium density with 2 floors)	2
	Residential (High density with 3 floors)	3
	Commercial	4
	Medical	5
	Educational	6
	Recreational	7
	Cultural	8
	Sportive	9
	Mix use commercial-residential (with 2 floors)	10
	Mix use commercial-residential (with 3 floors)	11
	Mix use commercial-residential (with 4 floors)	12
Urban scale	Office	13
	Tourism	14
	Religious	15
	Military	16
	Public amenities	17
	Workhouse	18
	Warehouse	19
	Transport	20
	Arid	21

served. Therefore, the codes greater than 12 could not assign to cells. Moreover, FID, a code which uniquely identifies a plot, was added to the code of land uses to prepare the outputs for analyzing and visualizing in Geographic Information System (GIS). It must also be noted that the FID could not be changed during the optimization process. In short, the first population is a string with 2 rows and 778 columns in which the first row represents land use type of each cell and the second row represents the FID of each cell and is constant during optimization process (Table 2). It must also be noted that the cells which include street networks are excluded from allocation problem. The area of each cell is equal to 200 m^2.

Optimization Considerations: As residential, commercial, medical, educational, recreational, cultural and sportive land uses are fundamental demanded land areas in district level[47], these seven land types are considered to allocate in the study area. In addition, acceptable mix use in this level is commercial-residential owing to the specification of each main land use types and nature of activities included. Moreover, residential land use is divided to low, medium and high density represented by permissible height and number of floor.

As the location of urban level land uses is determined by the upper hand policies and local government, these land uses could not change over time. Thus, urban scale lands located in the study area in current and future states are fixed in the optimization process.

Maximum height of buildings is determined for districts according to urban regulations and average width of the streets. In Iran, this value is specified by density and floor zoning which are represented in urban detailed plan of cities and the city council approvals.

The compatibility matrix of land use types derived from Delphi method is represented in Table 3. It must also be noted that three PhD of urban planning, two PhD of architecture, one PhD of urban design, four consultant engineers and two municipality staffs are engaged in the Delphi process.

As the land use optimization following from normative approach, the weight of objectives for combination of objective functions could be determined by the experts and local government. The aggregated weigh of objective functions obtained from specialists and professionals are shown in Table 4.

Table 2. Method of coding solutions

Land use type	1	1	8	…	12
FID	0	1	2	…	927

2.4 Implementation of NSGA-II based Land Use Optimization Model and Results

Study area: Baboldasht district is located in the south of 7th region of Isfahan. Baboldasht covers 20 hectares of 7^{th} region and has 928 plots and 873 residential units with 3492 populations currently. This district is less sustainable district[48], and suffers from shortage of fundamental land uses[49] (Figure 7).

The demanded land area for six fundamental land uses is calculated through the per capita and future population growth extracted from Isfahan's detailed plan (Table 5).

The maximum floor number determined by Isfahan's detailed plan for Baboldasht district is 4. The urban land uses which should be fixed in the optimization problem are shown in Figure 8.

The reasons for choosing this district are its logical number of land plots, variety of land uses in different levels and the problems which are in this district like: lack of fundamental land uses and the unsustainable conditions.

Table 4. Aggregated weight of objective functions

Objective function	Weight	Priority
f_1	0.35	1
f_2	0.3	2
f_3	0.03	5
f_4	0.12	4
f_5	0.2	3

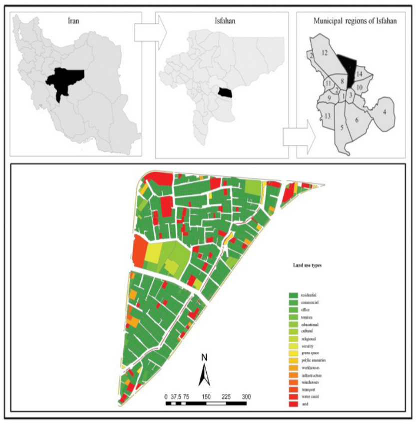

Figure 7. Study area.

