Europ. Countrys. · 1 · 2017 · p. 1-16
DOI: 10.1515/euco-2017-0001

European Countryside **MENDELU**

A MINIMUM INDICATOR SET FOR ASSESSING FONTANILI (LOWLAND SPRINGS) OF THE LOMBARDY REGION IN ITALY

Natalia Fumagalli, Giulio Senes, Paolo Stefano Ferrario, Alessandro Toccolini[1]

[1] Natalia Fumagalli, Giulio Senes, Paolo Stefano Ferrario, Alessandro Toccolini, Department of Agricultural and Environmental Sciences, University of Milan, via Celoria 2 – 20133 Milan Italy, e-mails: natalia.fumagalli@unimi.it; giulio.senes@unimi.it, paolo.ferrario@unimi.it, alessandro.toccolini@unimi.it

Received 25 March 2016; Accepted 19 July 2016

Abstract: This paper reports on the issue of *fontanili* assessment. A *fontanile* is a lowland spring, excavated by humans for the use of underground water for irrigation. From the XII century on, *fontanili* have been dug to extend water availability throughout the year and increase agricultural land use in the lowlands of Northern Italy. Because water of the *fontanile* stays at temperature without great changes throughout the year (between 8 and 15°C), this environment is host to a vast variety of flora and fauna and has ecological and landscaping value. Because these springs are typical and unique landscape features of Northern Italy, there is not an international background on assessing methods of *fontanili* functions inside the countryside. The first goal has been to define a set of simple and consolidated indicators to evaluate watering, ecological and recreational function of 1160 *fontanili* of the Lombardy Region. The second one has been to identify homogenous areas with groups of *fontanili* in close proximity and with similar indicator values using interpolation tools. This classification can be used by Regional Administration to assign money to recover and maintain *fontanili*. The most important areas will be protected by regional and local planning instruments.

Keywords: *Fontanil*e, low land spring, functional assessment

Abstract: Obiettivo dello studio sono l'analisi, la valutazione e la classificazione dei fontanili. Il fontanile è una presa d'acqua nella falda acquifera non affiorante creata dall'uomo per far risalire e utilizzare a scopo irriguo le acque sotterranee tipica della Pianura Padana del nord Italia e della Regione Lombardia in particolare. A partire dai secoli XI e XII i fontanili sono stati un elemento fondamentale per lo sviluppo dell'agricoltura lombarda. Nei secoli successivi mezzi di approvvigionamento idrico alternativi hanno spesso sostituito l'impiego dell'acqua dei fontanili che tuttavia mantengono ancora la loro funzione irrigua. Poiché le acque dei fontanili si mantengono durante l'anno in un intervallo di temperatura compreso tra 8 e 15°C, costituiscono un ecosistema ricco di specie animali e vegetali e svolgono un ruolo di particolare importanza anche dal punto di vista ecologico e paesaggistico. Dal momento che questa risorsa rappresenta un elemento unico caratterizzante la pianura padana non esiste una letteratura internazionale relativa a metodologie di valutazione funzionale dei fontanili. Il primo obiettivo è stato quello di individuare una serie di indicatori per valutare le funzioni idriche, ecologiche e ricreative dei 1160 fontanili della Regione Lombardia. Il secondo obiettivo è stato quello di individuare aree omogenee per caratteristiche simili dei fontanili stessi, utilizzano metodi interpolazione in ambiente GIS. E' stata elaborata una prima proposta per la definizione di una metodologia per la classificazione e misurazione del biotopo fontanile che potrà essere utilizzata dalla Regione Lombardia per l'assegnazione di finanziamenti mirati al recupero e alla conservazione di tale risorsa attraverso misure di protezione ambientale.

Keywords: *Fontanile*, sorgente di pianura, valutazione funzionale

1. Introduction

The *fontanile* (lowland water spring) is a phenomenon deriving from the rising up of phreatic strata, and it depends on the geological structure and the lithological composition of the great North Italian Plain. Historically, these plains were covered with a mosaic of wetlands, streams and ponds, but a drainage system was introduced starting in the 12th century to increase arable land area.

The *fontanili* are springs made and managed by humans. Through the excavation of "spring heads", the water flows out to the surface facilitated by tubes or "throats" stuck into the bottom. The raised water flows into the axis of the *fontanile*, which distributes it into the countryside for irrigation (De Luca et al., 2014) (Figure 1).

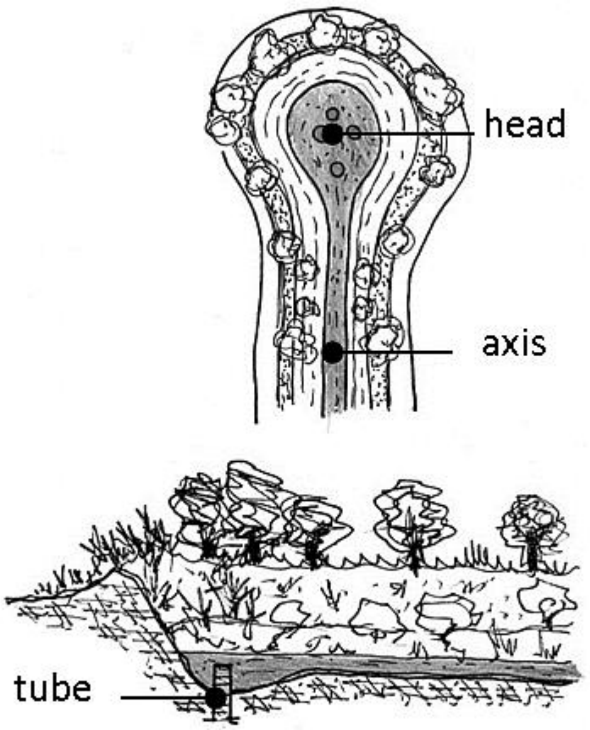

Fig 1. Typical fontanile structure. The diameter can range from 1 or 2 m to 100 m (drawing by authors, 2011).

Associated with the term *fontanile* is often found the term of *risorgiva*. The two terms, however, are not synonyms (Muscio, 2001); *risorgiva* is the natural surfacing of underground water due to the variation of the permeability of the sediments: the waters of the aquifer, which circulate freely inside the coarse-grained sediments (for example gravel), naturally surface when they meet the finer levels and therefore less permeable. While the *risorgiva* is a natural phenomenon, the *fontanile* is a product of human intervention that facilitates the waters flow out by the excavation and construction of a drainage channel.

