Geospatial Tools in Support of Urban Planning: A Possible Role of Historical Maps in Programming a Sustainable Future for Cities

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Abstract. In urban planning, a numerical and spatially based approach is expected to drive to the "best" choice. In this work a GIS-based procedure is proposed to model territorial dynamics by comparing maps of two different periods (1830 and 2000). The study area is located in the urban fringe of Torino (NW Italy) that suffered from important changes especially in the last 60 years. A workflow was defined and applied, based on a multi-criteria approach implemented by GIS. With reference to existing maps, strength and direction of forces, opposing urban to rural/semi-natural surroundings, were mapped and described operating through the following scheme: a) vectorization and qualification of both impacted (rural) and impacting (urban) landscape elements; b) implementation of spatially dependent functions representing strength and direction of urban pushes against rural; c) qualification of rural areas majorly exposed to urban growth. Accordingly, some maps, useful to read the playing urban growth dynamics, were generated and some applications proposed. Nevertheless some limitations still persist: the proposed methodology is based on simplified hypotheses, mainly related to the definition of spatial indices that somehow depend on the type of information that available maps contain. A second limitation is related to the persistence of a great component of subjectivity during the extraction of the starting information from the available maps and weights assignation.

Keywords: Transitional landscapes · GIS · Urban fringe · Urban pushes · Urban planning · Spatial functions

1 Introduction

GIS tools and spatial analysis techniques have already proved to be effective in urban planning [1, 2] and landscape description [3–6]. In the last few years, GIS technology and the increasing amount of free digital georeferenced data have encouraged the adoption of spatial analysis to support land planning, mainly relying on multi-criteria approaches [7, 8]. Many authors [9, 10] have investigated the spatial distribution of environmental factors, particularly to support management of metropolitan areas

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[11–13]. Highly populated peri-urban areas are very critical for different aspects, like soil sealing and degradation, urban sprawl and, in general, loss of ecosystem services [14]. Landscape metrics are widely adopted to characterize both planned [15–17] and unplanned urban areas expansion [18]. In some works remote sensing data and socio-economic factors [19, 20] were jointly used with landscape metrics. In spite of a wide literature, in the most of cases, GIS tools are used to generate mere representations by integrating data from different sources. Only in few cases, conversely, GIS-based works take into consideration quantitative concerns that are expected to increase the level of objectivity in landscape reading and future planning [21, 22]. From this point of view maps move from simple territorial representations and turn to be basic measurement tools, that planners and policy makers can adopt to base their decisions on. It is authors' conviction that, if one has to select among different planning solutions, a numerical approach, standardly adopted, can drive to the "best" choice. It is worth to remind that the concept of "best" strictly depends on the criteria used to base the choice on; therefore a choice is "the best" one only under "those" conditions. According to this operational philosophy, in this work a procedure is presented based on GIS advanced tools, specifically aimed at urban dynamics description (in space and time) for planning purposes. The initial assumption is that urban growth dynamics can be assimilated to a force balance where urban growth pushes against rural/natural areas, making desirable external landscape preservation. In a war, the programmed actions of a single battle, occurring in a specific moment of the conflict, represent "tactics"; differently, long-term decisions, possibly affecting more than one battle, define the "strategy". Transposing the same interpretation key to the urban planning context, it is easy to see that the representation of the pushing and resisting forces operated by urban growth and rural/natural surroundings, respectively, at a certain time (the one of the considered maps) is something related to "tactics". Differently, if two situations showing the same area at different times are compared, the underlying "strategy" can be guessed that planners chose to drive urban growth in the transitional period. This is the idea behind this work; consequently, GIS tools were initially used for representing the "battlefield" at two different times, i.e. the place where urban growth pushes and rural areas resist; successively, those scenarios were compared to analyze and represent the strategy that, possibly, drove urban growth in the study area.

