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Original article

Holistic model-based monitoring of the human health status in an urban environment system: pilot study in Verona city, Italy

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Key words

Environmental health • Public health • Urban environment system • Landscape ecology

Summary

Introduction. *In recent decades the global health paradigm gained an increasing systemic characterization. The ecosystem health theory states that a healthy ecosystem, whether natural or artificial, significantly contributes to the good health status of the human population.*

Methods. *The present study describes an interdisciplinary monitoring model that retrospectively analyzes the intersection between the urban environment and citizens. The model analyzes both the biophysical and the anthropic subsystems through the application of landscape ecology and environmental quality indexes along with human health indicators. Particularly, ecological quality of landscape pattern, atmospheric pollution, outdoor noise levels and local health indicators were assessed. Verona municipality was chosen as study area to test the preliminary efficiency of the model. Territory was split into two superimposed layers of land units, which were further geo-referentiated with Geographical Information System (GIS) technology. Interdependence of any of the analyzed traits was further investigated with Fisher exact test.*

Results. *Landscape composition was assessed and an Average Ecological Quality (AEQ) score assigned to each land unit. A direct proportionality emerged for concentrations of considered air pollutants and traffic levels: a spatial model for the atmospheric pollution was drawn. A map depicting the distribution of traffic-related noise levels was also drawn. From chosen indicators, a quality class score was assigned to every minor and major land unit. Age-standardised rates about hospitalizations for the municipal population and specific rates for the over-65s/1000 inhabitants were calculated. Quality class assignement for each health indicator was graphically rendered. After direct standardisation of rates for the population sample, data were compared with two reference populations, the Regional population and the Local Socio-sanitary Unit (ULSS20) population. Standardised hospitalization rates for the whole municipal population always resulted lower than the ULSS20 rates, except for auditory pathologies. It was notable that rates of hospitalizations for cancerous diseases for Verona municipal population were four times and two times lower than the ULSS20 and the Regional population ones, respectively. Contingency table were made for the health main indicator (specific rates for the over-65s/1000 inhabitants) and the environmental quality key factors of landscape ecological quality, outdoor noise level and air pollution. H_0 of independence was rejected for respiratory pathologies and air pollution and for the triad cardiocirculatory pathologies, air pollution and landscape ecological quality at ($\alpha = 0.05$). Fisher exact test confirmed the non-independence of cardiocirculatory diseases and biophysical environment and the analogous association for respiratory pathologies when comparison was made with global environmental quality index.*

Discussion. *The first testing of the model suggests some possible elements of implementation and integration which could further enhance it. Among them, the subjective investigation of the health status assumes a primary role. On the whole the monitoring model seems to effectively represent the real complexity of the urban environment systems and should be regarded as an important contribution to the new way of health research.*

Introduction

The human health paradigm kept evolving over the last decades. Health is characterized by a holistic trait since social, environmental and ecological factors critically contribute altogether to determine the health status of a population [1]. Human health in fact hinges not only on single environmental risk factors, but on ecosystem global integrity and ecological functionality [2, 3]. An interdisciplinary approach is therefore needed in order to undertake suitable and sustainable strategies to prevent the deterioration of the Urban Environment System (UES). Anthropic processes preeminently emerge in urbanized *loci*: in high-densely populated areas an unsustainable model of exploitation of natural resources and of ecological niches, quickly leads to the UES decay. A regardless exploitation can subsequently pose a serious threat to the health status and life quality of the human population itself [4]. One of the first conceptual models that place humans inside the ecosystem rather than seal them off in a mere artificial habitat, is the Butterfly Model of Health [5]. According to the model, the health of an individual or population is enveloped by biological and behavioral filters and is affected by both biophysical and socioeconomic environment, which in turn are reciprocally influenced through the actions of individuals. Though global health is undoubtedly present when the two environments are balanced [6], a UES is also characterized by a complex hierarchical organization. Each level of organization constitutes a self-standing subsystem, in which its own components interact with one another, leading to new emerging properties that dynamically outline the whole system [7, 8]. On the whole, a Biophysical Subsystem (BioS) and a Socioeconomic Subsystem (SocS) emerge. The BioS coincides with the natural environment, its available resources and its biotic factors: it represents the structural and functional basis of the whole ecosystem. The SocS on the other hand arises from the sociocultural, technological and economic evolution of the human population alone. BioS and SocS show relations of mutual conditioning, since there is an interactive insertion of human beings in the biophysical environment. The UES then remains vital and resilient when BioS and SocS are at equilibrium: an unhealthy dominance of the SocS over the BioS exploits and damages the system to the point that it soon becomes unable to endure the global dynamics and evolutionary rhythms. As the UES metabolism is characterized by flows of materials, energy, population and monetary [9], interdisciplinary studies should be priviledgely sought to assess the overall UES health status. Still, the issues associated with integrating socio-ecological systems are complex and constitute a major obstacle to this kind of holistic approaches [10]. The present paper describes a model that retrospectively analyzes the interdependency of the urban environment and the health status of the human population.

Holistic model-based monitoring of the UES

The proposed monitoring model operates at different levels of analysis, thus reflecting the hierarchical organization of the UES. Briefly, the model follows three distinct phases.

