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Urban Settlement Sensibility Assessment Morphological-Based Analysis in Italian Case Studies

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The proposed research describes an index which measures the land sensibility by urbanisation. This index has been developed from a retrospective analysis of the development of settlements where geographical morphology varies significantly. The preliminary study aims at gauging how morphological factors (slope altitude, gradient and aspect) have influenced current urbanisation in the studyareas: the Italian regions of Umbria, Marche, Abruzzo, Lazio and Molise. Calculating this index has identified the main morphological factors linked to land uptake and highlights areas that are more vulnerable to urbanisation, assuming urbanisation continues according to the model adopted over the past sixty years. It's clear that urban settlement sensibility depends from a lot of parameters as morphology, infrastructure and economic and social aspect, but, in a long term perspective, the morphometric characteristics influence all other in determining the spatial organization of settlement.

Introduction

Land uptake due to widespread urbanisation is tied to environmental, social and economic aspects and has always occurred and marked by cycles of escalation or decline in terms of interested geographic areas (Mumford, 1961).

In Europe, the debate has been lively with regard to political stances and has involved many social and territorial governance issues, as well as issues concerning participation in planning processes (Barlow, 1995; Cheshire, 1995). Investigation of the issues of the city-region and the sustainable development of this type of settlement is invaluable in this debate (Krueger & Savage, 2007; Hesse, 2007). There are a number of interesting studies that consider urban sprawl as a territorial "disease" for which curbing and mitigating actions and measures need to be studied (Johnson, 2001; Kasanko, Barredo, Lavalle, McCormick, Sagris & Brezger, 2006; Dietzel & Clarke, 2007; Clarke, 2008) including the work carried out by the European Commission (2006) which examined urban development in various European countries using a land uptake index. From this research it can be inferred that the average European land uptake between 1990 and 2000 amounts to about one million hectares.

In Italy, the phenomenon of "urban sprawl" has been considered for many years as one of the causes of urban functional disorganisation, in terms of use of services and efficiency of transport (INU, 1990; Indovina, 1990; Gambino, 1996; Indovina & Savino, 1999; Camagni, Gibelli & Rigamonti, 2002). Furthermore, minimal data are available to outline national urban growth dynamics since the end of World War II, and in particular in the past thirty years (Pileri, 2010; Romano & Zullo, 2012), which is undoubtedly the period when urban sprawl has occurred with significantly higher impact on land, especially in the flatter areas of the country (as in Figure 1).

More recently, responsibility towards the planning and towards the pathology of land uptake is becoming more and more important for the public opinion. Therefore we think that the future planning tools should gather these tendencies, by imposing rules to contrast or mitigate the land uptake. The control action should be effective mainly when the urban sprawl is relative to wide agricultural flat areas (which represent less than 25% of the national territory), with loss of crop production and of ecosystem services. Moreover the urban sprawl has serious effects on soil sealing, with devastating idrogeological impact on settled human communities (MEA, 2005; Jaeger, Bertiller, Schwick, Cavens, & Kienast, 2010; Santolini, 2011).
This paper aims to implement a "settlement risk index" tied to morphological components such as slope altitude, gradient and aspect.

The settlement risk model is implemented by measuring sensibility to urbanisation as expressed today by the various territorial factors. Using decisions already taken in similar geographical areas, already affected by urbanisation, it is possible to simulate in the mid- and long-term (30-50 years) the probability of areas undergoing similar processes, assuming no change is made to previous behaviour.
The settlement risk index has been tested in some Italian regions where morphology-related GIS layers are available to a sufficient level of detail, expressed by the nominal scale of 1:10.000 (Veneto, Marche, Umbria, Lazio, Abruzzo and Molise). The index has been calculated by implementing an automatic GIS model that uses commercial geo-processing functions.