While the temperature in most aquatic environments in the Po River plain varies from slightly above 0 to 30°C, the mean water temperature in the *fontanili* oscillates between 8 and 15°C. *Fontanili* waters reach their highest temperatures in autumn and their lowest during early spring. Water fluxes in the *fontanili* are quite constant throughout the year, pH is usually neutral, oxygen levels in the *fontanili* head do not reach saturation levels, and the groundwater that supplies the system is usually poor in nutrients (Kløve et al. 2011). Due to these conditions, this environment is host to a vast variety of wetland flora and fauna otherwise absent in the flat. Trees and shrubs, which are usually present on the banks and around the head, help to regulate temperature and provide shelter to wildlife. The *fontanili* are distinctive landscape features: woods and shrubs patches are landmarks in the flat landscape of the region (Figure 2).

The *fontanili* are relatively well studied in regard to their ecological and hydrochemical features (Battegazzore and Morisi 2012; Shestani et al. 2009) and their hydrogeological characteristics (De Luca, 2014), especially in Lombardy Region (Fumagalli et al. 2012; Gavazza et al. 2003; Laini et al. 2011; Laini et al. 2012; Vasileiadis et al. 2013). All of these studies are about the characteristics of a single spring: water, fauna and flora are studied but the relationships between the *fontanili* and their surrounding territory have not been investigated.

Three potential functions of *fontanili* have been identified: irrigation, ecological and recreational. Irrigation is the primary function: the *fontanili* have been excavated to supply water for agricultural uses. In addition to this, they allow for the recovery of irrigation water used in higher elevation agricultural fields that leaches through the soil and goes in the groundwater.

Fig 2. Examples of the head, (a) and (b), and the axis, (c) (photos by authors, 2011).

Fontanili provide an ecological function because they are semi-natural patches inside an agricultural matrix, therefore they offer protection and shelter to wetland wildlife and they can be part of an ecological network (Glazier, 2009). Lastly, the *fontanili* are characteristic features of the rural flat landscape and can represent a recreational element and a point of access to rural world; *fontanili* next to urban settlements are used as green parks (Treu et al., 2000).

Indicators are the appropriate tools for assessing the ecological function of the landscape surrounding *fontanili* (Dramstad et al. 1996; Fry et al., 2009; Gustafson, 1998) and for classifying the recreational function and visual quality of the landscape (Dramstad et al., 2006; Ode, 2010; Uuemaa et al., 2013). However, there are no indicators for the assessment of the irrigation function of these flat springs. The irrigation function is very difficult to measure because the water regime is not strictly related to the conditions around the head of the spring, and there is little local or old data available (Piccinini and Patrizi, 1985; Gandolfi et al, 2006).

These springs are typical and unique landscape features of North Italian Plain, so there is not an international background on assessing methods of *fontanili* functions. For this reason, our objectives were (a) to define a set of existing, simple and consolidated indicators to evaluate the irrigation, ecological and recreational functions of the 1160 *fontanili* of the Lombardy Region and (b) to identify homogenous areas with groups of *fontanili* in close proximity to each other and with similar indicator values using interpolation tools.

Our results should provide valuable criteria (1) for *fontanili* classification (2) for identifying the *fontanili* radius of influence on surrounding landscape and (3) for identifying areas most important for *fontanili* protection through interpolation techniques.

2. Materials and methods

2.1 Study area and database

We studied *fontanili* in the flat area of the Lombardy Region called the "spring strip". This is a strip of 3800 km^2 between sandy soils to the north and fine-grained sediments and impermeable soils to the south. Because of this different permeability, the water of the phreatic stratum rises up. Other causes of this phenomenon are the geomorphology (a depression of the ground promotes the rise of water on the surface) and the presence of rivers and irrigation canals that enrich the aquifer (Muscio, 2001).

In the first step of this study, we have collected all previous censuses made by regional and provincial authorities (starting from 1990) to create a database including 1,650 *fontanili*. After that we have checked them by direct survey: 490 *fontanili* were disappeared and 1,160 *fontanili* were classified. For every point, we collected data about position, status (working, not working, underground, not accessible), accessibility (road, bike path, trail), presence of features of natural or historical interest, land use (wood, meadow, arable land, urban green area, residential area, quarry area, industrial area, abandoned area), presence of water, presence of spring water, shape, vegetation, measurements of spatial dimensions, number of heads, water uses, etc.

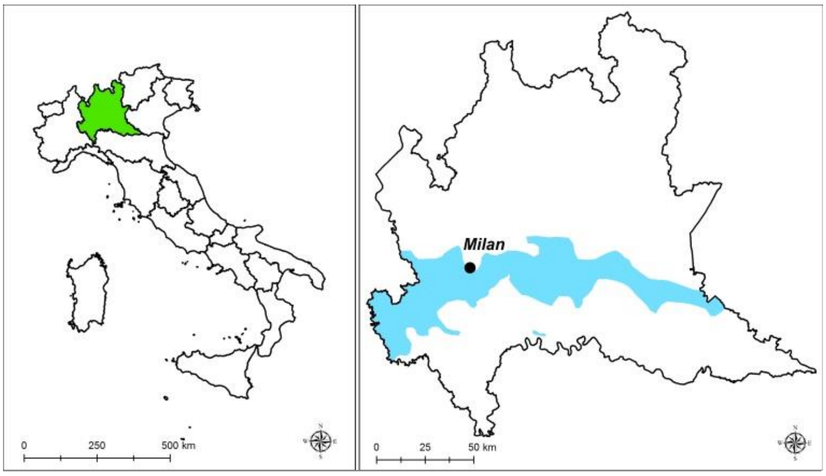

Fig 3. Lombardy Region (in green) and the Study area (in blue) (source: Lombardy Region Geographical Information System, 2012).

We created a GIS database (KML data), including 1,650 records and 45 fields, that is now available at the Regional Administration web *site (*www.cartografia.regione.lombardia.it/).

Other data have been used for the analysis of the surrounding area of the spring; they are available on the Geographical Information System of the Regional Authority in vector format. The description of the data and information is summarized in Table 1. In addition were carried out a series of direct surveys especially to verify land uses and type of vegetation.