- The first one splits the UES in a composite mosaic: a topographic survey of the whole urban area is performed and the territory is divided into smaller and contiguous land units, so that a higher analysis resolution is feasible. Land units are defined by following a criterion of structural homogeneity.
- The second phase contextualizes the UES and involves the characterization of the BioS and the SocS subsystems: prevailing factors and dynamics of both subsystems are identified. BioS characterization proceeds by gathering information about the climate, geomorphology, faunistic and floristic components, ecological pattern, atmospheric and water quality, outdoor noise level and electromagnetic fields intensity. Appropriate indicators reflect indeed the UES health status, by reducing the overall complexity of the system and connecting the theoretical eco-background to the anthropic factors [11].
- SocS is mostly investigated through classic demography parameters and socioeconomic indicators. Human health is specifically evaluated by collecting data about hospitalizations, deaths and consumption of prescription drugs, grouped by category.
- The third phase consists in a data-mining process: data extrapolated during the first and second step are processed to disclose any relationships linked with the health status of the whole UES. For each land unit specific quality indexes are calculated and geo-referentiated with Geographical Information System (GIS) technology: in the end they will score in a global quality scale. Statistical analysis then evaluates whether a real association between spatial distribution of data and health status of the population exists.

Case study

Verona is a medium-sized town and one of the seven province capitals of the Veneto Region, in North-eastern Italy. The municipal territory covers an area of 206.64 Km^2. With a resident population of 264 678 inhabitants [12], Verona is the second municipality of the region, the third one in North-eastern Italy and the twelfth in Italy. Birth rate is of 9.9‰, in line with regional and national trend. Average age of population is 42 years and life expectancy 71,6 years. Verona shows the typical features of an European urban area, that is high population density and a sheaf-shaped age/sex pyramid, determined by low birth-rate, low mortality, high proportion of adult population and an increasing immigration rate. Verona municipality belongs to the wider territory of the Local Socio-sanitary Unit (ULSS20), which encompasses four distinct Sanitary Districts and thirty-six municipalities of the Veneto Region altogether.

The whole Verona territory is protected by the Decree Law 490/99 landscape-environmental regulation. Landscape is divided in a northern hill area, which coincides with the southernmost slopes of the Lessinian Prealps and reaches a maximum altitude of 700 m, and in a southern plain area in which the Adige river flows from north-west to south-east. The hill area is mainly covered with mesophilic and thermophilic hardwoods, with prevalence of European hophornbeam (*Ostrya carpinifolia*), manna ash (*Fraxinus ornus*), common hazel (*Corylus avellana*) downy oak (*Quercus pubescens*) and Judas tree *(Cercis siliquastrum).* Some recent implants of conifers, European black pine (*Pinus nigra*) and Scots pine (*Pinus sylvestris*) are present. Agricultural areas are characterized by olive and chestnut groves, vineyards and cherry orchards. In the plain area both historical and modern buildings alternate with wide farming areas, in which oat, corn, wheat and apple and peach orchards are grown.

Verona climate is classified as a humid subtropical climate by the Köppen climate classification, with hot and dry summer seasons and cold and wet winters. Nevertheless the hill area has a lower relative humidity degree through the year, compared with the plain area in which fog forms frequently, especially during the winter. Annual mean precipitation is of ~800 mm, flatly distributed through the year and with an increasing South to North rainfall gradient. Alpine chain in the North and the Appennines mountain in the South act as natural barriers and brake air flows, often generating a lack of wind. When present, wind blows from either a ESE - SE or W - WNW direction. Such meteoclimatic conditions during the winter season restrain low atmospheric circulation with subsequent accumulation of air pollutants, making Verona one of the city with higher air contamination of the whole Po Valley [13].

Verona also covers a socioeconomic strategic position: it is a crucial highway and rail junction, connecting routes from Mid-Southern and North-western Italy to Europe, through the Brennero Pass. Verona ranks twelfth among Italian cities with a municipal GDP of € 6.7 million and a pro-capite GDP value of € 26.4 million, against an average national pro capite GDP of € 20.4 million [14]. In 2000 due to its favorable geomorphic and naturalistic traits, along with peculiar urban architecture, Verona became an UNESCO world heritage site.

Methods

Cartography

Cartography of the study area was finely reconstructed and digitized at a resolution of 1 pixel: 25 m^2. An accurate re-mapping job was done to update and juxtapose distinct original documents, which include the Regional Technical Map in a 1:10000 scale, orthophotos taken by the local Territorial Informative System and a vegetation map drawn by the Natural Science Museum of Verona.

Identification of land units

Verona UES was split into two superimposed levels of land units (Fig. 1). The first level encompasses eight major land units which coincide with the administrative districts: Old town center (D1), North-west (D2), West (D3), South-west (D4), South (D5), East (D6), South-east (D7) and North-east (D8). The second level is made up by twenty-three minor land units that coincide with the town quarters, into which districts are further subdivided: Old town (Q1), Cittadella (Q2), San Zeno (Q3), Veronetta (Q4), Borgo Trento (Q5), Valdonega (Q6), Ponte Crencano (Q7), Avesa (Q8), Parona (Q9), Quinzano (Q10), Borgo Milano (Q11), San Massimo (Q12), Santa Lucia (Q13), Golosine (Q14), Borgo Roma (Q15), Ca' di David (Q16), Borgo Venezia (Q17), Porto S.Pancrazio (Q18), San Michele (Q19), Quinto (Q20), S.ta Maria in Stelle (Q21), Mizzole (Q22) and Montorio (Q23).

Fig. 1. Verona UES was split into two superimposed levels of land units. The 8 major land units (D1 to D8) coincide with Verona administrative districts, while the 23 minor land units (Q1 to Q23) coincide with the town quarters, into which districts are futher subdivided.

Ecological quality of the landscape pattern

The ecological quality of Verona landscape was determined by applying five landscape ecology indexes: Relative Patch Richness (RPR), Interspertion Juxtaposition Index (IJI), Plain proportional extent of green and seminatural areas (PLAND), Mean Proximity Index (PROX) and Percentage of Like Adjacencies (PLADJ) [15]. The above described landscape ecology indexes were processed with Fragstats software. Indexes were further merged into a single Average Ecological Quality (AEQ) index. In the end a map reconstructing Verona's main landscape pattern was drawn at a 1:5000 scale.