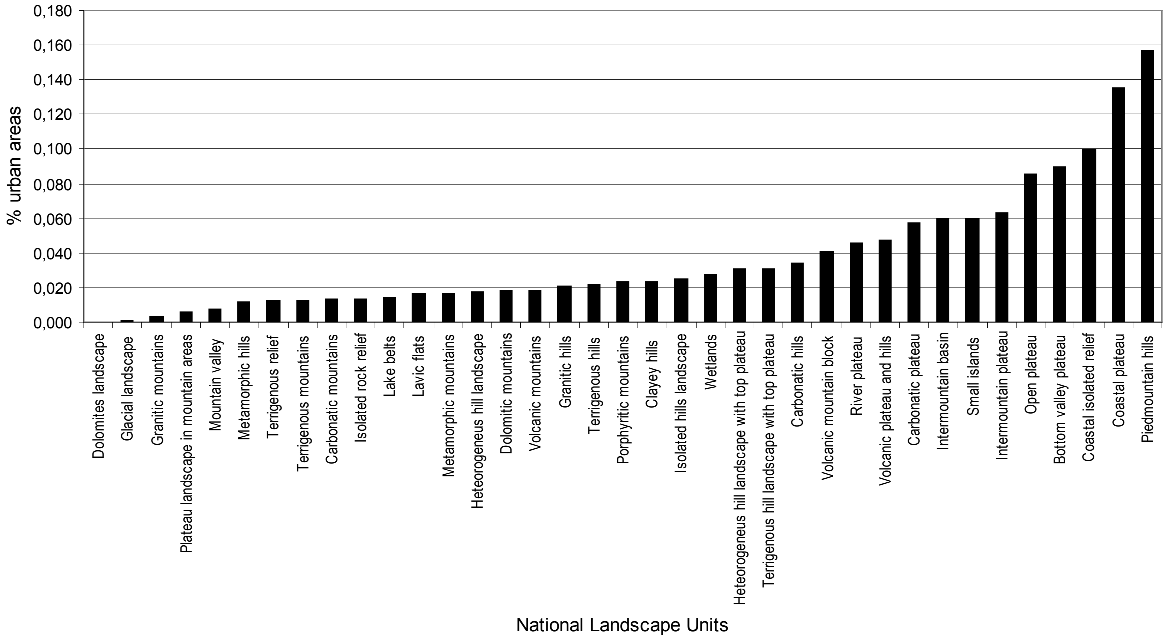

Figure 1 | Percentage of urbanisation on different kinds of national landscape units identified in 2004 by APAT (National Agency of Environment and Technical Services).

Why settlement risk ?

This paper refers to "settlement risk", as opposed to natural risks (e.g. seismic, hydro-geological, fire etc.). It may appear that urban control over features and functions is total, as described by a specific strategy or plan. Over very long periods of time, transformation trends, tied to human eco-ethology, emerge and are expressed by local communities, while plans follow these trends rather than control them (Romano, 2000; Romano & Tamburini, 2006; Pungetti & Romano, 2004). Territorial changes are driven by the qualitative and economic advantages of potential developments and by availability of areas that are believed to be better from a geo-morphological or urban point of view. It is not by chance that, for decades, planning has favoured new settlements along roads or near road junctions, but also along other linear elements as rivers and shorelines. Likewise, locations that tended to close gaps left by previous transformations have been preferred (i.e. parts of interstitial land either very near to or immersed in pre-existing urban matrixes). Considering geo-morphological aspects, settlements either tend to develop downstream, in flat areas or encroach upon hilly sectors. Some of these factors have already been considered on at various points in spatial decision-making disciplines (Barredo, Kasanko, McCormick & Lavalle, 2003).
All these aspects impact many countries worldwide with alternating periods of intensification and slowdown (Hammer, Stewart, Winwler, Radeloff & Voss, 2004) and are derived from the undisputed economic and qualitative benefits which communities express to local governments. Traditionally, there was no reason to oppose this social request: building on flat land, especially for building factories and commercial structures, costs far less for technical reasons. Likewise, locating buildings and urban services along existing roads helps the local economy, due to a better access to the territory. Hills are preferred for residential functions, as the quality of life is generally climatically better and hills also provide better protection against hydrogeological risks (e.g. floods, inundations etc.), even if sometimes is present landslide hazard in hilly terrains.
As a result, it is clear that areas near major urban centres (which act as service providers and job concentrators) and favourable geo-morphological positions (e.g. stable terrain in good climatic zones) are far more subject to settlement pressure, than other areas under different conditions and it is true worldwide.
If town planning only pursues the goal of guaranteeing the best residential and production conditions to