Tab 1. Dataset and information used (www.cartografia.regione.lombardia.it/).

Name	Description	Scale	Update
Hydrological network	Natural and artificial (SiBiTer) water system	1:10.000	2012
Road network	Road, rail, tube and other elements of transportation system	1:10.000	2012
Park system	National, regional and local natural park	1:10.000	2012
Land use	34 classes land-use vector map based on photo-interpretation	1:10.000	2011
Regional Landscape Plan	RER Rete Ecologica Regionale (Ecological network, green network)	1:10.000	2010
Natural system	Linear vegetation and natural land use map	1:10.000	2009

We use these data to define indicators and to calculate indices to evaluate the three functions mentioned above. We included non-functional *fontanili* in the studies as well because the potential function is more important than real function and an abandoned and partly underground *fontanile* can be recovered by simple maintenance work.

For every spring and every function, we considered different buffer areas to investigate (50, 100, 300, 500 m radius) to understand the *fontanile* influence on the value of surrounding area.

2.2 Irrigation function

The *fontanili* are springs made by humans for irrigation, and many of them are currently used for this function. The irrigation value of *fontanili* is given by their water flow rate (from 10 l/s to 1000 or more l/s). The flow rates change during the year, and unfortunately, measurements are not available for all of the *fontanili* of the Lombardy Region. Regardless, there appears to be a link between the *fontanili* water flow and the irrigation activities that induce water infiltration from the soil to the groundwater (De Luca et al, 2014).

Gandolfi et al. (2006) identified 50 m as being the maximum distance of influence of the *fontanili*.

We overlaid a canals network layer and a layer representing *fontanili* 50 m buffer areas. From this, the irrigation function is calculated using Irrigation index (I_IRR):

$$I\_IRR_{[0,1]} = L\ network\_buf / L\ network\_max \quad (1)$$

where:

L network_buf is the length of canals inside the 50 m buffer, and

L network_max is the maximum value of L_network_buf.

2.3 Ecological function

Ecology of landscape is founded on the criteria that there is a link between spatial ecological patterns and ecological processes. Several spatial indicators have been developed to study this link, using concepts of disturbance, island biogeography and information theory (Gustafson, 1998, O'Neill et al., 1988, and Turner et al., 2001).

These indices are commonly related to density of patches, size of patch, complexity and diversity. Density indexes measure the density of natural patches in the matrix. Size-related indices measure patch size characteristics. Complexity-related indices measure how complicated patch shapes are. Diversity-related indices measure how diversified patches are. Detailed mathematical descriptions of these indices are available in McGarigal et al. (2012).

In the rural matrix landscape, plant and animal habitats increasingly appear in scattered patches and corridors. The percentage of land area occupied by patches and corridors is the first measure of landscape ecological quality (Dramstad et al, 1996 and Baranyia et al. 2011).

We measured the ecological function of *fontanili*, using:

1) Patches index (I_patches) representing the percentage of patches area inside the buffer:

$$I\_patches_{[0,1]} = A\_patches\_buffer / A\_patches\_max \quad (2)$$

where:

A_patches_buffer is the sum of patches areas (broad-leaved forest, mixed forest, natural grassland, moors and heathland, transitional woodland-scrub, inland marshes and peat bogs) inside the buffer

A_patches_max is the maximum value of A_patches_buffer

2) Corridors index (I_cor) measures the length of corridors inside the buffer:

$$I\_cor_{[0,1]} = L\_cor\_buffer / L\_cor\_max \quad (3)$$

where:

L_cor_buffer is the sum of corridor lenghts (hedges, rows, wooded strips) inside the buffer

L_cor_max is the maximum value L_cor_buffer

3) I_font (0,1). (4)

The presence (1) or absence (0) of vegetation around the *fontanile* head is important because it offers sustenance or animals and because it keeps the water temperature constant. The minimum mapping unit (MMU) of the land use map is 20 m x 20 m, and the MMU of linear elements is 20 m in length.

The area of vegetation around the *fontanile* head is often smaller than MMU, so we included information about presence or absence from the direct survey database.

We measured habitat density inside each buffer area considering patches, edges and *fontanili* vegetation:

$I\_hab_{[0,1]} = [I\_patches *2 + I\_cor + I\_font (0,1)] / 4$ (5)

The factor 2 is used to consider the greater importance of patches for ecological stability (Evans et al. 2012).

Linear infrastructures are the most important barriers in the rural matrix; roads have many general detrimental ecological effects: mortality from road construction, mortality from collision with vehicles, modification of animal behaviour, alteration of the physical environment, alteration of the chemical environment, spread of exotics and increased use of areas by humans (Trombulak and Frissell, 2000).

The measure of disturbance depends on road length and road characteristics (Jaarsma, 1997):

$I\_barriers_{[0,1]} = [\Sigma^{n}_{i=1} (Density\ class_{[0,3]} * weight\ class_{[1,3]})/18$ (6)

where:

1) Density class score depends on the ratio “length roads/buffer radius" as shown in Table 2 (a)

2) Weight class score depends on road characteristics as shown in Table 2 (b)

Tab 2. Length of barriers scores (a) and barrier weight (b).

a) Length of barriers	Score
Length of barriers is > 2*radius of buffer area	3
Length of barriers is <2r and >radius of buffer area	2
Length of barriers is < radius of buffer area	1
Length of barriers is 0	0

b) Barriers characteristics	Weight
Highways, railways, tube	3
Other roads	2
Rural roads	1

Finally the Index of stability of the buffer is:

$I\_stab_{[0,1]} = I\_hab_{[0,1]} * (1- I\_barriers_{[0,1]})$ (7)

The I_stab (7) measures the ecological stability value inside the buffer area at the landscape level. This value can be increased or decreased at the regional level by connectivity with other elements of the ecological network (Li et al, 2005).

