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Soil quality and landscape metrics as driving factors in a multi-criteria GIS procedure for peri-urban land use planning

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ABSTRACT

Highly populated peri-urban areas are critical for urban sprawl, soil consumption and degradation, and, in general, loss of ecosystem services. In these areas, urban planning is usually based on a compromise among social, economic, political needs and geographic factors. Technicians cannot obviously intervene in political discussions, nor intercept social requirements; nevertheless, once a need has been recognized and a target identified, they can sustain politicians in their decisions concerning the way the new urban policy can be managed. Various territorial descriptors have been used to support planner's choices while programming urban expansion. In this context ecosystem services potentially affected by urbanization represent an important unsolved issue, most probably for the general lack of reliable datasets for urban and peri-urban areas and for the scarce integration of the involved disciplines. In this paper a GIS-MCDA (Multi Criteria Decision Analysis) approach is presented, aimed at generating synthetic maps useful for urban planners and authorities to make their decisions inclusive of territorial resources and environmental factors with special care about soil quality. The method was applied to a case study concerning the identification of the optimal location for a new leisure activity area in the peri-urban belt of the city of Torino (Italy). Landscape metrics, demographic data and soil chemical/physical properties - including contamination - obtained from extremely diverse sources, were jointly analysed. Some specific indices aggregating information were proposed and mapped using some advanced raster tools available in GIS.

Introduction

Highly populated peri-urban areas are critical for different aspects such as urban sprawl, soil sealing and degradation, and, in general, loss of ecosystem services (Antrop, 2004). In these areas, land planning is usually based on a compromise among social, economic, political needs and geographic factors. In general, urban planning heavily relies on choices resulting from interaction among a large number of often-conflicting alternatives and criteria. Ordinarily, urban administrators intercept a social need and plan a new intervention to satisfy it. Technicians cannot intervene in political discussions, nor intercept social requirements; nevertheless, once a need has been recognized and a target identified they can sustain politicians in their decisions about the way urban development policy can be managed. In particular, GIS (Geographic Information System) and landscape experts can support the decisional process by synthesizing and mapping all available information in order to drive new interventions towards the most suitable locations. The meaning of *suitable* depends on the criteria urban planners decide to adopt during the decisional process. Whatever the criteria, decisions can be managed through a spatial based multi-criteria approach where economic, social, political and environmental interests can interact each other playing their different, and sometimes opposite, role in the whole process.

In recent years, potentialities offered by the continuously expanding GIS technology and by the increasing availability of digital georeferenced data have been greatly improved, encouraging the adoption of multi-criteria spatial analysis to support land planning (Malczewski, 2006).

Ordinarily, geographic/topologic properties of the area (size, location, proximity to services, aesthetics…) are taken into consideration. For example, a GIS-Multi-criteria Decision Analysis approach was adopted by Borgogno-Mondino et al. (2014a; 2014b) to map over Piemonte region (Northwestern Italy) some *best* locations for large ground-mounted photovoltaic plants taking care of multiple topographic and legislative factors. In addition, landscape metrics have been widely used to define and interpret either planned (Weng, 2007; Aguilera et al., 2011; Frondoni et al., 2011) and unplanned urban areas expansion (Kuffer and Barros, 2011). In general, metrics consist of geometrical measurements (indices) useful for quantifying spatial patterning of land cover patches, land cover classes, or entire landscape mosaics of an area (McGarigal et al., 2009). In some cases landscape metrics were used jointly with remote sensing data (Herold et al., 2005) and with socio-economic indicators (Irwin and Geoghegan, 2001; Schwarz, 2010) in order to better interpret urban land use changes and, in particular, urban expansion. Kasanko et al. (2006) focused on the sprawl of 15 European cities basing their study on five indicator sets: built-up areas, residential land use, land taken by urban expansion, population density and urban density. Hu and Lo (2007) modeled the growth of Atlanta (USA) describing the relationship between urban growth and social, econometric and biophysical factors (major highways, economic activity centers, land use, institutional factors) with contrasting results. In Copenhagen (Denmark) a decision support system was proposed for the planning of green spaces based on indicators such as wilderness, feeling of forest, panoramic views, water and scenery, biodiversity and landform, cultural history, activity and challenge, service and gathering (Caspersen and Olafsson, 2010). Zellner et al. (2008) described a planning framework including spatial, economic, political, energetic, and pollution data. More recently, a study on the urban sprawl in Europe (Arribas-Bel et al., 2011) used urban morphology (scattering, connectivity, and availability of open space) and internal composition (density, decentralization and land-use mix) as descriptors. Some alternative approaches finally introduced soil or terrain properties in urban planning, mainly referring to geological layers (the deepest ones) or to geomorphological features of the area. For example, Bathrellos et al. (2012; 2013) proposed a method for evaluating the suitability of areas to support urban growth and industry development that considered natural hazards and geological–geomorphological–geographical characteristics. A study by Papadopoulou-Vrynioti et al. (2013) mapped the karst collapses susceptibility in the northern suburbs of Athens (Greece) taking into account physical processes (slope angle and aspect, hydrographic network, springs, lithology, tectonic features) along with anthropogenic parameters (road network and land use), introducing a new tool for sustainable urban development management by planners and engineers. The same authors (Papadopoulou-Vrynioti et al., 2014) finally focused on physical and chemical soil properties as soil texture, water extractable ions, exchangeable ions, aqua-regia extractable elements, calcium carbonate, organic matter, cation exchange capacity, soil moisture, pH and electrical conductivity. Their multi criterial GIS based approach study showed that agricultural land use and productivity depends on soil properties; in particular, they mapped soils in the Arta plain (western Greece) finding that saline alluvial ones, with elevated amounts of water-soluble salts, make agricultural exploitation not valuable.

In these works, ecological parameters or, more appropriately, ecosystem services potentially affected by urbanization, are rarely taken into consideration. Nevertheless, chemical and physical properties of soils are crucial to recognize if a specific site is suitable, or not, to supply a specific ecosystem service to the community. Urban soils have different properties with respect to agricultural or natural soils. Contamination, fragmentation, and mixing of extraneous materials are some of the issues typical of urban soils resulting from the alteration of soil forming factors (Pickett and Cadenasso, 2009; Biasioli et al., 2007; Vrščaj et al., 2008; Scalenghe and Ajmone-Marsan, 2009). However, urban soils can support a wide range of ecosystem services that are highly valuable due to their proximity to human population. This suggests that planning approaches operating in an urban context have necessarily to consider soil features to better plan or improve ecosystem services.

This gap in studies is probably due to a general lack of reliable datasets for urban and peri-urban areas and to a scarce integration of potentially involved scientific disciplines. From this point of view, Botequilha-Leitão and Ahern (2002) offered a rather complete overview of the possibility, and necessity, of introducing ecological considerations into land use planning. Verburg et al. (2009) suggested "*land functions''* for characterizing land use change in agricultural areas, where "*land functions"* are considered to be directly related to soil functions, included provision of goods and services for each specific land use, aesthetic beauty, cultural heritage and preservation of biodiversity. Uy and Nakagoshi (2008) used a landscape ecology approach. These authors appear to have overlooked the crucial contribution of intrinsic soil properties and their attempt have posed new challenges for a better interpretation of land use changes aimed at improving planning.