Concerning the first task, to give a rather complete description of the field of acting forces at a certain time, methodology operated at two levels. Firstly, it gave a representation of strength and direction of the pushing forces of urban against rural/semi-natural surroundings; this was obtained through a spatial comparison of the previously represented scenarios. Then impacted areas (rural, semi-natural) were qualified with a special focus on the perceptive impact that urban growth can generate onto an observer located within a still resisting rural/semi-natural area. According to these premises, a GIS-based procedure was proposed, with the explicit goal of supporting urban planners with a tool aimed at giving a spatial representation about the on-going territorial dynamics. The presented case study has to be intended as a paradigm for readers, i.e. a place where the core item of this work (the GIS-based procedure) is tested. For this purpose, a peri-urban area located in the proximity of Torino (NW Italy) was selected and the procedure applied with reference to the territorial changes that this area suffered from in the time range 1830–2000. The following workflow was defined and applied,

based on a multi-criteria approach modelled within GIS. With reference to the available maps a selection, vectorization and qualification of landscape features were done to define impacted players (rural areas) and threats (urban). According to the above mentioned philosophy some space dependent functions were designed and implemented by GIS tools to give a spatial representation of strength/direction of urban pushes against rural. Rural/semi-natural areas that were exposed, or potentially exposed, to urban growth aggression were analyzed and qualified. A discussion is finally given about results, proposing possible interpretations and deductions in terms of urban planning.

2 Materials and Methods

2.1 Study Area

The study area is located in the first urban belt of Torino (NW Italy) including the municipalities of Collegno and Grugliasco (about 32 km^2 and 80000 inhabitants, Fig. 1). This area is characterized by the permanence of historical and valuable farmhouses surrounded by agricultural pertinences which are prevailingly disused at present. The erosion of traditional rural landscape and the pressure onto farmhouses due to urban expansion after the World War II are especially evident on the North-Western fringes of the settlement. Around the middle of XX century local engineering industries and automotive factories (Pininfarina, Bertone, Westinghouse, etc.) determined radical changes that deeply modified the urban frame.

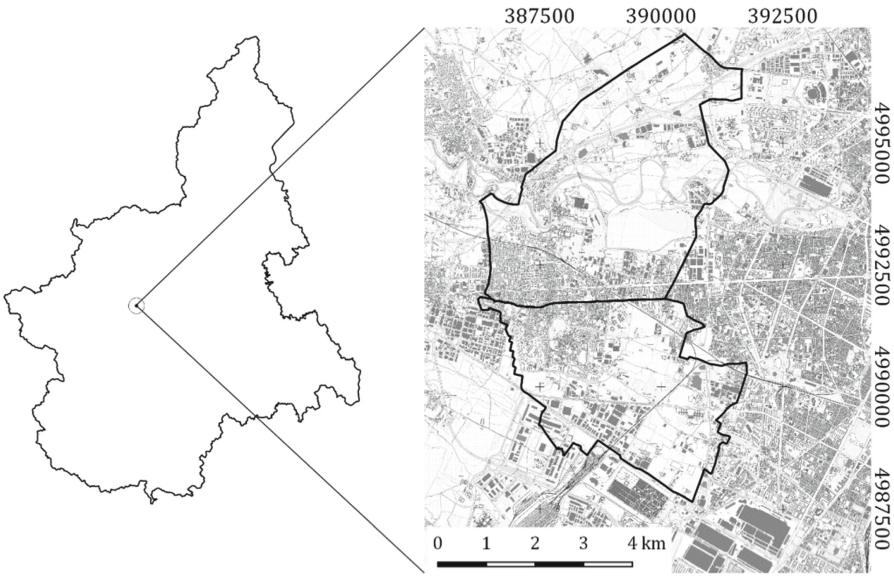

Fig. 1. Study area within Piedmont Region (NW Italy); Reference System is UTM/WGS84 32N.

Building activity frenetically increases as well: residential areas, infrastructures, industrial and commercial activities greatly affected the local rural landscape by cancelling the most of the pre-existing agriculture-devoted landmarks. Canals network for crop water supplying, service trails, rural buildings and crop fields were almost completely cancelled, finally determining the loss of the entire rural cultural background of the area. Moreover, some historical farmhouses progressively turned to dereliction and rural landscape gets more and more unreadable. In the area, urban pressure is still active making it a good laboratory to test new procedures to better manage future territorial changes instances.