The RER (Rete Ecologica Regionale) is the ecological network planned by the Lombardy Region Administration to protect and connect the most important natural areas (national parks, regional parks, rivers, wetlands and so on) of the Lombardy. To assign different levels of importance to RER elements, we overlaid the RER and *fontanili* datasets and applied these values:

I_rer = 1 if the *fontanile* point is inside a RER primary element (gangli)

I_rer = 0.9 if the *fontanile* point is inside a RER other element (minor patches or corridors)

I_rer = 0.8 if the *fontanile* point is outside RER area

This is the index used for the assessment of ecological values of *fontanili* (I_ECO):

$$I\_ECO_{[0,1]} = stab_{[0,1]} * I\_rer_{(1,\ 0.9,\ 0.8)} \quad (8)$$

2.4 Recreational function

The farming land at the fringe of the urban areas had a greater recreational role than constructed parks. Traditional farms and preserved nature areas were preferred to constructed parks for residents living in the urban fringe (Hietala et al, 2013). Traditionally, *fontanili* next to urban centres are used as green areas. The trees provide shade, and the flowing water and sounds of birds create a place with good microclimate conditions, especially during the hot season.

The description of landscape characteristics related to spatial patterns and the prospects for the quantification of spatial patterns has become an important topic in landscape ecology (Turner et al., 2001). Dramstad et al. (1996) stated that the use of landscape indices is necessary with the increasing need for quantitative assessment of impact and change. Different landscape metrics are recognized, although no generally accepted classification is available. Two types are used: the first measures patch characteristics, such as size, shape and edges. A second type addresses the spatial arrangement of adjacent patches and needs an aggregating spatial context to be calculated (Antrop and Van Eetvelde, 2000).

Considering both issues, the recreational index includes an accessibility index and a visual landscape quality index.

Accessibility index (I_Acc). Recreational areas can be reached by foot, bicycle, car or public transportation. However, recommendations regarding distance or proximity to recreational landscapes tend to focus on pedestrians and walking distance. Walking distance to recreational areas for everyday use is recommended to have a maximum of 250–300 m. 250–300 m is a critical distance for children and elderly to reach recreational areas by foot within an adequate amount of time (Neuvonen et al, 2007). On the basis of these recommendations, thresholds of 100 m, 300 m and 500 m were chosen as critical distances for recreational use in our analysis. Using population survey data (census data) combined with spatial data (land use map), we calculated how many people live within the buffer area (Koppen et al. 2014).

The presence of roads (I_road) is necessary for people access to *fontanili*. We included information about presence (value 1) or absence (value 0) of rural roads, trails or bike paths to access from the direct survey database.

$$I\_acc_{[0,1]} = (I\_road(0,1) + I\_pot\_users_{[0,1]}) / 2 \quad (9)$$

where:

I_road (0,1), value is 1 with access, value is 0 without access

$$I\_pot\_users = N\_people\_buffer / N\_people\_max \quad (10)$$

where:

N_people_buffer is the number of people living inside the buffer

N_people_max is the maximum value of N_people_buffer'

Landscape quality index (I_qual). Because of the intensity of land usage, the areas of intensive agricultural production and other modern land uses are void and empty with regard to natural structures and/or filled up with large-scale building structures. These areas are among the aesthetically most unattractive landscapes. Sustainable landscapes contain areas and places where nature can develop freely and spontaneously. That means that areas close to spontaneous nature let the beholder participate in perceptual processes, which may lead to a particular aesthetic attractiveness (Nohl, 2001).

We evaluated these aspects using Index of composition of landscape (I_comp):

$$I\_comp_{[0,1]} = [\Sigma^{n}_{i=1} (a_n/A\_buf)* w_v + \Sigma^{n}_{i=1} (1- a_n/A\_buf)* w_d)/2 \quad (11)$$

where:

A_n is the area of land use class in the buffer

A_buf is area of the buffer

w_v is the weight of class increasing visual quality of the landscape

w_d is the weight of class decreasing quality of the landscape

In accordance with Nohl (2001), we extracted the following from the land use vector map:

1) natural land use classes characterizing *fontanili* landscapes (increase the visual quality):

- fairly characterizing: water-meadow, bank vegetation
- characterizing: broad-leaved forests
- highly characterizing: riparian vegetation, inland marshes vegetation, peat bogs.

Different weights were assigned using a pairwise comparison method (on the basis of the Saaty scale) (Saaty, 1980) (Table 3 a).

2) artificial surface land use classes (decrease the visual quality):

- continuous artificial surfaces: industrial, commercial and transport units, mines, dumps and construction site
- discontinuous dense artificial surfaces: dense and medium dense urban fabric, unvegetated land without current use, sports and leisure facilities
- low density artificial surfaces: low density urban fabric, rural isolated structures, camping areas.

Different weights were assigned using a pairwise comparison method (on the basis of the Saaty scale) (Saaty, 1980) (Table 3 b).

Tab 3. Weights of natural land use classes (a) and weight of artificial use classes (b).

a) natural land use classes	Fairly characterizing	Characterizing	Characterizing very high	**Saaty scale value**
Fairly characterizing	1	0.5	0,20	**0.12**
Characterizing	2	1	0,33	**0.23**
Characterizing very high	5	3	1	**0.65**

b) artificial use classes	Not dense artificial surface	Discontinuous dense artificial surfaces	Continuous artificial surfaces	**Saaty scale value**
Not dense artificial surface	1	0.5	0.13	**0.10**
Discontinuous dense artificial surfaces	2	1	0.33	**0.21**
Continuous artificial surfaces	8	3	1	**0.69**

Land cover structure and composition play significant roles in the visual quality of the landscape. Two main categories of indices have been suggested: composition indices which quantify the variety and abundance of patch types within a landscape, but not their spatial arrangement, and configuration indices, which quantify the spatial distribution and the shape of patches within the landscape (McGarigal et al, 2012).

Of all spatial metrics of the landscape, legibility and heterogeneity are perhaps the easiest to relate to human perception of the environment. Greater coherence is generally thought to be positively related to scenic value (Kaplan and Kaplan, 1982 and Palmer, 2004). The fractal dimension should provide an indication of visible landscape complexity, which is thought to contribute to scenic value (Purcell et al., 2001).

To perceive high visual quality in a small view, a certain overall order has to be discovered (Staats et al., 1997) and a limited number of elements must be present in the landscape, allowing the observer to understand the scene (Todorova et al., 2004).