This work aims at filling the gap by explicitly introducing soil chemical and physical properties in the decisional process that is managed by a GIS-MCDA (Multi Criteria Decision Analysis) approach. A case study including a peri-urban area of Torino (Northwestern Italy) is presented to exemplify the way the methodology can be applied to generate a "map of vocation" of the area to host a new leisure facility, e.g. a green area, a garden or a park, etc. Landscape metrics, demographic data and soil chemical/physical properties, including contamination, were jointly analyzed trying to optimize some spatial dependent cost functions in which land use planning, ecosystem assessment, landscape analysis, and preservation criteria were considered. Starting from existing tabular data and digital geographical datasets, available mainly from regional institutions, some spatial indices were derived and mapped to represent the spatial distribution of some crucial features of the area respect to the leisure facility planning. Index maps were finally combined to synthesize the whole load of information and a final representation, mapping the degree of vocation of each point of the area to host the new leisure facility, was generated.

Materials and methods

The proposed methodology was tested over a pilot area of about 90 km^2, located in the peri-urban belt of Torino, Piemonte region, North-western Italy (Fig. 1).

[figure 1]

This area is heavily populated, urbanized and industrialised; but it also includes vast agricultural land and can be assumed as representative of urban-to-rural transition: buildings and roads cover about 42% of the area; population density is around 6700 inhabitants/km^2, 15 times higher than surrounding not-urban areas (ISTAT, 2011). The territorial context is characterized by a great variety of land use classes and soils; moreover, a high degree of urban sprawl, and, consequently, soil consumption, that accelerated in recent years, is present.

Primary data for this study were obtained from freely available national and regional institutional databases. They include raster and vector digital maps and tabular data. Geographical data were supplied in the WGS-84 UTM 32N reference frame. Table 1 reports the list of primary datasets; ID column contains acronyms used in the paper for these different datasets.

[Table 1]

Data were managed and processed by ArcView 9.3 GIS software (ESRI Inc., USA). Operations concerning raster layers were performed by Spatial Analyst extension of ArcView while landscape metrics were calculated using FRAGSTATS 1.0 (McGarigal et al., 2002). FRAGSTATS is a free extension software tool specifically designed to calculate a wide variety of parameters describing categorical map patterns, useful for landscape analysis.

The proposed methodology is based on the following steps: a) data acquisition and pre-processing; b) design and implementation of spatial dependent cost functions considering environmental, landscape and social factors; c) cost function maps generation; d) results interpretation.

Pre-processing included selection and extraction of some landscape metrics from PLCM using FRAGSTATS 1.0. Landscape metrics can transform categorical predictors providing qualitative information (e.g. attributes of vector polygon maps) of spatial patterns into a numerical representation of spatial dependent indices. GIS tools can generate a huge variety of landscape metrics; therefore, a selection is required, depending on the purpose of the analysis . For this work a bi-variate correlation analysis was performed to explore relationships between metrics generated by FRAGSTATS on class basis: two reference land use classes were defined for the area: *urban* and *not-urban*. Correlation analysis performed by SPSS-Statistics 17.0 software, showed that two not-correlated landscape metrics were able to synthetize the most of the landscape features of the area : Class Area (CA) and Total Edge (TE), whose definitions are given in table 2.

[Table 2]

Raster/grid format was considered the most suitable for representing spatial indices. All tabular and vector datasets were therefore preventively rasterized (25 m cell size). Rasterized primary data and the raster maps of CA and TE were jointly considered and some space dependent indices were specifically designed and mapped to qualify the area.

Soil Quality Index

Chemical and physical characteristics of soils were considered with the aim of characterizing ecosystem services that the area can provide. Soil is usually described by a large variety of physical, chemical, biological and morphological features; for this work, authors decided to focus on a limited number of soil features, in favour of a straightforward methodological approach. The following features were considered: a) soil *pH* and organic carbon content (C_{perc}): they are strictly related to soil capacity of sustaining vegetation and consequently biomass production; b) soil particle-size distribution (PSD) that indirectly describes porosity, density and, consequently, capability of soil of filtering water and buffering air temperature. Even if PSD is generally described by three size classes - clay, silt and sand - for this work, only sand content was taken into account: in fact clay is almost absent in the soils of the area. C_{perc} and *pH* maps were obtained from PTCOM while the map of sand content from PSM.

It is becoming more and more evident that influence of a city onto its surroundings is reflected in the contamination of soils at the rural-urban interface (Biasioli et al., 2006). This is the reason why Pb, Zn and Cu concentrations were selected to measure degradation of environmental quality of soil determined by contamination. These metals are in fact considered typical contaminants of urban environment (Ajmone-Marsan and Biasioli, 2010). Soil diffuse contamination can be synthetized by the enrichment factor *(fC)*. The *fC* is defined as an a-dimensional index that integrates information about soils pollutants. According to Hakanson (1980) and Sutherland (2000) contamination categories can be recognized based on *fC* values: $fC < 8$ (low degree of contamination), $8 < fC < 16$ (moderate degree of contamination), $16 < fC < 32$ (considerable degree of contamination), $fC > 32$ (very high degree of contamination). The value of *fC* was calculated, for each contaminant, by the following formula (Biasioli et al., 2012):

$$fC_i = X^i_{sample} / X^i_{bck} \qquad (1)$$

where X^i_{sample} is the mean concentration and X^i_{bck} is the background level of the considered contaminant (*i*) referred to the whole area. The overall sample factor (fC_{tot}) is obtained according to (2).

$$fC_{tot} = \sum_{i=1}^{n} fC_i \qquad (2)$$

For this study *n* was assumed equal to 3 as the three contaminants Pb, Zn, and Cu were taken into account.

Once calculated, all variables (C_{perc}, *pH*, *Sc*, fC_{tot}, *CA*, *TE*) were normalized to a common scale [1-10]. Raster maps of soil properties (C_{perc}, *pH*, *Sc*, fC_{tot}) were then combined through eq. 3 to obtain an *Intrinsic Soil Quality Index* (Q_s).

$$Q_s(x, y) = \frac{C_{perc} \cdot (pH_f + S_f)}{fC_{tot}} \tag{3}$$

where $pH_f = 5^2 - (\mathrm{pH\text{-}5})^2$; $S_f = 5^2 - (Sc - 5)^2$ (4)

This formula assumes that C_{perc}, *pH* and S_f improve local intrinsic soil quality (from an ecological/agricultural point of view) while fC_{tot} limits it. In particular, intermediate values of *pH* and *Sc* (around 5 in the normalized scale) were considered optimal; a parabolic model (eq. 4) was adopted to describe their contribution. C_{perc} participates as gain to the function. The range of variation of Q_s is consequently between 0.2 (C_{perc}, *pH* and *Sc* =1; fC_{tot} = 10) and 100 (C_{perc}, pH and *Sc* =10; fC_{tot}=1).