2.2 Available Data

Focusing on urban growth affecting the study area, the following two periods were assessed and compared: one preceding the industrial revolution (1816–1830), hereinafter called T1; one corresponding to the present situation (2000), hereinafter called T2. As far as T1 is concerned, the reference map was the so called "*Carta topografica degli Stati di Terra-ferma di S.S.R.M. Carlo Alberto Re di Sardegna fatta dal Corpo dello Stato Maggiore Generale alla scala di 1:50,000*" (hereinafter called M1830). It is dated between 1816 and 1830 and reports continental estates (islands excluded) of the Savoia Italian Royal Family.



Fig. 2. (Right) A digital scanned image of the M.10 sheet obtained from the Italian Military Survey Office (Istituto Geografico Militare, IGM) used as reference for describing T1 situation (1830). (Left) Overall scheme of map sheets.

Main technical features of M1830 are the following: a) the geodetic reference frame is centred on the Real Observatory of Torino, assumed as the origin of the Cartesian system; b) adopted projection is a modified Sanson-Flamsteed one; c) the whole mapped area is covered by 112 sheets (format is about 0.42 × 0.60 m); d) planimetric positioning was derived by reduction of pre-existing maps integrated with some new surveys; e) altitude is only qualitatively reported, being obtained "by landscape visual

interpretation operated by an experienced surveyor"; f) no reference grid is reported, but a scale bar is drawn in each sheet, with reference to the ancient local measurement unit of distance: the Piedmontese Trabucco (3.0864 m). For this work, a digital scanned image of the paper tile labelled as M.10 (Fig. 2) was obtained from the Italian Military Survey Office (Istituto Geografico Militare, IGM).

Scanning was performed @300 DPI (dots per inch), determining a pixel physical size of 84.6 microns that, in ground units, corresponds to 4.23 m. This value is consistent with the reference accuracy officially expected for a modern 1:50,000 scale map in the Italian cartographic context, i.e. 10 m. As far as T2 is concerned we used the present Regional technical vector map 1:50,000 (hereinafter called CTR50), obtained for free from the online Geoportal of the Piemonte Region Cartographic Office (http://www.geoportale.piemonte.it/cms/). Map metadata report that CTR50 is updated at the year 2000 and the reference frame is the WGS84 UTM 32N.

2.3 Data Pre-processing

Data processing was operated by QGIS 3.8 and SAGA GIS 7.0.0. Concerning M1830, since only a scanned image was available, it was preventively georeferenced (Fig. 3). Native map symbols were decoded, and the main local land cover classes vectorised by editing. The meaning of the vectorised land cover classes was assigned with reference to Table 1. In the proposed landscape interpretation model, urban growth was considered a threat for the rural/semi-natural areas (impacted objects); consequently, built-up classes were labelled as "impacting" and rural/semi-natural classes were labelled as "resisting".

The same classes were consequently extracted from the available CTR50 vector map by GIS attribute selection. For both the maps, a weight was assigned, depending on the considered land cover class of Table 1 with the following criteria: a) weights of built-up areas define the level of threat that a certain type of urbanization is expected to generate onto resisting rural surroundings. Higher weights were assigned to industrial areas and main roads; b) weights of rural/semi-natural areas define landscape value of local land cover. In this case, weights were assigned admitting that higher the degree of naturalness, higher the local landscape value.

Table 1. Impacting and resisting classes used in this work. They were selected/edited from the two compared maps (M1830 and CTR50). Table also shows weights whose meaning is reported in the text.

Classes	Weights		Classes	Weights	
	M_{1830}	CTR50		M_{1830}	CTR50
Impacting			Resisting		
Secondary roads	Not present	1	Other natural surfaces	Not present	1
Main roads	1	3	Agricultural land cover	1	2
Residential	2	2	Meadows	2	3
Industrial	Not present	4	Forest	3	4
			Vineyards	4	Not present

With reference to the assigned weights, two land cover maps, hereinafter called LC1830(x, y) and LC2000(x, y) were generated from M1830 and CTR50 respectively.