Urban atmospheric pollution

Mean concentrations of Total Particulate Matter (TPM), carbon monoxide (CO) and nitrogen dioxide (NO_2) were recorded from six different sampling stations that belong to ARPAV, the regional agency for environmental protection. Traffic flows of motor vehicles were evaluated with a continuous spatial distribution of pollution levels and the air quality index MV_{eq} [16] was adopted to represent the average number of motor vehicles-equivalent in the rush hour. Traffic flows between 7.30 and 8.30 a.m. were monitored and further expressed in motor vehicles-equivalent. Cars and motorbikes were regarded as *light vehicles* while vans, trucks and such as *heavy vehicles.* Correspondence is of 1 heavy vehicles = 2 light vehicles. Discrete data were converted in a continuous spatial distribution with G.I.S Idrisi®. A grid with 1 km^2 squares was drawn and traffic flows measured in every street were superimposed on each square. Discrete data were then given a continuous distribution with the interpolation of the Gaussian Idrisi® filter. In the end the continuous distribution was superimposed on the corresponding territorial units and an average value of the traffic flows was obtained.

Outdoor noise levels

Outdoor noise levels in Verona urban area were homogeneously sampled over the whole municipality road grid following the infrastructural typologies, as stated in the Urban Traffic Plan. Samplings were evaluated with the statistical method proposed by Adami et al. [17] based on the probabilistic association of each road typology to an equivalent acoustic level (AL_{eq}). The number of roads with an AL_{eq} > 60 dB over the total of the roads in a single land unit was chosen as index to assess the outdoor noise levels. The threshold value of 60 dB was set as critical value since, if constantly exceeded, can lead to psycho-physiologic extra-auditory effects on the digestive, cardiocirculatory and endocrine systems [18].

Human health status

Human health status was assessed through the analysis of reports and registry of the ULSS20 for the sanitary district of Verona, recorder over the full year 2008. Population sample consist in the resident population of Verona UES. Two reference populations were considered: the whole ULSS20 population (470,877 inhabitants) [19] and the Veneto Region one (4,912,438 inhabitants) [20]. Data about hospitalizations rates were grouped according to the International Classification of Diseases (ICD-10-CM) [21] in respiratory (hRESP), cardiocirculatory (hCARD), gastrointestinal (hGINT), cancerous (hCANC), and auditory (hAUD) pathologies. Data about prescription drugs were categorized according to the Venetian Regional Drug Center standards as anti-asthmatics (dRESP), anti-hypertensives (dCARD), anti-ulcers (dGINT) and anti-depressive (dDEP). Deaths were extrapolated from hospital discharge forms. No data about private hospitals nor drug prescription made by private doctors were collected in the present work. Data were subsequently partitioned by major and minor land units. For each of the above categories, age-standardised rates for the whole municipal population, using 5-year age groups, and specific rates for the over-65 yrs population out of every 1000 inhabitants were calculated. Choosing the over-65s as indicator of choice is due to it being less mobile and more linked to the urban environment, and therefore more exposed to local risk factors. Plus, the over-65s are still young enough to avoid the enhanced degenerative processes of the elderly [22]. Age-standardised rates and specific rates for the over 65s were further compared with those of the ULSS20 population and the Regional one. In order to successfully compare the datasets, direct standardization was applied on Verona municipality rates for the whole population, following the age distribution in 5-year age groups of the two above mentioned reference populations.

Quality class assignement

For each analyzed element of Verona UES, the above described indexes were processed both at district and at quarter level in order to obtain an easy-to-understand quality class scoring. As an exception, landscape pattern AEQ index was applied only to districts, since quarters were not homogeneous enough to represent suitable structural units. Quality class scoring was cartographically rendered using a simplifying three colors code (green: high quality; yellow: medium quality; red: low quality). The quality scale was structured according to the percentile distribution of the indexes values: the class-limiting point is set in correspondence of the 25^{th} and the 75^{th} percentile, respectively.

Statistical analysis and geo-referetiation of land units

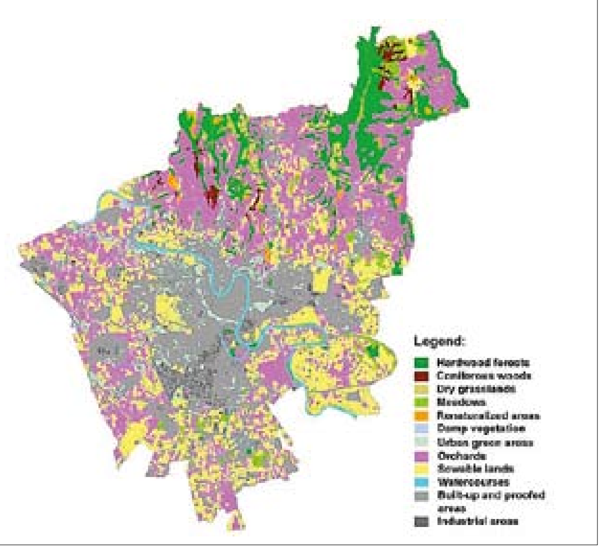
Quarters were considered in statistical analysis since numerosity of districts was too small to allow implementation of significance tests. BioS indexes were dicothomized assigning a value of 1 when scoring in the low quality class (> 75^{th} perc.) and a value of 0 when scoring in the medium or in the high quality class (< 75^{th} perc.). BioS indexes were then compared in a 2 × 2 contingency table with specific rates for the over 65s. One-tailed Fisher exact test of independence was applied with SAS® software to each pair, the null hypothesis H_0 being the independence and randomness of the value of the two indexes. A significance level of $\alpha < 0.05$ was set for the test. For further simplification, all BioS-related indexes were merged into a Global Environmental Quality (GEQ) index, equal to the summatory of the values assumed by each indicator, and categorized in two classes only. Statistical analysis was performed on data thus processed to assess any association of GEQ with significative indexes linked to human health. In the end, land units were geo-referentiated with processed indexes through GIS technology.