Land take/Fragmentation Index

To take into account landscape features, *CA* and *TE* metrics were considered as indicators of soil use and landscape fragmentation, respectively. They were combined mathematically in a new index, hereafter called *Land take/Fragmentation Index* (Q_m). The index (eq. 5) is designed to increase with CA_{du} and TE_{du} (class *urban*) and to decrease according to CA_{nu}, TE_{nu} (class *not-urban*).

$$Q_m(x, y) = \frac{(\mathrm{CA}_{du} + \mathrm{TE}_{du})}{(\mathrm{CA}_{nu} + \mathrm{TE}_{nu})} \tag{5}$$

The index represents the vocation of the area to be re-qualified by human interventions and planning policies according to its ecological value (expressed by CA) and potential resilience (expressed by TE). High values of CA_{nu} and TE_{nu} mean “valuable ecological condition” where large valuable areas are highly exposed to external threats potentially coming from an extended perimeter; in this case the situation is critical and, therefore, protection is needed: urban expansion has therefore to be limited or completely avoided. On the contrary, high values of CA_{du} and TE_{du} suggest a highly diffused urbanization with a high level of sprawl. In these areas, ecological value is already compromised and the possibility of filling spatial gaps by means of interventions serving urban context can be convenient.

Computation of CA and TE for *urban* (du) and *not-urban* (nu) classes was performed using a regular sample grid having a cell size of 250 m (i.e. including 10×10 original 25 m pixels). The window size depends on the distance human eye can explore reasonably in a city, receiving emotions from the surrounding landscape. Four raster maps (CA_{nu}, TE_{nu}, CA_{du}, TE_{du}) were generated by FRAGSTATS. Original maps having a pixel size of 250 m were finally oversampled (nearest neighbour resampling method) to 25 m in order to be spatially coherent with other raster maps.

Suitability Index

$Q_s(x,y)$ and $Q_m(x,y)$ were further combined in order to give a simple representation of the *suitability* of the site to host leisure facilities (e.g. a green area, a garden or a park, etc.). Intrinsic properties of potentially involved soils were related with landscape features in the following way:

$$\mathrm{I_s}(\mathrm{x},\mathrm{y}) = \frac{Q'_m(x,y)}{Q'_s(x,y)} \qquad (6)$$

where $Q'_s(x,y)$ and $Q'_m(x,y)$ are the normalized values of $Q_s(x,y)$ and $Q_m(x,y)$ and $I_s(x,y)$ is the *suitability index map* representing the degree of vocation of each point to host leisure facilities. In this sense the areas where landscape fragmentation is higher, i.e. small patches of not-agricultural and not-urban soils are mixed, and soil quality is lower appear to be the most suitable to be considered.

Usability Index

While looking for the *best* location of a leisure facility it cannot be forgotten that the right choice depends not only on the inner peculiarities of the site, but also on the possibility that people have to reach it and to benefit of its services. Therefore, once local suitability is mapped, local accessibility has to be evaluated, in order to verify if the ones that appear to be the most suitable areas are also appealing and comfortable for use. For this purpose, using Spatial Analyst tools, distance-from-urban settlements map, $D_{ur}(x,y)$, and population density map, $D_{pop}(x,y)$ were generated (Fig. 4). The former reports the horizontal distance that separates each pixel from the nearest urban border, the latter the number of resident people per km^2 as stated by the available Census data. A *Usability Index* (I_u) was then introduced, integrating these information (eq. 7).

$$\mathrm{I}_u(\mathrm{x},\mathrm{y}) = \frac{I_s(x,y) + D_{pop}(x,y)}{D_{ur}(x,y)} \tag{7}$$

$I_u(x,y)$ takes into account: a) the distance from the nearest urban area, $D_{ur}(x,y)$; b) the surrounding population density, $D_{pop}(x,y)$; c) the suitability Index, $I_s(x,y)$. All factors of eq. 6 were normalized to the common scale [1-10]. $I_u(x,y)$ is assumed to be directly proportional to both $I_s(x,y)$ and $D_{pop}(x,y)$, considering that, for the same I_s value, the higher is the number of resident people close to the area, the higher is the probability the area is visited and used. Congruently, it is assumed that the longer is the distance from residential areas the less is usable the area. The combination of the I_s with D_{pop} and D_{ur} generates an a-dimensional value that can be interpreted as high-moderate-low usability of an area in terms of leisure/recreation.

Results and discussion

The proposed methodology was tested in the study area to generate a map useful to locate a new forecasted leisure area. Statistics concerning soil properties and landscape metrics of the area are shown in Table 3. Diffuse Contamination Index Map, $fC_{tot}(x,y)$, was directly obtained by ARPA Piemonte (Regional Enrvironmental Protection Agency of Piemonte) with a cell size of 25 m; both $pH(x,y)$ and $Sc(x,y)$ raster maps (25 m cell size) were obtained from PSM, supplied in vector format, by rasterizing it respect to the proper attribute of its associated table. Finally Topsoil Organic Carbon Map, $C(x,y)$, was obtained by rasterization (25 m cell size) of the available PTOCM vector map.

[Table 3]

Raster map of $Q_s(x,y)$ index was generated according to eq. 3 and 4 (Fig. 2, left). A positive gradient of soil quality can be observed from urbanized areas (lowest values), where contamination is higher, towards agricultural/natural areas (index highest values). $Qs(x,y)$ peaks are sited in the northwestern sector where natural systems prevail.

[Figure 2]

Quite surprisingly, a low value of $Qs(x,y)$ is observed along the Dora Riparia River; this is probably due to the low content of organic carbon and high *pH* value of these soils, which are in general not favorable to plant growth. Successively, according to eq. 5, $Q_m(x,y)$ was obtained (Fig. 2, right). It can be noticed that high values of the index are sited in the inner urban part where fragmentation and soil consumption are higher, while it decreases in the outskirts. Fig. 3 shows, in the upper part, the maps of $I_s(x,y)$ and $I_u(x,y)$. Looking at $I_s(x,y)$ it can be noticed that sites of high and moderate suitability concentrate within the urban areas or at the interface with the rural zone; the resolution of this indicator was anyway not sufficient to effectively drive urban policies. In fact, favorable areas (green and pale green) are still too wide. To better focus selection “usability” of the area was evaluated. This was obtained by introducing social and spatial discriminants: population density (D_{pop}) and distance-from-urban (D_{ur}). Raster maps of these factors were obtained by using the GIS Proximity grid tools. Their representation is given in the lower part of Fig. 3. By eq. 7 a map of area usability for leisure purposes, $I_u(x,y)$, was obtained. $I_u(x,y)$ finally shows well delimited sites presenting features that can be retained the most favorable for location of a new leisure activity area. In general zones with low usability are external to urban areas. The reason is that in those conditions distance from residential buildings is too long, therefore surrounding population density is too low. Moreover soil properties are not so compromised and their ecosystem role still valuable.