The analysis was conducted at two levels, to contemporarily investigate dynamics of urban growth and its impacts against surrounding rural landscape: a) firstly, a representation of strength and direction of the pushing forces of urban against rural/natural surroundings was generated; b) successively the impacted/exposed areas were qualified.

2.4 Representing Strength and Direction of Threats

Regarding representation of urban pushes, it must be admitted that they are related to the local difference of "Urban Potential", (UP). In the present work UP was computed and mapped in terms of "local urban density". Computation was achieved by rasterizing the urban class from *LC1830(x, y)* and *LC2000(x, y)* and converting the original content into the correspondent binary representation, hereinafter called *Ur(x, y, t)*, where t = [1830, 2000]. *Ur(x, y, t)* is a grid where built-up pixels were labelled as 1 (independently from building type) while all the other ones as 0. Grid resolution was set to 10 m, consistent with a 1:50000 scale map. Successively an "area of influence" (AI) was defined around each pixel of *Ur(x, y, t)* and the correspondent urban local density map, hereinafter called UDM(x, y, t), computed. It was obtained running over *Ur(x, y, t)* a 150 × 150 m sliding window (AI) in charge of locally computing the following value:

$$UDM(x, y, t) = 100 \cdot \frac{N_{urb}}{N_{tot}} \tag{1}$$

where N_{urb} and N_{tot} are the local number of built-up pixels and the total number of pixels, respectively, within the 150 × 150 m sliding window (i.e. AI) at the generic position within the analyzed raster map. *UDM(x, y, t)* was assumed as map of the "local potential" of urban forces pushing against rural/semi-natural surrounding areas. The local difference of potential, consequently, was assumed as descriptor of the local acting force (push). The passage from the representation of the potential to the correspondent field of acting forces can be managed considering *UDM(x, y, t)* as a 3D surface, i.e. a sort of Digital Surface Model. A pre-processing step was initially achieved aimed at down-sampling *UDM(x, y, t)* from 10 m to 150 m pixel size, with the aim of cutting off high frequency components of urban density variations (micro changes), thus focusing on the low frequency ones (macro changes). The underlying hypothesis was that, at the scale of this work (1:50,000) only low frequency components of the density can be reliable enough to describe the actual urban pushes against rural.

Successively, slope, *SL(x, y, t)*, and aspect, *AS(x, y, t)* grids were computed from the down-sampled UDM(x, y, t). Slope was interpreted as measure of the local force strength; aspect was assumed as measure of its direction. To translate this disaggregated information (two independent raster layers) into a more effective representation, closer to an ordinary field of forces, *SL(x, y, t)* was vectorised, obtaining two point layers for T1 and T2, respectively. The slope local value was recorded as numerical

attribute in the tables associated with the two newly-generated vector layers. The attribute table was then completed with a further field containing the aspect local value extracted from *AS(x, y, t)*. Finally, using the proper visualization tool available in QGIS (Vector Field Renderer - https://github.com/ccrook/QGIS-VectorFieldRenderer-Plugin), the field of forces was mapped for the two investigated periods. From the original 10 m *UDM(x, y, t)* was also derived a contour line-based representation to improve readability of the vector field (Fig. 4).

2.5 Representing Landscape Exposed Values

In the proposed model both the exposed value of a rural/semi-natural areas and the degree of impact local (one can perceive looking from country to town) related to the advancing urbanization were considered. The "exposed value" was assumed depending on the type of land cover class (eventually from the shape properties of the each patch of the polygon layer). The degree of local impact, differently, was assumed to be strictly related to: a) the distance between the generic location within rural areas and the closest built-up element; b) the type of the nearest built-up element (residential, industrial, public facility, etc.). In terms of spatial analysis, the latter was represented as a grid map where the threat affecting the generic rural position is inversely proportional to the distance from the nearest urban feature and directly proportional to its impacting strength (the previously mentioned "weight").