Results and discussion

Landscape pattern and ecological quality

At a 1:5000 scale from Verona landscape emerge four main classes of elements: green and seminatural areas (urban green areas, hardwoods, conifers woods, dry grasslands, meadows, re-naturalized areas, i.e. abandoned fields, and damp vegetation), agricultural areas (sowable fields and orchards), built-up areas and/or asphalt paved areas (civil and industrial buildings, roads and car parks) and watercourses (Fig. 2). Overall, prevalence of one landscape element leads to the identification of three broad zones: the Northern hill area (woods and orchards), the middle area (heavily urbanized territory) and the Southern periurban one (sowable fields with interspersed urbanized blocks). Structural specificities emerge in every land unit: description of their fine structure was achieved for every district. Detailed results are here omitted for concision but can be requested to authors at any time. Synthetically, from the

Fig. 2. Verona landscape composition map (1:5000 scale). Four main classes of elements emerge: green and seminatural areas (green shades), agricultural areas (fuchsia and yellow), built-up areas areas (grey) and watercourses (light blue).

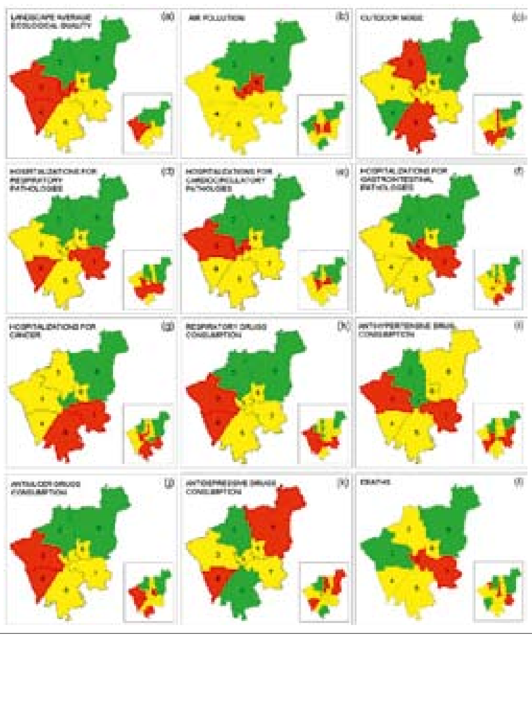


Tab. I. Average Ecological Quality (AEQ), Motor vehicle-equivalent (MVeq) and percentage of 60 dB trespasses (ALeq > 60 dB) for Districts and Quarters.

District		Quarter		AEQ	MVeq		% ALeq > 60 dB	
D1	Old town center	Q1	Città Antica	1,2	10342	3618	20,3	8,3
		Q2	Cittadella			2586		42,2
		Q3	St. Zeno			14413		25,4
		Q4	Veronetta			18233		27,9
D2	North-West	Q5	Borgo Trento	3,2	2581	5225	29,7	42,3
		Q6	Valdonega			3552		28,0
		Q7	Ponte Crencano			2311		22,0
		Q8	Avesa			2597		32,5
		Q9	Parona			1773		27,3
		Q10	Quinzano			2096		16,2
D3	West	Q11	Borgo Milano	1,2	4427	10433	20,3	20,2
		Q12	St. Massimo			1997		20,5
D4	South-West	Q13	St. Lucia	1,0	5109	3421	19,1	29,3
		Q14	Golosine			21034		8,8
D5	South	Q15	Borgo Roma	1,4	2729	3451	29,6	31,3
		Q16	Ca' di David			1853		25,0
D6	East	Q17	Borgo Venezia	2,4	9022	9022	26,1	26,1
D7	South-East	Q18	Porto S. Pancrazio	1,8	7246	8446	23,4	45,2
		Q19	St. Michele			6792		12,8
D8	North-East	Q20	Quinto	4,0	1706	1946	11,2	5,9
		Q21	St. Maria in Stelle			524		5,3
		Q22	Mizzole			254		9,3
		Q23	Montorio			5057		19,2

landscape composition and its upkeep degree the RPR, IJI, PLAND, PROX and PLADJ indexes were calculated. Values of the resultant index AEQ are shown in Table I and ecological quality achieved by each land unit is depicted in Figure 3a.

Fig. 3. Land units quality scores. Parameters chosen as indicators were graphically converted in an easy-to-read quality scale. Green represent high quality scoring areas, yellow medium quality and red low quality ones.



Atmospheric quality

Mean concentrations of pollutants, i.e. TPM, CO and NO_2, registered by the six monitoring stations were plotted against corresponding esteemed mean vehicular flow in a 1 km^2 area around each station. Regression coefficients for the obtained curves are: $R^2_{TPM} = 0.8654$, $R^2_{CO} = 0.8516$, $R^2_{NO2} = 0.7061$. A direct proportionality with traffic levels emerged for concentrations of considered air pollutants. Table I shows the obtained values for MV_{eq} index; atmospheric final quality class assignment is shown in Figure 3b. The spatial model of traffic flows in Verona UES obtained with GIS Idrisi® software is presented in Figure 4. Heavier flows are obviously found in urban belt quarters crossed by paths running North-to-South (Q4, Q5, Q14 and Q17) and East-to-West (Q3, Q4, Q11 and Q19). Critical MV_{eq} values were especially recorded in Q14 (> 21,035), Q4 (18,233), Q3 (14,413) and Q11 (10,433). MV_{eq} values in these quarters are mainly ascribable to two distinct structural backgrounds, that are old and narrow streets (Q3, Q4) *vs.* arterial thoroughfares (Q11, Q14).