humans, with little conservation consideration (Brand, 2007), we can expect that planning tools will mainly support transformations desired by private stakeholders (it has been the case for decades in Italy). As a result, parts of a territory which suffer extremely intensive land consumption due to urbanisation will always be driven by the priorities of local communities. This would largely be the case even in the absence of any governance. Under this scenario, planning mainly exerts control over size rather than location, aligning itself to the trends declared by the local community. On the other hand, a tendency to by-pass planning rules is evidenced by a large number of works relating to spatial simulations of urban growth dynamics using different methods, among which include methods based on logistic regression and the cellular automata model (Clarke, Hoppen & Gaydos, 1997; Couclelis, 1997; Batty, Xie & Sun, 1999; Li, Sato & Zhu, 2003; Frenkel & Ashkenazi, 2008).

It is clear that the tendency toward urbanisation, as described before, may either be slowed or diverted from its previous course. The introduction of measures, such as protected areas, may stop, mitigate or change the direction of historical trends. This may be demonstrated by considering the global warming debate and measures to mitigate the process.

Risk settlement mapping, initially carried out using the basic determining factors described in this paper, may later undergo different forms of validation and audit, by comparing it with the mosaic of ongoing urban and infrastructural programmes or environmental policies. These different steps should provide clear indications regarding the approach to ecological sustainability of urban growth.

Urbanisation characteristics of the study regions

Analysis has been based on the contents of the EU CORINE Land Cover, Level 3. The data shows that urban areas, including built-up areas for residential and production purposes as well as surrounding areas (but excluding suburban roads) cover on average 4% of the territory at national level

The amount of urban area varies considerably across various regions, ranging from approximately 3% in southern regions, such in Molise, to almost 10% in more industrialised regions, such in Lazio (Table 1).

These urbanised areas do not include suburban roads where national data are very uncertain as homogenous GIS information on roads, is not yet available in Italy. By analysing some regions, we can extrapolate a parameter of land uptake due to the road network: Umbria has a road network which, by including roads of all types, motorways and railways, amounts to about 5600 km, with a regional density of about 0.7 km/km2 and land uptake amounting to 0,5 % of the regional territory. The percentage of land occupied by the road network increases to 1% in Veneto (21,000 km of roads, 1,2 km/km2) and in Abruzzo too (11,000 km of roads, 1,1 km/ km2).

REGIONS	Area (km^2)	Urbanised Area (km^2)	Urbanised area %
Abruzzo	10765,61	416,98	0,04
Lazio	17194,45	1478,19	0,09
Marche	9716,50	490,19	0,05
Molise	4435,33	112,25	0,03
Umbria	8450,47	300,87	0,04
Veneto	17711,69	1881,81	0,11

Table 1 | Territorial characteristics of the study regions (morphological characteristics derived from the ISTAT database (National Central Institute of Statistics).

Nationwide data on urban growth over the past 30-50 years are lacking. Databases of regions are increasing both in terms of quantity and quality at a fast pace and, in a few years time, important information will be available. Some recent studies, based on GIS processing of urban growing from 1956, have produced some