Table 3. Compatibility matrix (High compatible=1, moderately compatible=0.8, neutrally compatible=0.6, moderately incompatible=0.4 and high incompatible=0.2)

Land use types		Residential			Commercial (4)	Medical (5)	Educational (6)	Recreational (7)	Cultural (8)	Sportive (9)	Mix commercial-residential			Office (13)	Tourism (14)	Religious (15)	Military (16)	Public amenities (17)	Workhouse (18)	Warehouse (19)	Transport (20)	Arid (21)
		Low density (1)	Medium density (2)	High density (3)							Mix low dense (10)	Mix medium dense (11)	Mix high dens (12)									
Residential	Low density (1)	1	0.8	0.4	1	0.6	0.8	1	0.8	0.8	1	0.6	0.4	1	0.4	0.6	0.2	0.4	0.2	0.4	0.6	0.4
	Medium density (2)	0.8	1	0.8	1	0.6	0.8	1	0.8	0.8	1	1	0.6	1	0.4	0.6	0.2	0.4	0.2	0.4	0.6	0.4
	High density (3)	0.4	0.8	1	1	0.6	0.8	1	0.8	0.8	1	1	1	1	0.4	0.6	0.2	0.4	0.2	0.4	0.6	0.4
Commercial (4)		1	1	1	1	0.4	1	1	0.8	0.8	1	1	1	0.8	1	1	1	1	0.8	0.8	1	0.8
Medical (5)		0.6	0.6	0.6	0.4	1	0.8	0.6	1	0.6	0.6	0.6	0.6	0.8	0.6	0.6	0.2	0.6	0.2	0.2	0.4	0.8
Educational (6)		0.8	0.8	0.8	1	0.8	1	0.8	0.6	0.6	0.6	0.6	0.6	0.8	0.6	1	0.2	0.8	0.4	0.4	0.8	0.8
Recreational (7)		1	1	1	1	0.6	0.8	1	0.8	1	0.8	0.8	0.8	0.8	1	0.8	0.2	0.8	0.4	0.4	0.8	0.8
Cultural (8)		0.8	0.8	0.8	0.8	1	0.6	0.8	1	0.6	0.6	0.6	0.6	0.8	1	0.8	0.2	0.8	0.4	0.4	0.8	0.4
Sportive (9)		0.8	0.8	0.8	0.8	0.6	0.6	1	0.6	1	0.8	0.8	0.8	0.6	0.6	0.6	0.4	0.6	0.4	0.4	0.6	0.6
Mix commercial-residential	Mix low density (10)	1	1	1	1	0.6	0.6	0.8	0.6	0.8	1	0.8	0.8	0.6	0.8	0.8	0.2	0.6	0.4	0.4	0.6	0.4
	Mix medium density (11)	0.6	1	1	1	0.6	0.6	0.8	0.6	0.8	0.8	1	0.8	0.6	0.8	0.8	0.2	0.6	0.4	0.4	0.6	0.4
	Mix high density (12)	0.4	0.6	1	1	0.6	0.6	0.8	0.6	0.8	0.8	0.8	1	0.6	0.8	0.8	0.2	0.6	0.4	0.4	0.6	0.4
Office (13)		1	1	1	0.8	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.6	1	0.8	0.6	0.6	0.8	0.6	0.4	1	0.6
Tourism (14)		0.4	0.4	0.4	1	0.6	0.6	1	1	0.6	0.8	0.8	0.8	0.8	1	0.8	0.2	0.6	0.4	0.4	0.6	0.4
Religious (15)		0.6	0.6	0.6	1	0.6	1	0.8	0.8	0.6	0.8	0.8	0.8	0.6	0.8	1	0.2	0.8	0.6	0.6	0.8	0.6
Military (16)		0.2	0.2	0.2	1	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.6	0.2	0.2	1	0.6	0.6	0.6	0.8	0.6
Public amenities (17)		0.4	0.4	0.4	1	0.6	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.8	0.6	0.8	0.6	1	0.6	0.8	0.8	0.6
Workhouse (18)		0.2	0.2	0.2	0.8	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.4	0.6	0.6	0.6	1	1	0.8	0.8
Warehouse (19)		0.4	0.4	0.4	0.8	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.8	1	1	1	0.8
Transport (20)		0.6	0.6	0.6	1	0.4	0.8	0.8	0.8	0.6	0.6	0.6	0.6	1	0.6	0.8	0.8	0.8	0.8	1	1	0.6
Arid (21)		0.4	0.4	0.4	0.8	0.8	0.8	0.8	0.4	0.6	0.4	0.4	0.4	0.6	0.4	0.6	1	0.6	0.8	0.8	0.6	1

Table 5. Aggregated weight of objective functions

Land use type	Min per capita (m)	Max per capita (m)	Min demanded area (m2)	Max demanded area (m2)
Residential	25	40	129000	206400
Commercial	2	3.5	10320	18060
Educational	1.5	3.9	8091	20227
Medical	0.18	0.3	945	1575
Recreational	2.1	3	161178	265289
Cultural	0.1	0.2	571	1189
Sportive	0.2	0.4	1416	2359