In order to better interpret results, urban and not-urban classes were considered separately. I_u mean value was calculated for each class and an “anomaly” map (I_u/mean[I_u]) was generated for both urban and not-urban classes. Areas where anomaly value was higher than 1 were mapped against those having an anomaly value lower than 1 generating two clusters for each investigated class. These were finally vectorized and superimposed over a 1:10,000 scale aerial ortho-image of the area to favor interpretation (Fig. 4). In this way areas favorable for hosting a new leisure site are made evident and the surrounding context, potentially including it, explicit to the planner.

[Figure 3]

[Figure 4]

Conclusions

A methodology based on a GIS multi-criterial approach was devised and tested with the aim of supporting/improving traditional land use planning workflow. GIS can support the decisional process by synthesizing, weighting and mapping all available information in order to drive new interventions towards the most suitable locations. The meaning of "*suitable*" depends on criteria urban planners decide to adopt during the decisional process. Whatever criteria are, decisions can be managed through a spatial based multi-criteria approach where economic, social, political and environmental interests can interact each other playing their different, and sometimes contrasting, role in the whole process. Scientific works dealing with this topic often neglect to include soil physical and chemical properties as crucial factors in the decision process, where preservation of ecosystem services is basic. A methodology was presented and tested based on a GIS-MCDA approach where more traditional landscape metrics are integrated with soil chemical and physical features. Some new space dependent indices were proposed to evaluate and map *suitability* and *usability* of the area with respect to the new facility - a leisure site, in the case study - that is expected to be located in the urban/peri-urban zone. These maps represent an effective tool to drive new planning policies, where soil properties play a basic role. Chemical and physical features of soils where mapped and used to calibrate space dependent cost functions and indices useful in the decisional process. The proposed methodology, in fact, generates an easy accessible operational map useful for identifying those landscape patches, within a study area, that can be considered as the best candidates to host new leisure facilities. In it is worth to remind that soil properties are used in addition with more traditional features that other studies already used (landscape metrics, demographic data, road network, etc.). Implicitly, in this work, a *direct* and *indirect* economical value is recognized to soil properties: *direct* is the one straightly related to terrain commercial dynamics; *indirect* is the one related to the environmental potential the soils offer to community. The dataset employed in the presented case study showed to be effective in the selection of an area. However, refinements and specific calibration are required for each different situation. The model in fact can be easily customized by introducing further or different parameters that, according to local planning realities, are considered more appropriate.

The methodology presented here is an attempt to encourage the community of planners to closely interact during their decisional process with local environmental protection agencies, that, usually, are the ones in charge of monitoring and mapping soil properties (with particular regard to pollutants and agricultural productivity).

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Table 1

Primary datasets. ID column contains acronyms used in the paper for these different datasets. *IPLA: Istituto per le Piante da Legno e l’Ambiente – Regione Piemonte, Italy; CSI Piemonte: Consorzio per il Sistema Informativo, Torino, Italy; ISTAT Italian National Institute of Statistics, Roma, Italy; ARPA: Agenzia Regionale per la Protezione dell’Ambiente, Torino, Italy.

ID	Data type	Reference scale	Digital format	Reference Date	Producer*
PSM	Regional Soil Map	1:50,000	Vector	2010	IPLA
PLCM	Regional Land Cover/Use Map	1:10,000	Vector	2008	CSI Piemonte
PTOCM	Topsoil Organic Carbon Map	1:250,000	Vector	2008	IPLA
PCSM	Census Data Map	1:25,000	Vector	2001	ISTAT
fC_{tot}	Diffuse Contamination Index Map	1:100,000	Raster	2012	ARPA

Table 2

Landscape metrics computed by FRAGSTATS tool and used for this study.

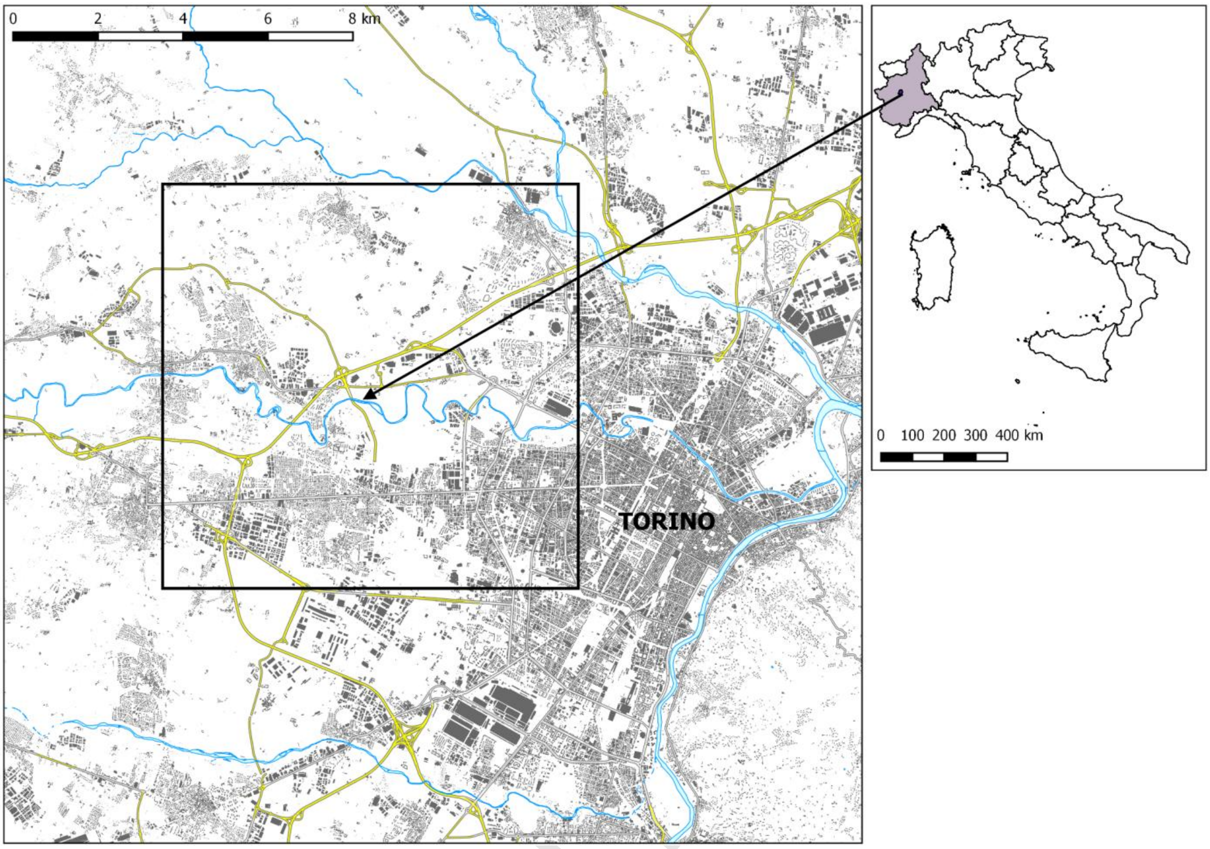
Metric	Description	Formula	Unit
Class Area (CA)	Area (ha) of each patch type (class) or the percentage of the landscape comprised of a particular patch type	$CA = \sum_{i=1}^{N} A_i$	ha or %
Total Edge (TE)	Sum of perimeters of the patches belonging to the same class	$\mathrm{TE} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{P_i}$	m

Table 3

Main statistics of soil properties and landscape metrics for the study area.