This relationship was modelled defining the Local Pressure Index, *LPI(x, y, t)*, Eq. 2, for both the considered periods (T1 and T2).

$$LPI(x,y,t) = \frac{A(x,y,t)^{-}}{D(x,y,t)^{-}} \tag{2}$$

where $A(x, y, t)^{-}$ and $D(x, y, t)^{-}$ are respectively the Allocation and Distance spatial operators, generated with a pixel size of 10 m, from *LC2000(x, y)* and *LC1830(x, y)* respectively; only the "impacting" classes were considered at this point with reference to Table 1. It is worth to remind that $A(x, y, t)^{-}$ defines, for each pixel, the weight value of the corresponding threatening nearest feature (road or building). Differently, $D(x, y)^{-}$ defines, for each pixel, the Euclidean horizontal distance that separates that specific location from the nearest threatening feature. *LPI(x, y)* was generated under the following hypotheses: a) the contribution of the impacting factor decreases while increasing the distance from the nearest impacting feature; b) its initial (and maximum) value is the one corresponding to the weight of the nearest feature.

Successively, in order to quantify the potential depletion of the local rural landscape quality, due to the surrounding urban features, a Local Impact Index (LII) was calculated according to Eq. 3.

$$LII(x,y,t) = \frac{A(x,y,t)^{+}}{LPI(x,y,t)} \tag{3}$$

where $A(x, y, t)+$ is the raster map of positive weights assigned to rural/semi-natural areas.

It is worth to remind that index maps are space-and time-dependent since they have been generated for both the periods.

3 Results and Discussion

3.1 Data Pre-processing

Concerning M1830 georeferencing, given the flatness of the area, it was successfully operated by applying a 2nd order Polynomial transformation in QGIS. Fifty-two regularly distributed GCPs were collimated with reference to CTR50 (Fig. 3) determining a RMSE (Root Mean Squared Error) of 22.1 m; this value is two times the expected value (10 m) that, however, concern maps produced by modern technical instruments. Considering the time and the type of survey, and assuming a rigorous positioning not so relevant for this type of application, this type of result was retained reasonable. Georeferenced image was consequently generated with a pixel size of 5 m.

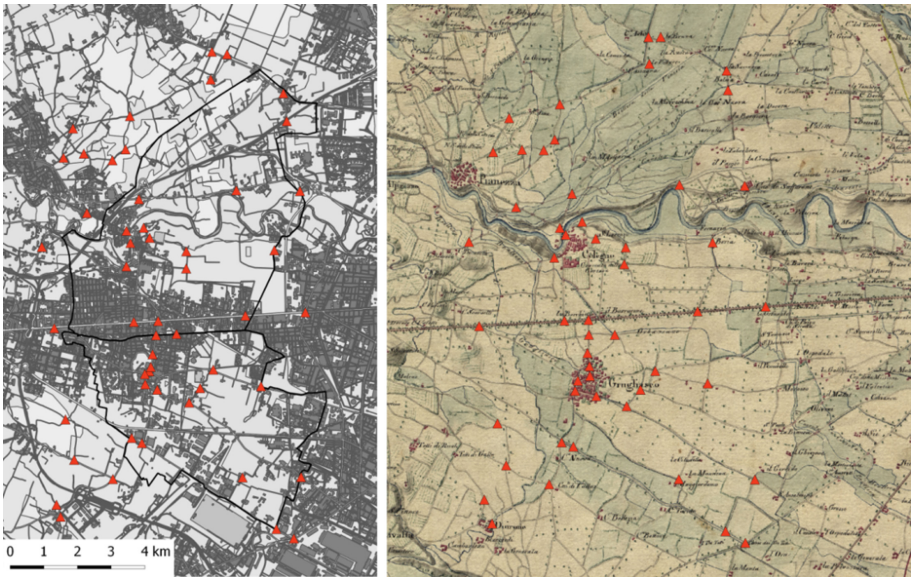

Fig. 3. (Right) Scanned image of the 1830 map. (Left) CTR50 map used as reference layer during georeferencing. Red triangles show the position of Ground Control Points. (Color figure online)

The georeferenced M1830 was interpreted to generate the *LC1830(x, y)* polygonal vector layer, mapping the recognized land cover classes at T1 (Table 1). Differently, land cover classes at T2 were selected by ordinary GIS query (select by attribute) from the available CTR50 vector map to generate *LC2000(x, y)*. This step was needed to reduce spatial content by aggregation in few classes. Both *LC1830(x, y)* and *LC2000(x, y)* were

finally completed by weights assignation using newly added fields of the correspondent attribute tables.