Outdoor noise levels

Quarter distribution of outdoor noise levels reveals a certain dishomogeneity (Tab. I). Also, an incongruity between noise levels and traffic flows emerges, but this is easily explained if considering the different nature of the two indexes. MV_{eq} assesses indeed the atmospheric quality through the mean number of motor vehicles, since the local emission of air pollutants affects a widespread area. AL_{eq} on the other hand considers the whole quarter road grid and it is linked to the urbanistic

Tab. IIa. Age-standardised rates by 5-year age groups for Verona municipal population.

District	Quarter	$hRESP_{STD}$		$hCARD_{STD}$		$hGINT_{STD}$		$hCANC_{STD}$		$hAUD_{STD}$	
D1	Q1	9,0	6,7	21,8	21,1	12,6	10,6	4,2	3,4	1,0	1,5
	Q2		7,3		19,3		13,4		4,4		0,9
	Q3		10,1		25,0		15,4		5,2		1,3
	Q4		11,8		22,7		12,2		4,5		0,8
D2	Q5	9,2	8,7	19,3	18,3	11,9	13,7	3,8	4,0	1,1	1,1
	Q6		7,3		23,2		10,3		5,2		0,6
	Q7		10,4		21,3		10,4		3,8		1,7
	Q8		6,3		16,1		12,1		3,9		0,6
	Q9		12,2		16,7		8,9		2,2		0,5
	Q10		9,5		18,0		12,8		2,0		1,2
D3	Q11	12,0	12,0	24,2	24,9	12,7	13,1	5,0	5,0	1,1	1,2
	Q12		12,0		21,9		11,7		5,2		0,8
D4	Q13	11,4	10,9	21,7	21,3	13,4	13,3	4,7	4,7	1,1	1,2
	Q14		11,7		22,0		13,5		4,7		1,0
D5	Q15	11,9	12,3	21,1	21,8	13,3	13,2	6,1	6,5	2,1	2,2
	Q16		10,4		19,0		13,7		4,8		1,6
D6	Q17	9,5	9,5	22,5	22,5	12,5	12,5	4,7	4,7	1,2	1,2
D7	Q18	12,2	12,8	21,8	23,0	13,4	11,1	5,2	3,0	1,2	1,3
	Q19		11,9		21,5		14,2		6,1		1,1
D8	Q20	9,2	10,1	16,2	15,8	12,7	14,5	2,6	3,7	0,7	0,6
	Q21		7,9		13,5		11,6		1,9		1,5
	Q22		8,2		19,1		13,5		0,8		0,6
	Q23		9,2		16,7		10,8		2,1		0,7

Tab. IIb. Specific rates for the over-65 yrs population out of every 1000 inhabitants.

District	Quarter	$hRESP_{>65}$		$hCARD_{>65}$		$hGINT_{>65}$		$hCANC_{>65}$		$hAUD_{>65}$	
D1	Q1	18,4	13,6	74,3	68,4	24,6	19,5	11,6	10,9	1,0	2,7
	Q2		14,8		67,1		22,7		10,2		0,5
	Q3		8,2		87,4		31,2		13,7		1,5
	Q4		25,3		78,0		26,6		12,5		0,0
D2	Q5	15,6	14,9	61,3	60,2	19,5	25,4	13,9	15,7	1,4	1,6
	Q6		11,9		67,0		17,3		20,5		1,1
	Q7		21,5		67,7		15,5		11,9		2,0
	Q8		4,4		59,8		13,1		13,1		1,5
	Q9		17,9		52,0		12,5		5,4		0,0
	Q10		12,5		45,8		16,7		9,7		0,0
D3	Q11	24,0	24,9	76,6	79,4	19,6	20,4	14,5	14,8	1,4	1,6
	Q12		20,9		67,4		18,7		13,7		0,8
D4	Q13	24,7	23,6	68,5	67,4	20,0	22,3	13,7	13,6	2,0	2,9
	Q14		25,7		69,3		26,7		13,7		1,3
D5	Q15	22,5	23,6	64,1	64,8	21,5	20,7	17,8	17,9	1,9	2,0
	Q16		18,7		61,8		24,3		17,4		1,4
D6	Q17	16,5	16,5	70,7	70,7	21,5	21,5	13,6	13,6	1,7	1,7
D7	Q18	26	25,3	64,2	67,6	21,5	17,1	16,7	9,8	2,3	3,3
	Q19		26,2		63,0		23,1		19,1		2,0
D8	Q20	12,1	16,6	45,2	47,1	14,8	20,1	6,9	10,5	0,7	0,9
	Q21		5,6		25,1		2,8		0,0		0,0
	Q22		7,1		49,5		10,6		3,5		0,0
	Q23		0,8		48,7		14,4		6,3		0,0