In accordance with these papers:

$I\_conf_{[0,1]} = (I\_patches_{[0,1]} + I\_shape_{[0,1]}) / 2$ (12)

where

1) $I\_patches_{[0,1]} = 1\_ (N\_patches\_buffer/N\_patches\_max)$

with:

N_patches_buffer is the number of patches inside the buffer

N_patches_max is the maximum value of N_patches_buffer

2) $I\_shape = (\Sigma^{n}_{i=1} SI_{n})/SI\ max$ (13)

with

SI is the Shape Index of the buffer area

SI max is the maximum value of SI

and

$SI = p_i/2 \sqrt{\pi * a_i}$ (14)

with

p_i is the patch perimeter

a_i is the patch area

SI values close to 0 indicate that the landscape is aggregating to form simple shape, values closer to 1 indicate that the landscape is fragmented and has convoluted shapes.

The landscape quality index is:

$I\_qual_{[0,1]} = (I\_comp_{[0,1]} + I\_conf_{[0,1]}) / 2$ (15)

Finally the Index of recreational function (I_RECR) is:

$I\_RECR_{[0,1]} = (I\_acc_{[0,1]} + I\_qual_{[0,1]}) / 2$ (16)

3. Results

We used above-mentioned indexes to classify 1,160 *fontanili* of the Lombardy Region and investigate the relationship between the *fontanili* and the territory in which they are included (Table 4).

Tab 4. Buffer areas investigated for different function (x) and buffer area used to classify fontanili (grey cells).

	Buffer area			
Function	50 m radius	100 m radius	300 m radius	500 m radius
Irrigation	x	x	x	x
Ecological	-	x	x	x
Recreational	-	x	x	x

For the irrigation function, we measured $I\_IRR_{[0,1]}$ (1) inside a 50 m radius buffer to find links with canal systems (Figure 4).

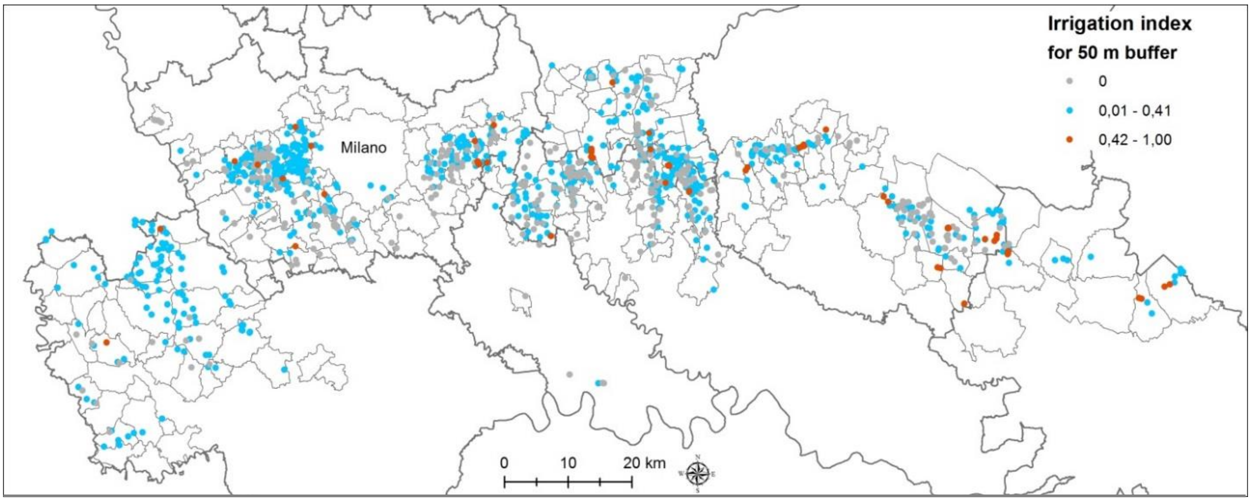

Fig 4. Irrigation index values of fontanili.

The I_IRR measures the length of canals inside *fontanile*'s 50 m buffer. Unfortunately irrigation channels network database is not complete and uniform for the study area so 30% of *fontanili* result not connected with irrigation network. This can means the water from *fontanili* is no more used for irrigation or, most probably, that the network database is uncorrected. Excluding this percentage the medium value is 0.20 with a standard deviation of 0.15. A great number of unconnected *fontanili* are concentrated in the central part of study area.

For the ecological and recreational functions, we measured $I\_ECO_{[0,1]}$ (8) and $I\_RECR_{[0,1]}$ (16) inside 100 m, 300 m and 500 m radius buffers. Then, we applied ANOVA analysis and Dunnett's C Post Hoc test to confirm different index values for increasing buffer radius:

- ecological function: the values decrease significantly between 100 m and 300 m buffer radius (Mean difference of Dunnett's PHT = -0.7665)
- recreational function: the values maintain similar magnitudes between 100 m and 300 m (Mean difference of Dunnett's PHT = -0.0489) and decrease significantly between 300 m and 500 m buffer radius (Mean difference of Dunnett's PHT = -0.2694)

The maps of Figures 5 and 6 show the distribution of *fontanili* with ecological and recreational values inside 100 m buffer for the ecological one and 300 m buffer for the recreational one.

Only the 2% of *fontanili* doesn't have ecological value (I_ECO = 0). The medium value is 0.30 with a standard deviation of 0.15. The Province of Milan has the greater concentration of highest values.

The I_RECR has values higher than other indices. The media is 0.48 and there aren't *fontanili* without recreational value. The proximity to the main urban centres determines the value increasing.

The graphs of Figure 7 show the values measured for these different indexes whit the trend described above.

To identify homogenous areas with groups of *fontanili* in close proximity and with similar indicator values, we used interpolation tools. For all three functions, interpolation was made using the ArcMap GIS kriging tool, setting a maximum distance of 1000 meters.