LC1830(x, y) and *LC2000(x, y)* were used as starting point for successive selections (and rasterizations) to generate following maps needed for the goals of this work.

3.2 Strength and Direction of Threats

UDM(x, y, 1830) and *UDM(x, y, 2000)* were generated using information about built-up areas derived respectively from *LC1830(x, y)* and *LC2000(x, y)*.

In Fig. 4, a representation of *UDM(x, y, t)* is given for both the periods, adopting a contour lines visualization (lines connecting points having the same urban density level).

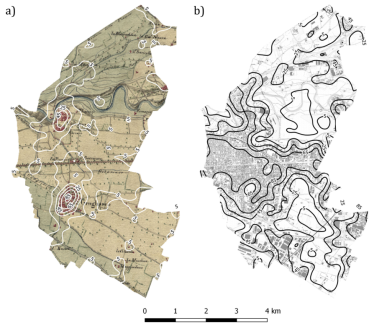

Fig. 4. Urban Density Maps generated respectively for the years 1830 (a) and 2000 (b). Contour lines join points having the same density value.

From maps, it can be noted that urban sprawl proceeded along two preferred directions: a) new residential buildings were built to close the gap between the two existing main urban agglomerates (centripetal direction); b) new industrial areas, differently, were placed in the external parts of the historical towns following a centrifugal direction. These two coupled dynamics moved the "hot spots" (highest urban density) to new positions and determined an almost completely loss of the agricultural pattern of the local landscape. To give an easiest and immediate reading key of the situation at the two compared times, a vector field representation was generated. *UDM(x, y, t)* maps were therefore down-sampled to a Ground Sample Distance (GSD) of 150 m to cut off weak local potential differences and emphasizing only the strongest ones. This simplification permitted a more efficient representation in the next step of the work, when slope and aspect information, derived from *UDM(x, y, t)*, where converted into a point vector layer to generate the vector field visualization of Fig. 5.



Fig. 5. Comparison between fields of pushing forces for the 1830 (red ones) and 2000 (green ones). (Left) Whole area. (Right) A detail of the squared area. (Color figure online)

As expected, pushes @T1 were stronger than @T2. Potential of urban growth was huge, in force of the enormous free space around towns potentially available to extend built areas. Nevertheless, they remained spatially constrained in a limited area (the one immediately close to the existing urban agglomerates). Differently, at T2 pushes appeared to be weaker; vector field minima are higher in respect of maxima, determining a general reduction of the strength of pushes; this can be related to the high degree of proximity between different built-up areas that makes pushing forces unable to completely exhaust their strength before entering a new built zone. The reading key is that in this situation rural landscape is too degraded by a badly managed soil sealing. In fact, resisting and occluded agricultural areas cannot be anymore perceived felt and lived by people like "true" agricultural ones. Presently, the remaining strong pushes are pointing towards the remaining agricultural context in the South-East part of the area.

Another notable aspect in 2000 is that pushing forces appear to be more diffused and poorly concentrated, confirming the idea that agricultural pattern is almost completely loss and the remaining parts are only waiting to turn to urban. The new assault to remaining agricultural areas comes from every part and no new strategy in urban planning can be imagined different from the ordinary simplest and deprecable one, i.e. to fill the gaps. In other words, these considerations confirm that pushes of the first generation are almost exhausted in the area just for an objective lack of further free space and not for a more virtuous planning strategy.