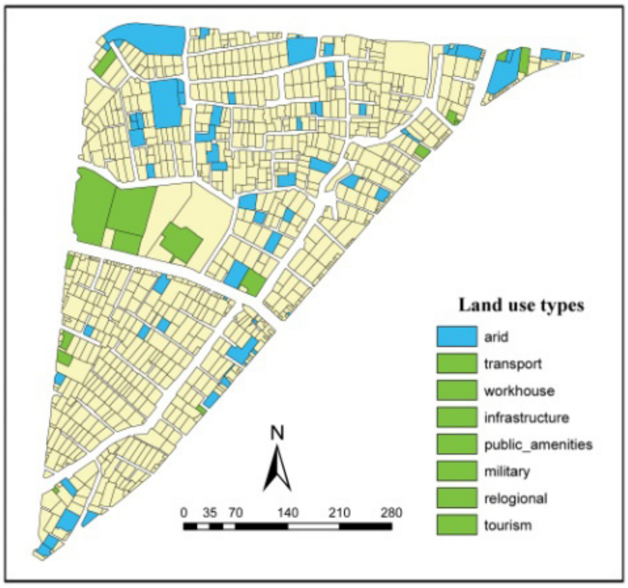

Figure 8. Excluded plots.

2.4.1 Model Implementation and Results

In order to optimize land use allocation through NSGA-II, a program was developed in MATLAB based on mentioned operators and encoding method of initial population. The model was executed for 300 iterations, 100 initial populations, 40 mutation and 100 crossover points. Execution of the model for above parameters and 5 indicated objectives in the study area takes 5.8 hours on a laptop computer with an Intel (R) Core™ 2 Duo CPU T9550 @ 2.66 GHz and 3 GB RAM. Figure 9 shows solutions in two and three dimensional projection.

To represent how well the algorithm has promoted the solutions during the optimization process, the value of objective function which has been calculated through weighted sum method is represented in Figure 10 and 11 for each solution.

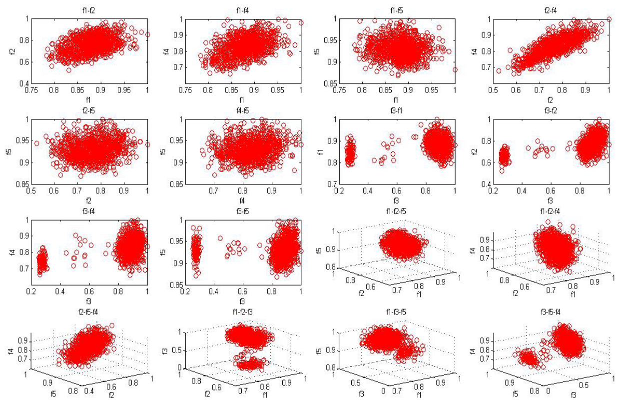

Figure 9. Generated solutions.

Figure 12 represents the best generated land use plan for each objective function and combined objective function with their best values.

The output of the model is compared with values of objective functions in the current state (Table 6). The comparison represents significant improvement of objective functions and sustainability of the study area.

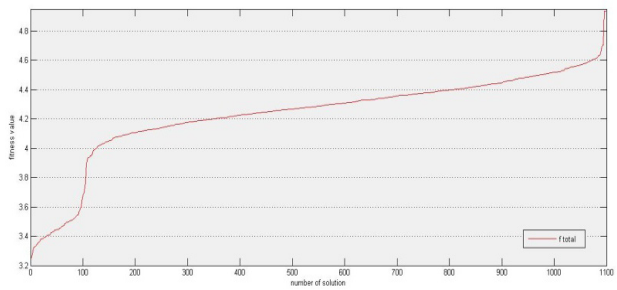

Figure 10. Improvement of fitness function in new solutions (y axis is fitness value and x axis is the number of solution)

Table 6. Comparison between the results of the model and current state

Objective function	Value in current state (non-normalized)	Output of the NSGA-II (non-normalized)	Percentage of improvement
f1	65859.85	133400	102.5
f2	0	34449	Completely improved
f3	129	208	61.2
f4	25.8	48.48	96.1
f5	1234.52	1843.9	49.3

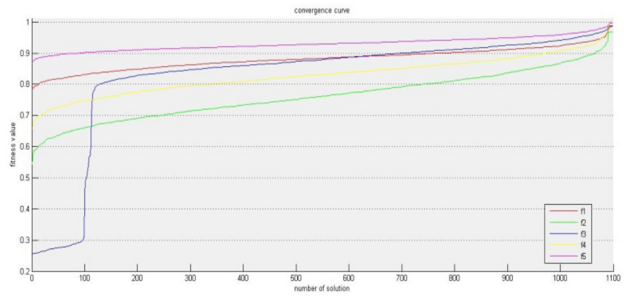

Figure 11. Improvement of fitness function for each objective function (y axis is fitness value and x axis is the number of solution)

The outputs of the model are compared with the conventional genetic algorithm (GA) in Table 7.