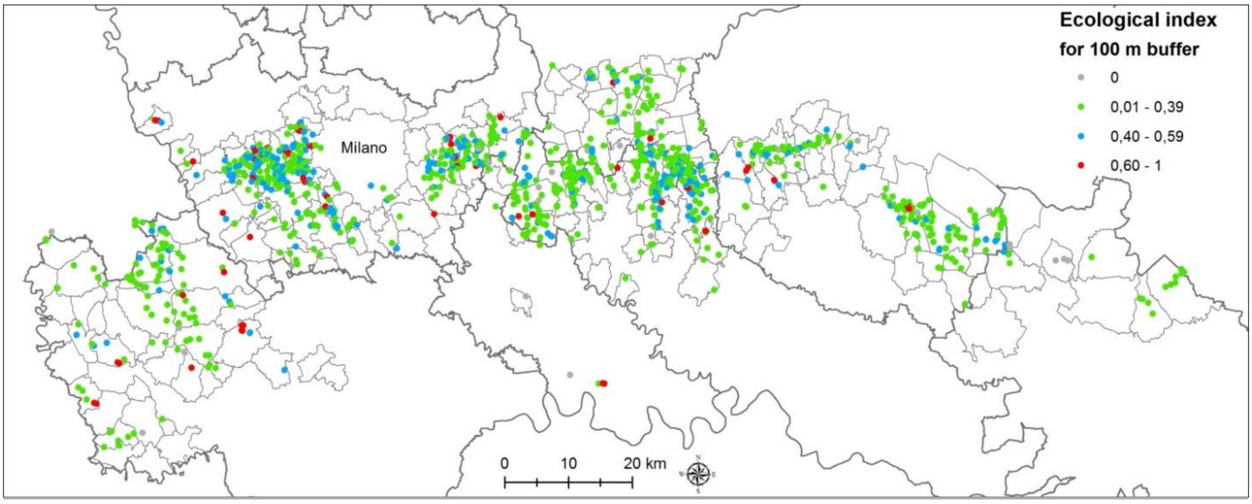

Fig 5. Ecological index values of fontanili.

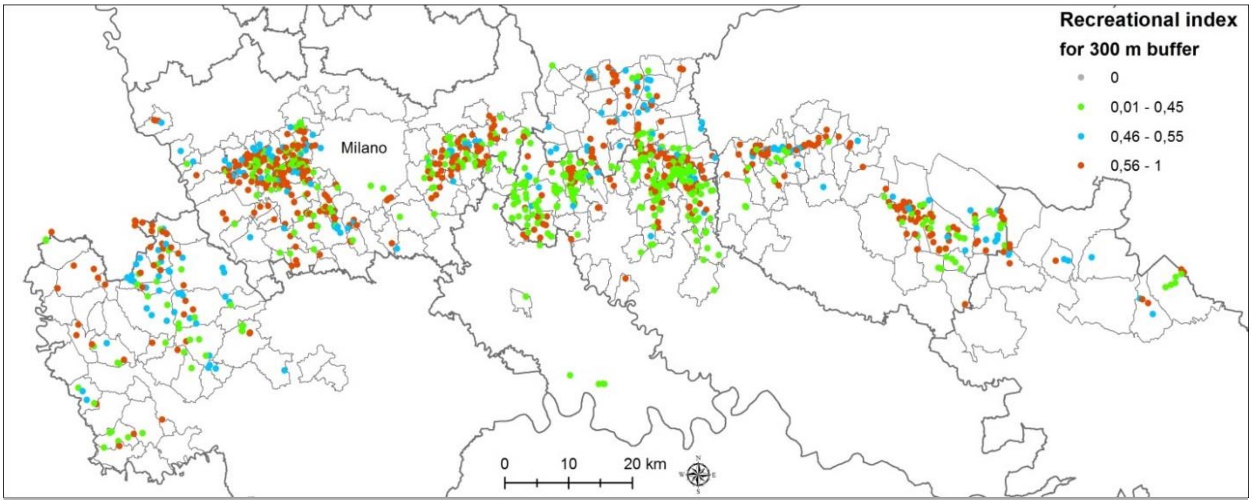

Fig 6. Recreational index values of fontanili.

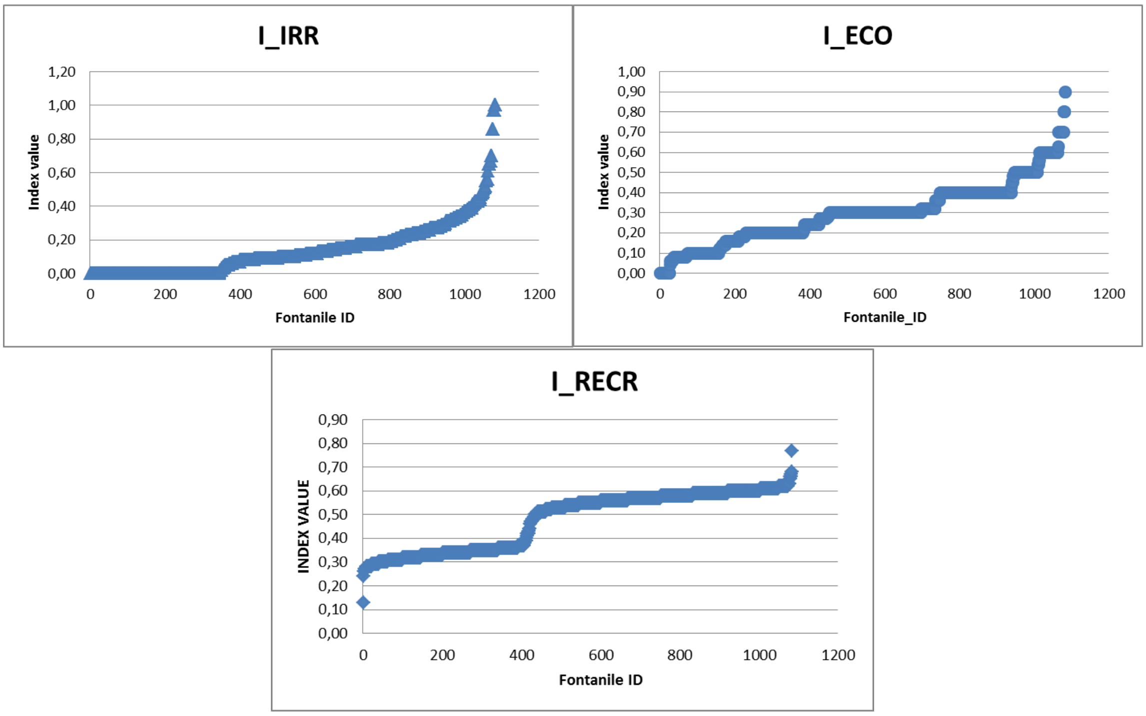

Fig 7. Values of calculated indexes.