3.3 Representing Landscape Exposed Values

Once *LC1830(x, y)* and *LC2000(x, y)* were generated, proper weights (Table 1) were assigned to classes to describe their influence on surrounding features (Fig. 6). It is worth to remind that during weights values assignation, a high level of subjectivity is applied, since they strictly depend on the existing cultural/political situation. Weights can operate positively or negatively according to the instances expressed by local

population, or urban planners, at the moment when the analysis is performed. In this work pushes of built-up areas against rural/natural ones were negatively intended. Consequently, were assumed as "threats". Oppositely, agricultural/natural areas were interpreted as landscape valorising elements. In Fig. 6, both *LC1830(x, y)* and *LC2000 (x, y)* are reported, mapping the above mentioned distinction between "threats" (negative) and "valorising elements" (positive). The latter were also interpreted as map of the "exposed landscape values" showing the resisting rural areas waiting for a new aggression by urban growth.

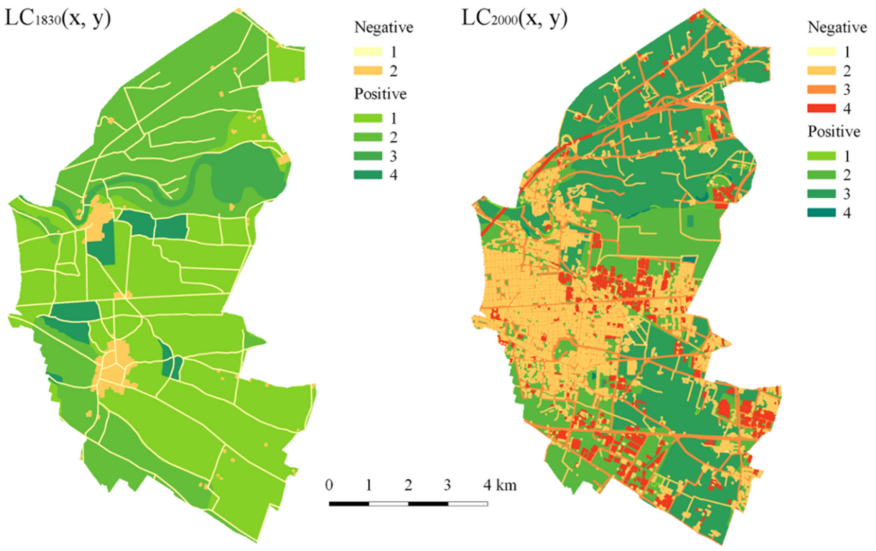

Fig. 6. Urban threats (negative) and landscape exposed values (positive) represented according to the assigned weights. (left) 1830; (right) 2000.

Successively, *LPI(x, y, t)* was calculated for both 1830 and 2000, assuming that it represents the local impact (in landscape feeling and perception) that built-up areas generate onto people. Figure 7(a, c) shows that, in both the periods, *LPI* highest values can be related to urban and peri-urban areas, gradually decreasing while moving outside. The difference between 1830 and 2000 is evident both in strength and in spatial distribution. In 1830, stronger pressures were located very closed too built-up areas, exhausting their effect immediately after a small distance. In 2000 urban pushes are diffused all around and, in general, they act more strongly everywhere.

LII(x, y, t) was generated too, assuming that natural and semi-natural areas improve landscape quality; *LII* takes contemporary into account the local landscape quality and the degree of impact given by the nearest built-up areas (synthesized by *LPI*). The lower is the distance from threat, the higher is the impact. Consequently, *LII(x, y, t)* maps can be assumed as a proxy of environmental/landscape quality as perceived by people at the generic position in the area and, consequently, as a measure of the expected impact that urban pressure generates at that position (landscape exposed

value). Figure 7(b, d) shows that lowest values of *LII* are reasonably located close to built-up areas and roads network. It also shows that in 1830 *LII* values were higher and higher (maximum value is 10) than in 2000 (maximum value is 3.50); this is a further confirmation that the present situation has turned to a too compromised condition from the rural/natural landscape point of view. In fact, the expected perception of urban advancing, seen from the few (and small) resisting natural/rural patches, is lower and lower than in the past. This is the effect of the encirclement that urban achieved in respect of the remaining rural areas.