	Mean	**St. Dev.**	**Max**	**Min**
Soil chemical/physical properties				
fC_{tot} [%]	11.90	2.40	17.50	7.60
C [%]	2.37	0.99	4.00	1.00
s [%]	8.00	12.00	35.00	0.00
pH	7.80	2.40	9.00	5.00
Landscape metrics				
TE_{nu} [m]	1778	766	4377	5
CA_{nu} [%]	60.90	35.00	100.00	0.00
TE_{du} [m]	1512	1106	4727	4
CA_{du} [%]	28.30	26.70	100.00	0.00

Fig. 1. Location of the study area: peri-urban context of Torino (NW Italy).


0
2
4
6
8 km
TORINO
0
100
200
300
400 km

435 **Fig. 2.** Left: *Intrinsic Soil Quality Index* (Q_s). Right: *Landscape Consumption/Fragmentation Index* (Q_m). Both

436 indices were normalized in the range [0-1]. Map scale can be deduced by the associated coordinate system.

437

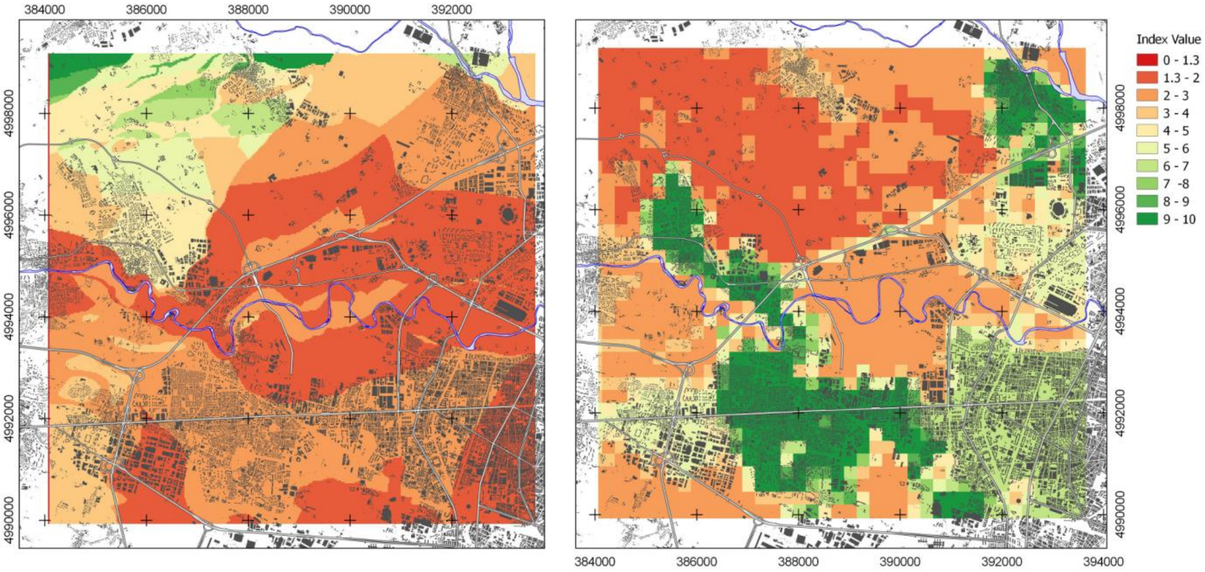
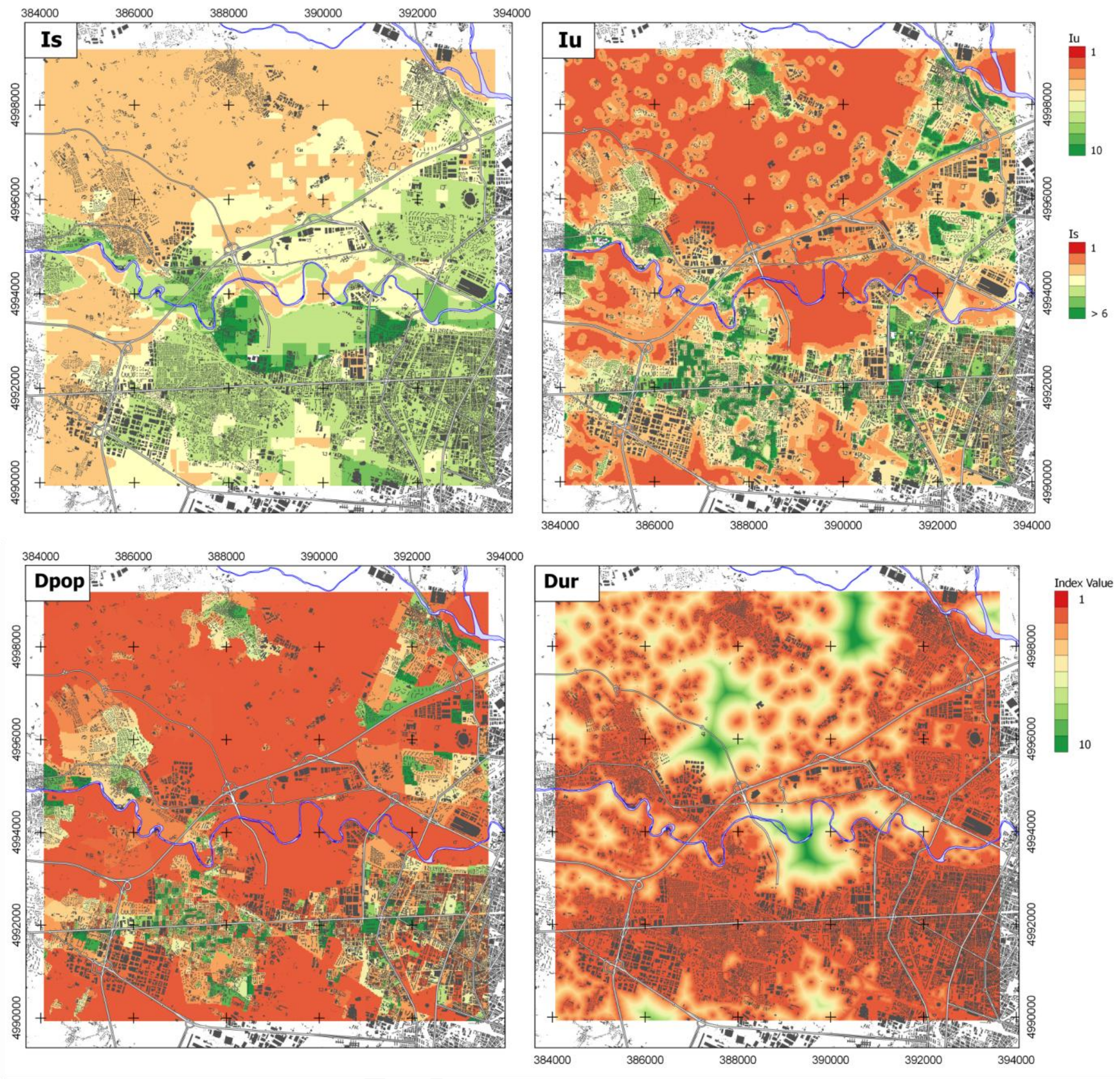