4. Discussion

For the first time, we have classified all *fontanili* of the Lombardy Region territory, using:

- direct survey to collect data on every *fontanile*
- an existing geo database to evaluate the areas around the springs.

We have ranked irrigation, ecological and recreational values. Because of the method of creating indexes, they are not absolute values but relative ones. Unfortunately, there is no other published research about *fontanili* function assessment, so it is not possible to compare our results and our indices with different approaches.

Any way:

-I_IRR seems to be not able to describe the irrigation value of *fontanili*. It is necessary to complete the assessment using a more complete channels network geo-database. The Regional authority is implementing this database;

- I_ECO seems to be able to measure the ecological value of *fontanili*. *Fontanili* with very different values are spread in the entire study area. The media value of 0.30 is not very representative of great variability of index value;

-I_RECR seems to be able to measure the recreational value of *fontanili.* The great part of *fontanili* present values around the media value (with a standard deviation of 0.09).

5. Conclusions

Ecological and recreational indices are based on consolidated parameters used in other studies:

- connectivity level and patches, corridor and barrier density for spatial ecological pattern evaluation
- accessibility level for recreational use, land cover structure and composition for visual quality evaluation.

The parameters used to calculate the irrigation index, however, are instead overly simple. The lack of flow rate measurements is the main problem for building an index with greater significance. The weakness of this index is the most important limitation of the study. This is the reason because we have decided to not calculate a synthetic index including the three functions.

The assessment of *fontanili*' functions has permitted to determine the independence of every *fontanile* from his surroundings. The value of every single index seems not to be influenced by the presence of other *fontanili. Fontanili* with low, medium, high quality can be closed to each other.

The next step is to compare the results of this assessment with the regional and local planning instruments.

This classification can be used by the Regional Administration to assign resources for the recovery and maintenance of *fontanili*. The most important areas, identified using the kriging tool of ArcMap GIS, are going to be protected by regional and local planning instruments.

Acknowledgements

This research is part of the research n. 1276 “Sistema per la tutela e la valorizzazione dei *fontanili* del territorio Lombardo – System for the protection and enhancement of the low land spring of the Lombardy territory” (FonTe) founded by the Regional Research programme for Rural areas 2007–2009 of Lombardy Region. All digital map data layers are available on Regional Administration web *site (*www.cartografia.regione.lombardia.it/).

[1] Antrop, M. & Van Eetvelde, V. (2000). Holistic aspects of suburban landscapes: visual image interpretation and landscape metrics. *Landscape and Urban Planning*, 50(1–3), 43–58. DOI: 10.1016/S0169-2046(00)00079-7.

[2] Baranyia, G., Saurab, S., Podanic, J. & Jordánd, F. (2011). Contribution of habitat patches to network connectivity: Redundancy and uniqueness of topological indices. *Ecological Indicators*, 11(5), 1301–1310. DOI: 10.1016/j.ecolind.2011.02.003.

[3] Battegazzore, M. & Morisi, A. (2012). Environmental evaluation of springs in the intensely cultivated and industrialized inland plain of Cuneo (Northwest Italy). *Journal of Environmental Science and Engineering* 1B(1),19–24.

[4] De Luca, D. A., Destefanis, E., Forno, M. G., Lasagna, M. & Masciocco, L. (2014). The genesis and the hydrogeological features of the Turin Po Plain *fontanili*, typical lowland springs in Northern Italy. *Bulletin of Engineering Geology and the Environment* 73(2), 409–427. Doi 10.1007/s10064-013-0527-y.

[5] Dramstad, W. E., Olson, J. D. & Forman R. T. T. (1996). *Landscape Ecology Principles in Landscape Architecture and Land Use Planning*. Washington, DC: Island Press.

[6] Dramstad, W. E., Tveit, M. S., Fjellstad, W. J. & Fry, G. L. A. (2006). Document Relationships between visual landscape preferences and map-based indicators of landscape structure. *Landscape and Urban Planning*, 78(4), 465–474. DOI: 10.1016/j.landurbplan.2005.12.006.

[7] Evans, D. M., Turley, N. E., Levey, D. J. & Tewksbury, J. J. (2012). Habitat patch shape, not corridors, determines herbivory and fruit production of an annual plant. *Ecology*, 93(5), 1016–1025. DOI: 10.1890/11-0642.1.

[8] Fry, G. L. A., Tveit, M. S., Ode, Å. & Velarde, M. D. (2009). The ecology of visual landscapes: Exploring the conceptual common ground of visual and ecological landscape indicators. *Ecological Indicators*, 9(5), 933–947. DOI: 10.1016/j.ecolind.2008.11.008.

[9] Fumagalli, N., Bischetti, G. B., Piantanida, E. V., Senes, G., Negri, G., Pellitteri, T., Gomarasca, S. & Marziali, L. (2012). *Tutela e valorizzazione dei fontanili del territorio lombardo–FonTe. Quaderni della Ricerca n. 144*. Milano: Regione Lombardia.

[10] Gandolfi, C., Rienzner, M. & Ortuani, B. (2006). Documento d5: rapporto sul modello falda-*fontanili*, Progetto TwoLe – Sottoprogetto TwoLe-B – Modello Falda-*Fontanili* [unpublished research report]. Milano: Università degli Studi di Milano.

[11] Gavazza, E., Bolis, C., Donelli, E., Ravizza, L. & Camatini, M. (2003). Procedure standard al sensi del D.Lgs. 152/99 per la valutazione dello stato di qualita` dei *fontanili* della Provincia di Milano. *Inquinamento* 45(46), 52–56.

[12] Glazier, D. S. (2009). Springs (pp. 734–755). In Likens, G. E., ed., *Encyclopedia of Inland Waters.* Amsterdam: Elsevier.

[13] Gustafson, E. J. (1998). Quantifying landscape spatial pattern: What is the state of the art? *Ecosystems*, 1(2), 143–156.

[14] Hietala, R., Silvennoinen, H., Tóth, B. & Tyrväinen, L. (2013). Nearby Nature and Experiential Farming: How are their Roles Perceived within the Rural-Urban Fringe? *Landscape Research*, 38(5), 576–592. DOI: 10.1080/01426397.2012.674497.

[15] Jaarsma, C. F. (1997). Approaches for the planning of rural road networks according to sustainable land use planning, *Landscape and Urban Planning*, 39(1), 47–54. DOI: 10.1016/S0169-2046(97)00067-4.