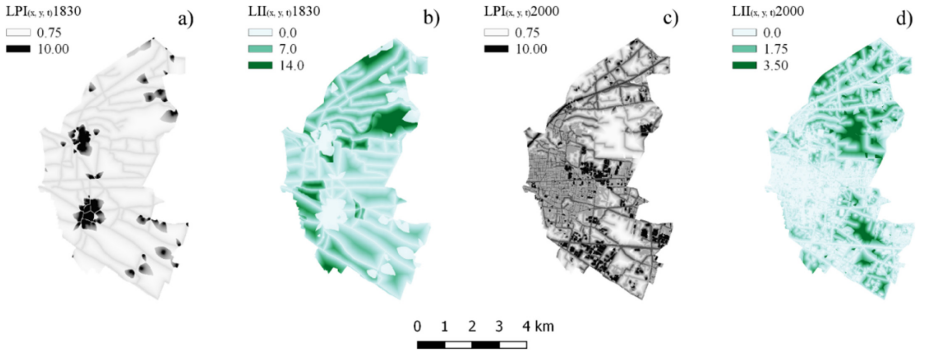

Fig. 7. Local Pressure Index (*LPI*) and Local Impact Index (*LII*) maps generated for the two periods. In *LPI* (a, c) highest values represent urban and peri-urban areas which have the greatest influence on the surrounding surfaces, gradually decreasing far from them; in *LII* (b, d) lower values represent areas where environmental/landscape quality is low.

4 Conclusions

In this work a procedure based on GIS advanced tools specifically aimed at urban dynamics description and planning (in space and time) was proposed. Native authors' assumption was that urban growth dynamics can be assimilated to a force balance where urban growth pushes against rural/natural areas. Somehow, it was admitted that in peri-urban areas a battle is continuously on, opposing urban growth instances to rural, or natural, landscape preservation ones.

As a case study we assessed and compared two extreme situations concerning urban growing in the proximity of Torino (Piemonte, NW Italy): one preceding industrial revolution (years 1816–1830) and one showing the contemporary situation (year 2000). The proposed methodology was based on space-dependent index maps specifically designed to locally measure landscape factors retained involved in urban growing processes. It is authors' opinion that a complete description of urban growth dynamics is only possible by comparison of consequent situations. Urban Density Maps were considered as the starting point to derive this information from, at the single time. Strength and direction of pushes were derived by considering slope and aspect of UDM and representing them through a vector field approach.

The reading of vector fields representing urban pushes at different times is a useful tool to interpret strategy underlying urban growth management in the assessed transitional period.

The possibility of mapping the importance of both built-up and agricultural/natural areas, by measuring their chances of advancing (urban) or resisting (rural), can give a further interpretation key for peri-urban landscape dynamics reading. Two space-dependent indices (LPI and LII) were proposed to map, at the single time, these peculiarities. The combined interpretation of these indices in time and space can support planners to recover the meaning of the hidden dynamics that drove urbanization in the area.

The same approach is expected to be adopted to compare the present situation with a planned (potential) future one to evaluate the properness, or limitations, of the suggested planning solutions. Consequently, planners will be provided of a further tool to validate their proposals and, eventually, to re-calibrate them.

Nevertheless some limitations can be still recognized in this approach: firstly, the proposed methodology is based on simplified hypotheses, mainly related to the definition of spatial indices that somehow depend on the type of information that available maps contain. A second limitation is related to the persistence of a great component of subjectivity during the extraction of the starting information from the available maps and weights assignation. A bad interpretation can lead to a wrong description of the reality. In conclusion to improve results and, in particular, to properly set land cover weights in respect of the forecasted social/economic development of an area, a strong synergy among planners, landscape experts, local administrators and population has to be activated. Moreover new professionals, well skilled in spatial analysis and GIS advanced tools have to enter the decisional process to support the above mentioned main actors. Their expected role is the numerical formalization of technical and political instances tending to effective representation in the shape of maps (of space dependent indices).

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