384000
386000
388000
390000
392000
394000
4990000
4992000
4994000
4996000
4998000
Index Value
🟥 0 - 1.3
🟥 1.3 - 2
🟧 2 - 3
🟧 3 - 4
🟨 4 - 5
🟨 5 - 6
🟩 6 - 7
🟩 7 -8
🟩 8 - 9
🟩 9 - 10

Fig.3. Upper left: *Suitability Index* map (I_s). Upper right: *Usability Index* map (I_u). Lower left: *Surrounding* P*opulation Density* map (D_{pop}). Lower right: *To-urban Distance* map (D_{ur}). All indices were normalized in the range [0-10].Map scale can be deduced by the associated coordinate system.


Is
Iu
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384000
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390000
392000
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4990000
4992000
4994000
4996000
4998000
Iu
1
10
Is
1
> 6
Index Value
1
10

446 **Fig.4.** Map showing favourable (high score) and inappropriate (low score) areas for leisure activity site location. Urban and not-urban classes are considered separately. Favourable areas are the ones showing a I_u/mean[I_u] ratio fairly higher than 1; inappropriate areas are the ones showing a I_u/mean[I_u] ratio fairly lower than 1. Zones were superimposed over a 1:10,000 nominal scale aerial orthoimage. In the main image scale factor can be deduced by the associated coordinate system.

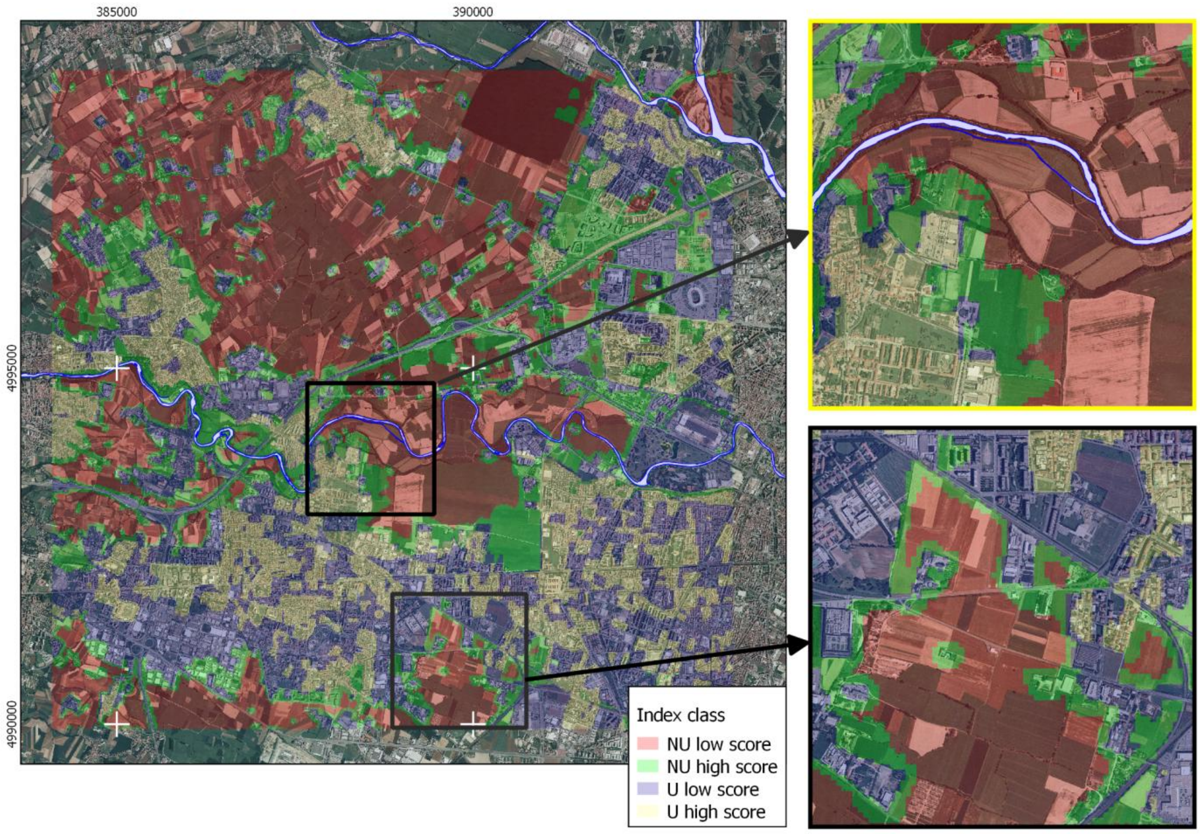

385000
390000
4995000
4990000
Index class
NU low score
NU high score
U low score
U high score