$dRESP_{STD}$		$dCARD_{STD}$		$dGINT_{STD}$		$dDEP_{STD}$		$deaths_{STD}$	
264,2	241,4	2448,4	2326,7	437,5	434,7	335,9	295,4	8,4	9,7
	279,3		2485,7		438,4		385,5		6,9
	277,9		2603,6		453,7		327,2		7,6
	272,9		2479,6		427,5		351,8		8,9
272,1	253,4	2481,1	2369,9	394,4	382,3	313,7	350,9	7,6	7,2
	287,4		2617,4		342,9		361,4		9,2
	300,5		2496,5		454,7		327,8		7,7
	234,8		2775,3		354,4		238,2		6,8
	254,0		2441,0		435,1		212,6		9,5
	270,6		2143,9		266,9		241,2		6,5
401,4	409,4	3264,0	3304,9	585,0	580,6	327,0	337,5	8,1	7,9
	375,1		3111,2		600,4		295,7		8,7
380,4	391,1	3088,4	3133,0	549,2	520,8	403,8	405,4	8,5	7,6
	370,1		3047,3		569,1		403,0		9,3
328,0	318,9	2939,4	2994,0	498,8	501,6	305,5	324,6	8,7	8,9
	356,5		2752,8		488,1		237,6		8,1
348,2	348,2	2735,8	2735,8	512,8	512,8	338,1	338,1	7,6	7,6
424,0	374,5	3742,5	3305,9	516,8	407,4	387,4	325,3	10,9	8,7
	440,3		3882,0		551,4		408,7		11,7
312,4	311,9	2745,6	2762,9	367,5	437,6	363,7	368,1	7,0	8,3
	270,9		2313,6		354,5		296,3		7,4
	224,1		2258,3		256,6		442,9		3,7
	350,2		3002,8		327,3		356,9		6,5

$dRESP_{<65}$		$dCARD_{<65}$		$dGINT_{<65}$		$dDEP_{<65}$		$deaths_{<65}$	
505,6	450,4	7432,5	7416,7	1144,2	1104,2	614,4	645,1	37,4	42,9
	502,3		7145,7		1217,4		641,1		37,0
	411,9		7794,8		1128,4		528,9		30,4
	601,9		7503,9		1117,9		613,5		37,4
459,6	425,0	7143,7	7247,1	969,6	970,4	591,7	688,8	34,2	34,0
	477,3		8020,5		1073,4		734,3		43,2
	553,0		7213,8		1158,4		544,2		33,0
	354,2		7899,4		723,0		434,4		29,2
	277,8		6112,9		862,0		428,3		39,4
	536,1		5301,4		491,7		334,7		27,8
807,1	839,0	9269,3	9566,0	1507,7	1497,4	611,2	627,5	30,6	30,4
	702,6		8297,4		1541,5		557,9		31,2
798,3	825,6	8846,7	9061,2	1442,6	1440,9	760,9	765,3	33,2	30,2
	776,3		9673,7		1444,0		757,3		35,7
613,3	618,5	8273,7	8439,6	1264,1	1262,2	597,1	622,8	33,0	33,5
	595,4		7707,2		1270,7		509,4		31,2
611,5	611,5	8039,7	8039,7	1298,4	1298,4	663,8	663,8	30,7	30,7
683,8	601,5	9499,1	9490,6	1063,2	922,6	612,5	576,2	43,9	34,2
	712,7		9502,0		1112,3		625,1		47,3
501,2	513,1	7752,9	7680,6	921,6	1085,5	788,4	801,9	26,9	33,2
	463,7		5441,3		701,1		592,2		27,9
	240,3		5724,4		597,2		738,5		17,7
	567,6		9090,1		906,3		850,5		22,5

Fig. 4. Spatial model of traffic flows in Verona urban environment system.

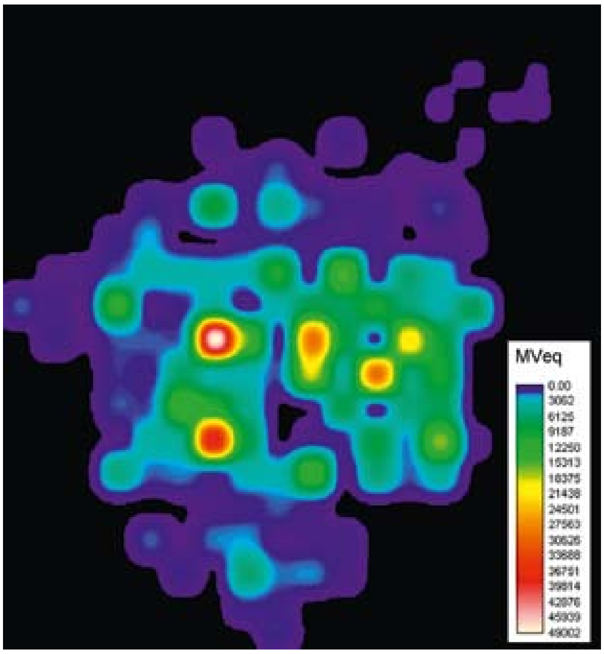
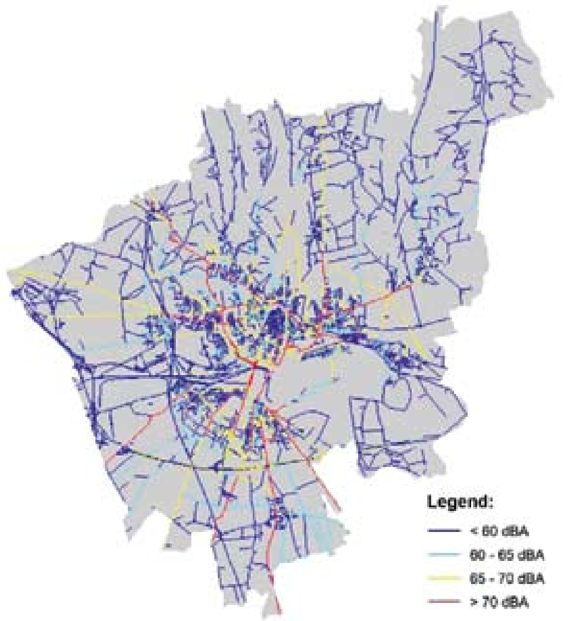