[16] Kaplan, S. & Kaplan, R. (1982). *Cognition and Environment: Functioning in An Uncertain World*. Westport, CT: Praeger.

[17] Kløve, B., Ala-aho, P., Bertrand, G., Boukalova, Z., Ertürk, A., Goldscheider, N., Ilmonen, J., Karakaya, N., Kupfersberger, H., Kvœrner, J., Lundberg, A., Mileusnić, M., Moszczynska,

A., Muotka, T., Preda, E., Rossi, P., Siergieiev, D., Šimek, J., Wachniew, P., Angheluta, V., & Widerlund, A. (2011). Groundwater dependent ecosystems. Part I: Hydroecological status and trends. *Environmental Science and Policy*, 14(7), 770–781. DOI: 10.1016/j.envsci.2011.04.002.

[18] Koppen, G., Sang, O. Å. & Tveit, M. S. (2014). Managing the potential for outdoor recreation: Adequate mapping and measuring of accessibility to urban recreational landscapes. *Urban Forestry & Urban Greening*, 13(1), 71–83. DOI: 10.1016/j.ufug.2013.11.005.

[19] Laini, A., Bartoli, M., Castaldi, S., Viaroli, P., Capri, E. & Trevisan, M. (2011). Greenhouse gases (CO2, CH4 and N2O) in lowland springs within an agricultural impacted watershed (Po River Plain, northern Italy). *Chemistry and Ecology* 27(2), 177–187. DOI: 10.1080/02757540.2010.547489.

[20] Laini, A., Bartoli, M., Lamastra, L., Capria, E., Balderacchia, M. & Trevisana, M. (2012). Herbicide contamination and dispersion pattern in lowland springs. *Science of Total Environment* 438, 312–318. DOI: 10.1016/j.scitotenv.2012.08.080.

[21] Li, F., Wang, R., Paulussen, J. & Liu, X. (2005). Comprehensive concept planning of urban greening based on ecological principles: A case study in Beijing, China. *Landscape and Urban Planning,* 72(4), 325–336. DOI: 10.1016/j.landurbplan.2004.04.002.

[22] McGarigal, K., Cushman, S. & Ene, E. (2012). FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps [computer software program]. Amherst: University of Massachusetts. Available at: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

[23] Muscio, G. (2001). Aspetti geologici e morfologici (pp. 13–28). In Minelli, A., Ruffo, S., Stoch, F., eds, *Risorgive e fontanili. Acque sorgenti di pianura dell'Italia settentrionale*. Roma: Ministero dell'Ambiente e della Tutela del Territorio – Udine: Museo Friulano di Storia Natura.

[24] Neuvonen, M., Sievänen, T., Tönnes, S. & Koskela, T. (2007). Access to green areas and the frequency of visits – A case study in Helsinki. *Urban Forestry and Urban Greening*, 6(4), 235–247. DOI: 10.1016/j.ufug.2007.05.003.

[25] Nohl, W. (2001). Sustainable landscape use and aesthetic perception–preliminary reflections on future landscape aesthetics. *Landscape and Urban Planning*, 54(1–4), 223–237. DOI: 10.1016/S0169-2046(01)00138-4.

[26] O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L., et al. (1988). Indices of landscape pattern. *Landscape Ecology*, 1(3), 153–162. DOI: 10.1007/BF00162741.

[27] Ode, A., Hagerhall, C. M. & Sang, N. (2010). Analysing visual landscape complexity: Theory and application. *Landscape Research*, 35(1), 111–131. DOI: 10.1080/01426390903414935.

[28] Palmer, J. F. (2004). Predicting scenic perceptions in a changing landscape: Dennis, Massachusetts. *Landscape and Urban Planning*, 69(2–3), 201–218. DOI: 10.1016/j.landurbplan.2003.08.010.

[29] Piccinini, A. & Patrizi, G. (1985). *Rilievo della portata liquida in un campione di fontanili della pianura lombarda tra Adda e Chiese*. Milano: Regione Lombardia – URBIM Lombardia.

[30] Purcell, T., Peron, E. & Berto, R. (2001). Why do preferences differ between scene types? *Environment and Behavior* 33(1), 93–106. DOI: 10.1177/00139160121972882.

[31] Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

[32] Shestani, L., Morisi, A. & Fenoglio, S. (2009). Analisi qualitativa della fauna macrobentonica di *fontanili* e risorgive della pianura cuneese. *Pianura. Scienze e storia dell'ambiente padano*, 24, 25–45.

[33] Staats, H., Gatersleben, B. & Hartig, T. (1997). Change in mood as a function of environmental design: Arousal and pleasure on a simulated forest hike. *Journal of Environmental Psychology*, 17(4), 283–300. DOI: 10.1016/j.landurbplan.2005.05.003.

[34] Todorova, A., Asakawa, S. & Aikoh, T. (2004). Preferences for and attitudes towards street flowers and trees in Sapporo, Japan. *Landscape and Urban Planning*, 69(4), 403–416. DOI: 10.1016/j.landurbplan.2003.11.001.

[35] Treu, M. C., Magoni, M., Steiner, F. & Palazzo, D. (2000). Sustainable landscape planning for Cremona, Italy. *Landscape and Urban Planning*, 47(1–2), 79–98. DOI: 10.1016/S0169-2046(99)00065-1.

[36] Trombulak, S. C. & Frissell, C. A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1), 18–30. DOI: 10.1046/j.1523-1739.2000.99084.x.

[37] Turner, M. G., Gardner, R. H. & O'Neill, R. V. (2001). *Landscape ecology in theory and practice*. New York: Springer.

[38] Uuemaa, E., Mander, U. & Marja, R. (2013). Trends in the use of landscape spatial metrics as landscape indicators: A review. *Ecological Indicators*, 28, 100–106. DOI: 10.1016/j.ecolind.2012.07.018.

[39] Vasileiadis, S., Puglisi, E., Arena, M., Capp, F., Van Veen, J. A,, Cocconcelli, P. S. & Trevisan, M. (2013). Soil microbial diversity patterns of a lowland spring environment. *FEMS Microbiology Ecology*. 86(2), 172–184. Doi:10.1111/1574-6941.12150.