Figure 1

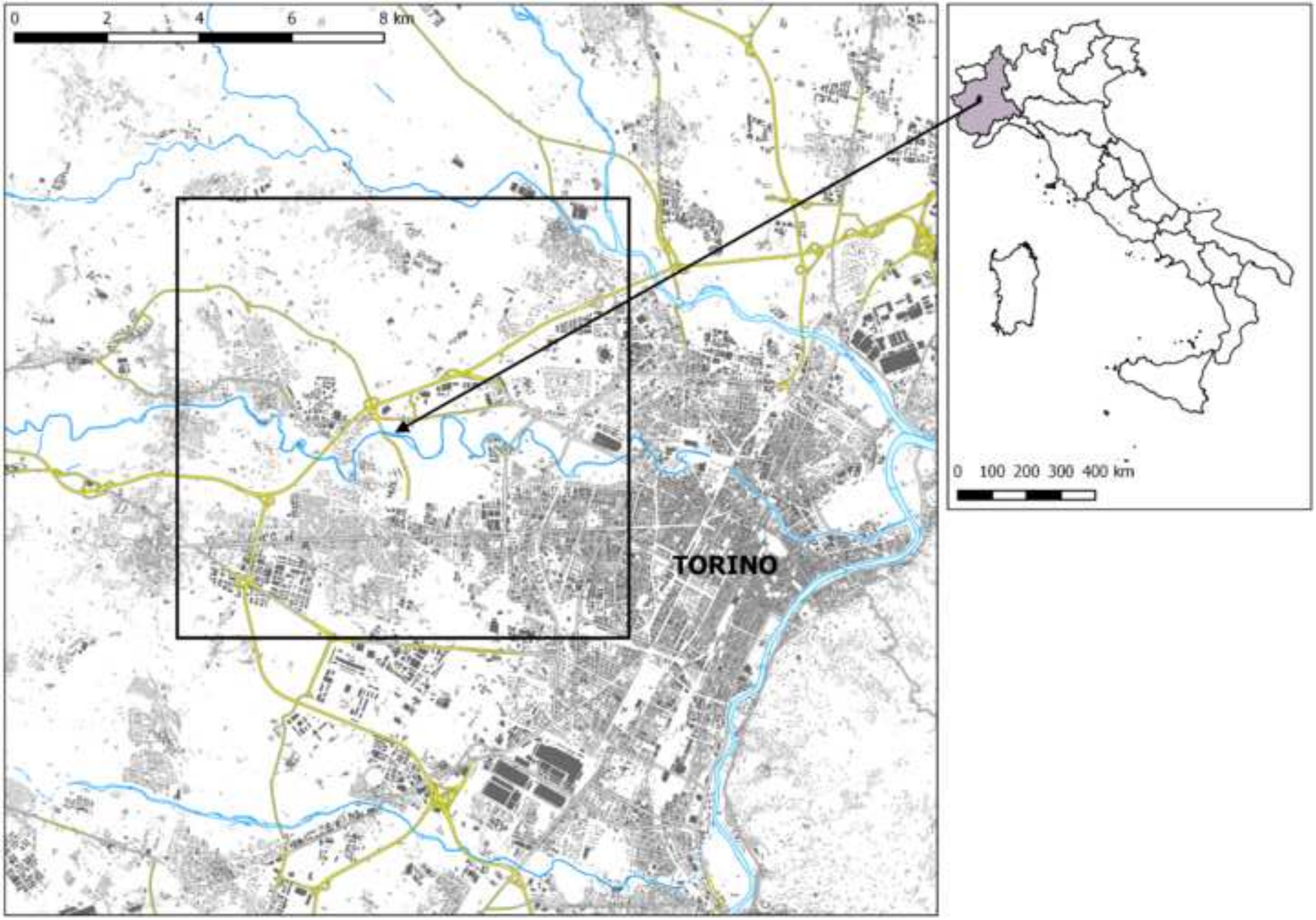
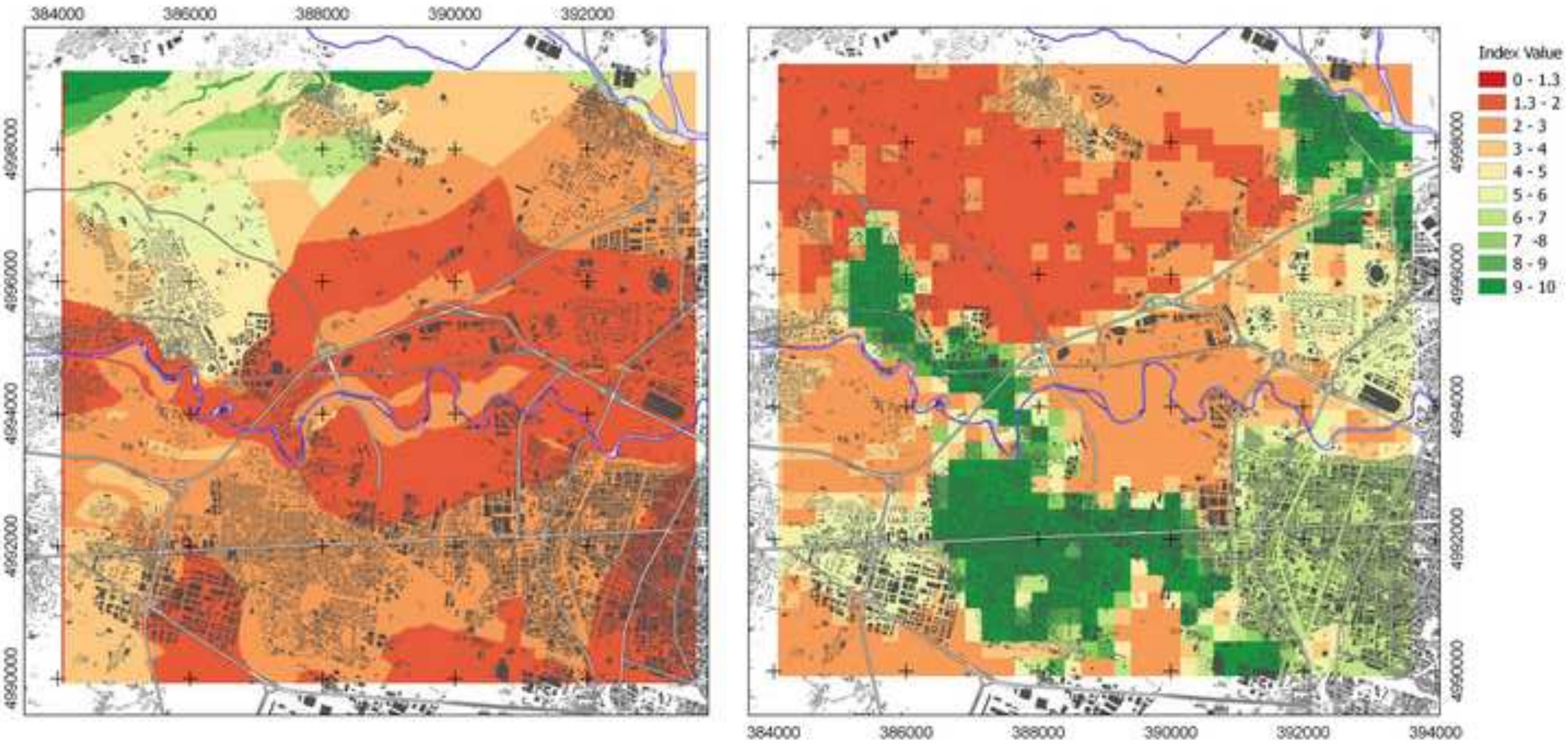