Fig. 5. The map depicts the distribution of traffic-related noise level in Verona urban area. Noisy roads trespassing the 60 dB threshold are painted in dark blue.



background: buildings produce a shielding effect that confines noise spreading. A map depicting the distribution of traffic-related noise level in Verona was drawn (Fig. 5). Critical situations verify locally, but they do not condition the whole land unit. For example Golosine (Q14) is one of the less noisy quarters, even if high traffic flows pour in through the main inter-quarter roads. This way high localized noise levels are determined, but the many residential roads found in the quarter can still succeed in maintaining a low exceeding percentage of the noise threshold. At district level noise levels appear highly differentiated among land units. Overall exceedings of the 60 dB threshold are represented with the percentile color code in Figure 3c.

Human population health

Age-standardised rates for the municipal population and specific rates for the over-65s/1000 inhabitants are listed in Table IIa and IIb. Quality class assignment for each health indicator is depicted in Figures 3d to 3l. After direct standardisation of rates for the population sample, data were compared with the two reference populations. Table III shows the rates for the Regional population and for the ULSS20 population. Full tables of standardised rates are here omitedd for plainness and only main findings are discussed. Standardised hospitalization rates for the whole municipal population always resulted lower than the ULSS20 rates, except for auditory pathologies. Some Verona land units (D5, Q1, Q7, and Q21) showed indeed higher hAUD values. It's notable that hCANC rates for Verona municipal population are four times and two times lower than the ULSS20 and the Regional population ones, respectively. hCANC for the over 65s was also 50% lower than the Regional rate. Drug consumpition rates showed again a lower trend if compared to the ULSS20 reference population. Deaths rates are higher than the ULSS20 and the Regional rate only in D7 and especially in its Q19. Again, standardised rates for the over 65s have frequencies lower than the corresponding ULSS20 cathegory but for auditory diseases. D4, D5, D6, D7 and their quarters have higher hAUD rates.

Statistical analysis

Table IV contains the contingency tables obtained for the health main indicator (specific rates for the over-65 population/1000 inhabitants) and the environmental quality key factors of landscape ecological quality, outdoor noise level and air pollution. At $\alpha = 0.05$, H_0 is rejected only for respiratory pathologies and air pollution, and for cardiocirculatory pathologies, air pollution and landscape

Tab. III. Hospitalization, drug consumption and death rates out of 1000 inhabitants for the two reference populations.

Ref. Pop.		hRESP	hCARD	hGINT	hCANC	hAUD	dRESP	dCARD	dGINT	dDEP	deaths
Regional	Total pop.	5,03	10,77	7,53	8,87	0,82	-	-	-	-	9,00
	Over 65s	16,25	34,92	15,03	22,76	0,88	-	-	-	-	-
ULSS20	Total pop.	12,49	30,15	18,53	20,77	1,32	332,09	3844,09	629,34	394,59	9,00
	Over 65s	26,19	107,02	35,99	58,25	1,50	-	-	-	-	-

Tab. IV. Contingency tables for the main health indicator and the environmental quality key factors. Significative p-values are marked with an asterisk.

Over 65 population specific rate %	Landscape pattern ecological quality			Outdoor noise level			Air pollution			Global Environmental Quality		
	High	Low	Fisher Exact Test	High	Low	Fisher Exact Test	High	Low	Fisher Exact Test	High	Low	Fisher Exact Test
hRESP	20,00	50,00	0,156	25,53	50,00	0,239	17,65	66,67	0.045 *	10,00	46,15	0,077
hCARD	6,67	62,50	0.000 *	35,29	0,00	1,000	5,88	83,33	0.000 *	0,00	46,15	0,017
hGINT	20,00	37,50	0,334	29,41	16,67	0,877	17,65	50,00	0,156	-	-	-
hAUD	26,67	25,00	0,712	17,65	50,00	0,156	29,41	16,67	0,877	-	-	-
hCANC	33,33	12,50	0,950	23,53	33,33	0,510	29,41	16,67	0,877	-	-	-
dRESP	13,33	50,00	0,081	23,53	33,33	0,510	23,53	33,33	0,510	-	-	-
dCARD	20,00	37,50	0,334	23,53	33,33	0,510	17,65	50,00	0,156	-	-	-
dGINT	13,33	50,00	0,081	29,41	16,67	0,877	17,65	50,00	0,156	-	-	-
dDEP	26,67	25,00	0,712	29,41	16,67	0,877	29,41	16,67	0,877	-	-	-
Deaths	20,00	37,50	0,621	29,41	16,67	1,000	29,41	16,67	1,000	-	-	-

ecological quality as well. Anyhow, it's relevant that hypothesis H_0 of independence could be eventually rejected assuming the less restrictive $\alpha = 0.1$ in two more cases, that is for respiratory and gastrointestinal drugs consumption versus landscape ecological quality. Further studies could eventually furnish elucidation about this hinted association. Anyway, only significative cases at $\alpha = 0.05$ were further analyzed, comparing specific rates of the health indicators with the global environmental quality (GEQ) index. Results of Fisher exact test again confirm the non-independence of cardiocirculatory diseases and biophysical environment, while the analogous association for respiratory pathologies could only be accepted at an upper significance limit of $\alpha = 0.1$.