The results are demonstrated that NSGA-II is 74% faster than GA. Moreover, the greater total objective function is attained through application of NSGA-II (3.7 %).

Table 7. Comparison between the modified and unmodified NSGA-II operators

Algorithm	Iterations	Time (h)	Total value of objective functions
NSGA-II	300	5.8	4.935619
GA	300	22.8	4.756188

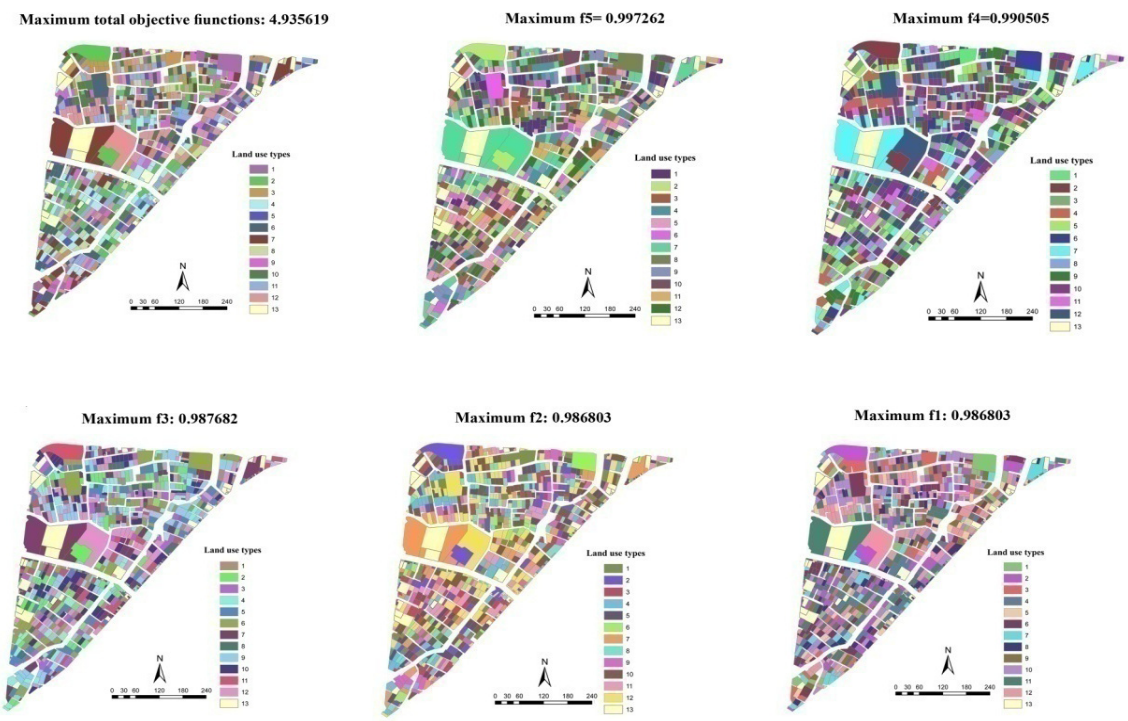

Figure 12. The best land use plans.

3. Conclusion

Sustainable land use planning is directly related to logical arrangement and allocation of land resources. As land is a limited resource, optimized allocation of land uses to urban units (cells) is inevitable. The main objective of this paper was to develop a NSGA-II based land use optimization model to optimize multi-objective land use allocation problem. To derive optimization objectives and constraints, the predominate notion of urban planning, sustainable development, is considered and the sustainability literature translated to mathematical formulas. Five non-linear maximizing objective functions, six land use types and six constraints are defined and weighted sum method is applied for combination of objective function values after normalization. The operators of NSGA-II are modified and the proposed model developed in MATLAB programming language. The model is executed under the modeling considerations. To visualize the exports of the model, special solution coding method which link exports to GIS software is defined. The outputs of the model are compared with the current state and GA. The results demonstrate the effectiveness and efficiency of the proposed model and its potential in supporting urban planning and decision making processes through generating numerous land use alternatives and representing optimal solutions.

4. Acknowledgement

This paper is extracted from the dissertation entitled: “Multi-objective land use optimization through meta-heuristic algorithms (Case study: Baboldasht district of Isfahan)” carried out by Alireza Sahebgharani under the supervision of Prof. Mahmoud Mohammadi and Prof. Mahin Nastaran in Art University of Isfahan. The authors thank to editor and the anonymous reviewers for their attention and comments.

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