Figure 2


384000
386000
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4998000
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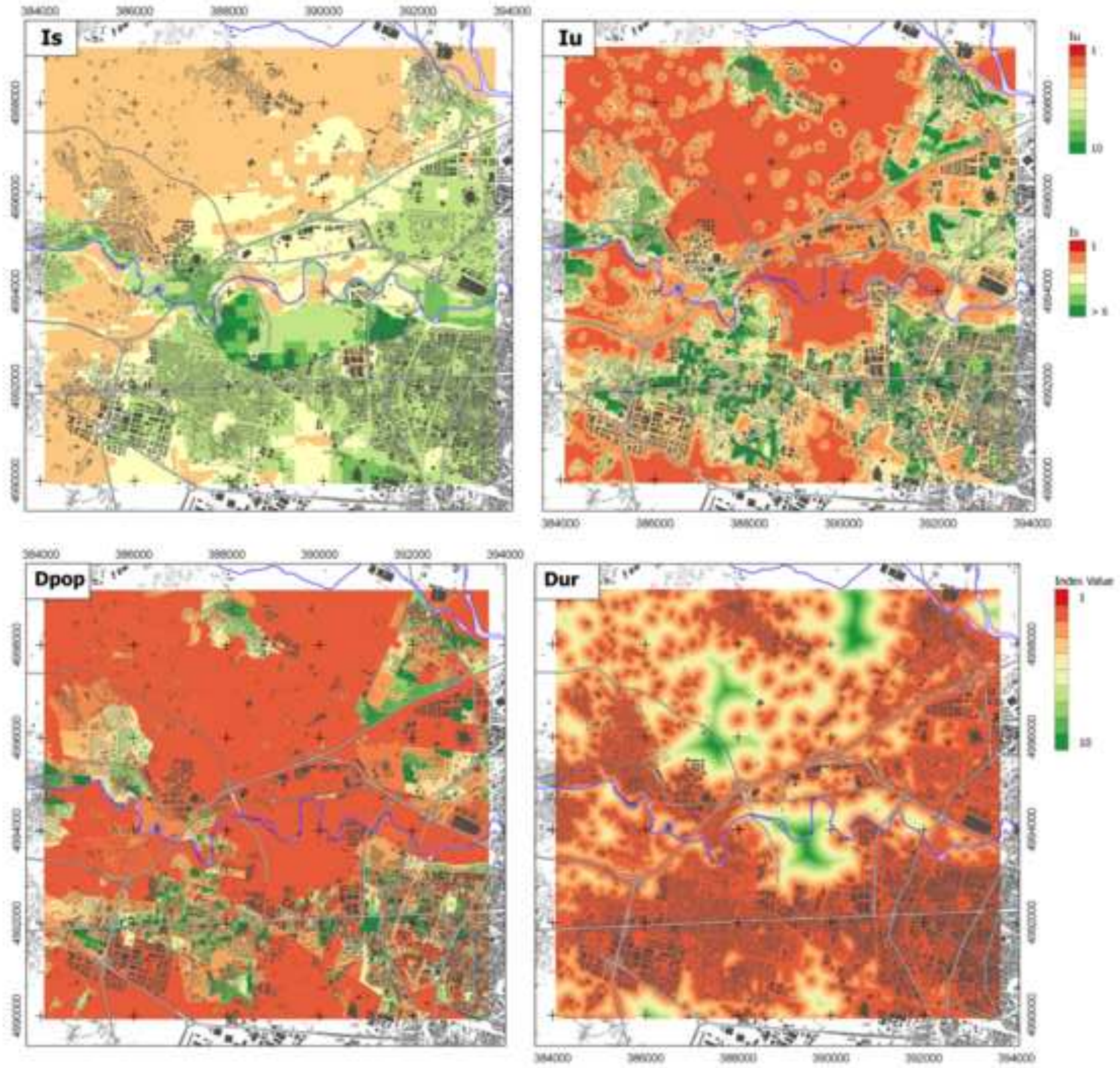
4990000
Index Value
0 - 1.3
1.3 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 -8
8 - 9
9 - 10

Figure 3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Index Value
1
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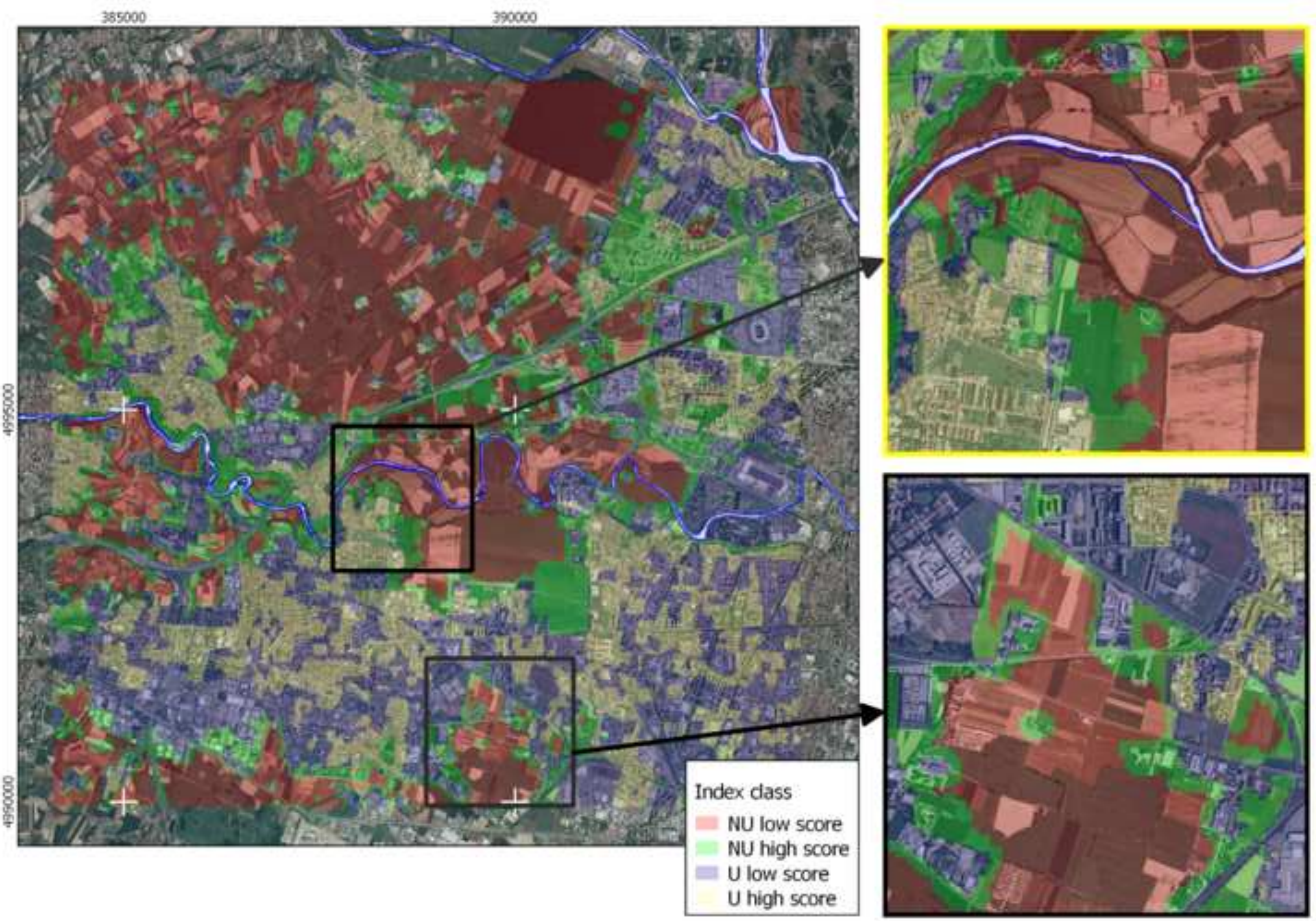
Figure 4


385000
390000
4995000
4990000
Index class
NU low score
NU high score
U low score
U high score

NOTE:

Table captions are BEFORE Tables.

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Highlights

- A multi-criteria GIS-based approach for urban planning is presented.
- Physical/chemical features of soil are retained basic in urban planning policies
- Planning need to fill is the location of a new leisure area in an urban context
- Soil, landscape and demographic information were jointly considered.
- Area vocation to host leisure activity was mapped.