Conclusions

A positive relation emerges between quality of the landscape pattern, low frequencies of hospitalization for respiratory, cardiocirculatory, gastrointestinal pathologies, and a low consumption of anti-ulcer drugs in the hill area (D8 and D2), which also has the lowest levels of atmospheric pollution. On the other hand, negative relations between high rates of hospitalization and drug consumption and bad environmental conditions are less clear, except for the following zones: Veronetta, Borgo Milano, Golosine and San Zeno.

Specific rates for the over 65 population confirm a similar trend for most indicators. As highlighted by the results of the statistical analysis, the over 65 population, and in particular its specific hospitalization rate, is the most informative indicator. The most significant result concerns hospitalizations for cardiocirculatory pathologies, which can be associated both to the ecological quality of the landscape pattern and to air pollution. The comparison between the GEQ index and the hospitalizations confirms how the latter are significantly associated with the global quality of the biophysical environment.

The model of health suggested and worked out according to the systemic and ecological point of view seems to represent in an effective way the real complexity of the urban environment systems, as the tested monitoring model has proved an interesting and profitable means of analysis, able to provide suitable tools to interpret the systemic state of health and, consequently, potentially useful to direct and support the policies of sanitary management and of territory planning, as well as the prevention strategies on a local scale.

The first testing of this model suggests some possible elements of implementation and integration which could further complete the analysis. Among them, the subjective investigation of the status of health seems to take on a relevant importance; this type of investigation can strongly condition the life quality and provide information on the community's inclination towards its living environment.

The initial phase in which the present research was lead allows or better needs a discussion and elaboration path, opened to some possible elements of implementation and integration. Environmental quality assessment could for instance be entwined with an in-depth analysis of the population socio-economic background and its cultural level, since both factors are closely related to appropriate life-styles and a proper health awareness.

References

[1] Thrusfield MV. *Veterinary epidemiology.* Second edition. Oxford: Blackwell Science 1995.

[2] Daily G. *Nature's services: societal dependence on natural ecosystems.* Washington: Island Press 1997.

[3] McMichael AJ. *Human frontiers, environment and disease: past patterns, uncertain futures*. Cambridge: Cambridge University Press 2001.

[4] United Nations. *Population, environment and development*. Department of Economic and Social Affairs, Population Division. New York: UN Press 2001.

[5] Bormann FH. *Ecology: A personal history.* Rev Energ Environ 1996;21:1-29.

[6] VanLeeuwen JA, Toews D, Abernathy, et al. E*volving models of Human Health towards an ecosystem context.* Ecosystem Health 1999;5:204-19.

[7] O'Neill RV, Deangelis DL, Waide JB, et al. *A hierarchical concept of ecosystems.* Princeton: Princeton University Press 1986.

[8] Naveh Z, Lieberman AS. *Landscape ecology: Theory and Application.* New York: Springer-Verlag 1984.

[9] Liu GY, Yang ZF, Chen B, et al. *Emergy-based urban ecosystem health assessment: A case study of Baotou, China.* Communications in Nonlinear Science and Numerical Simulation 2009;14:972-81.

[10] Tzoulas K, Korpela K, Venn S, et al. *Promoting ecosystem and human health in urban areas using Green Infrastructure: A iterature review.* Landsc Urban Plan 2007;81:167-78.

[11] Su M, Fath BD, Yang Z. *Urban ecosystem health assessment: a review.* Sci Total Environ 2010;408:2425-34.

[12] Istituto nazionale di statistica. *Movimento e calcolo della popolazione residente* (modello Istat D.7.B). 2009. www.istat.it/dati/db_siti Accessed on 7 December 2010.

[13] Poli S. *Caratterizzazione meteoclimatica dell'area di Verona e sua applicazione sui problemi di qualità dell'aria.* University of Bologna, PhD School of Sanitary Physics, unpublished 2001.

[14] Censis. *La ricchezza del territorio italiano: stima del PIL dei Comuni Italiani.* 2004. www.censis.it Accessed on 3 December 2010.

[15] McGarigal K, Ene E, Holmes C. *FRAGSTATS: spatial pattern analysis program for categorical maps.* Software produced at the University of Massachusetts. 2002. www.umass.edu/landeco/research/fragstats.html Accessed on 10 March 2007.

[16] Istituto nazionale di statistica. *Ambiente e territorio: Indicatori ambientali urbani.* 2006. www.istat.it/salastampa/comunicati/non_calendario/20070829_00/testointegrale.pdf Accessed on 28 November 2010.

[17] Adami C, Giuliano F, Gabrieli T. *Costruzione di un indicatore di esposizione al rumore urbano da traffico per la città di Verona.* University of Parma, Faculty of Natural Sciences, Master Thesis, unpublished. 2003.

[18] Callegari A, Franchini A. *Rassegna degli effetti derivanti dall'esposizione al rumore.* Sistema Nazionale Conoscitivo dei Controlli in Campo Ambientale, Centro Tematico Nazionale Agenti Fisici (ANPA) 2000.

[19] ULSS20. *Presentazione dell'Azienda ULSS20 di Verona - Assistiti al 31.12.2008.* http://www.ulss20.verona.it/ Accessed on 23 February 2011.

[20] Regione del Veneto. *I numeri del Veneto - la statistica in tasca.* 2010. http://statistica.regione.veneto.it/pubblicazioni_elenco.jsp Accessed on 3 December 2010.

[21] World Health Organization. *International Classification of Diseases ICD-10-CM.* 2007. http://www.cdc.gov/nchs/icd/icd10-cm.htm Accessed on 14 December 2010.

[22] European Commission Directorate - General Environment. *Environment and Ageing - Final Report.* 2009. ec.europa.eu/environment/enveco/others/pdf/ageing.pdf Accessed on 18 December 2010.

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