interesting results. For example, the Molise region, one of the smallest in Italy with a surface about 446,000 km2, has seen its urban areas growing from 2,330 ha in 1956 to almost 12,000 ha in 2005: a 500% rise in fifty years. Considering that this region, situated in the central-southern part of Italy, has rather modest social and economic dynamics, it is plausible that in other regions, where economic energy is far greater, the rise in urban surface over the same period has also increased by a greater degree (Romano, Zullo, Cargini, Febo, Iezzi, Mazzola & Rollo, 2011).
The data obtained, albeit limited, show that, due to national economic trends, the average land uptake in Italy will be approaching 10% soon. In particular, the phenomena which lead to increased building are tied to the need of municipalities to collect more taxes on buildings in order to finance public services, but there is also a tendency for people to invest in real estate when interest rates has been low in Italy until year 2010. 10% urbanisation may seem hardly alarming, but the most concentrated areas of buildings and their surrounds (such as, parking lots, services, manoeuvring and ancillary areas) are very limited. In a country like Italy, where mountain areas occupy approximately 35% and hilly areas over 40%, urban settlement densification is quickly saturating the flat areas which occupy only 25% of national territory.
The negative effects of making land impermeable are already very significant and there is concern that climate change, the destruction and fragmentation of the habitats of internationally important species in central Italy (such as the bear, the wolf and the lynx), the alteration of surface and ground water, the reduced capability to absorb domestic and industrial emissions, the irreversibility of land to agriculture once it has been transformed by urbanisation and, in short, overall reduced resilience to the disturbances affecting ecosystems (Holling, 1973). Added to this, there are problems tied to urban sprawl, such as dissipation of energy, pollution, mobility-related difficulties, identity loss and higher economic and social costs.

Results

The settlement risk index measures how sensitive a territory is to urban land consumption. It is an evaluation based on previously analysed phenomena taking into account morphological features such as slope altitude, gradient and aspect. The index is not “spread” over pre-established minimum territorial units, such as environmental units or administrative limits, but instead over self-derived units.
Really the index is also administrative-based because is implemented on single regions. This is due to the fact that urban settlement is driven by human beings and not by Nature and so linked in a measure to land transformation regional policies.
The GIS model used generates territorial units, by means of a sequence of spatial intersections among the various thematic layers, which represent the selected morphological variables (Unique Condition Unit) (Calcaterra, Di Martire, Palma & Parise, 2010). A similar methodology has been used in different frameworks, e.g. for estimating the landslide hazard and risk (Brabb, 1984, 1987). Anyway, the base concept is very different for settlement risk, because the urban growing is an evolutive phenomenon, with time constant of the order of decades, with drivers which are both natural and economic-social, and moreover is a phenomenon for which it is possible to construct a statistic, at local territorial scale.
Urban Settlement Risk has been assessed by considering morphometric parameters. It is true that among the most important drivers of urban settlement and growing, social and economic features play a key-role, but historically these features depend in turn on morphological factors. Morphological features (or categories) is ranked down into “classes”.
The altitude classes have the thresholds derived by statistical morphological classification (ISTAT) which in Italy is the following:

h < 300 m a.s.l. (coastal belts and low hills)
300 – 600 m a.s.l. (hills)
600 – 800 m a.s.l. (high hills and low mountains)
800 – 1000 m a.s.l. (middle mountains)
> 1000 m a.s.l. (mountains)

The gradient classes derived by Land Capability Methods (Agriculture Canada Expert Committee on Soil Survey, 1987; Costantini, 2006), where land capability is evaluated for agricultural and settlement uses, based on different characteristics, such as the slope gradient. The thresholds are the following:

$p<5\%$	(flat areas)
$5\%<p<10\%$	(slight slope)
$10\%<p<20\%$	(middle slope)
$20\%<p<50\%$	(high slope)
$p>50\%$	(very high slope)

The aspect classes are ranked using the quadrants NE-NW, NW-SW, SW-SE, SE-NE.
The settlement distribution rate is measured for each class examined. This is expressed as a percentage of urban cover within the each class.
This percentage is called ij-Settlement Sensitivity Index (Ssxij), where i=1,2,3 and represents the categories, j=1,2,…ci and denotes the class. ci is the number of classes in category i. Ssxij represents the extent to which the class j in category i is sensitive to the phenomenon of urbanisation over time.
Given a study territory with area equal to S, Ssxij is formally defined as follows:

$$Ssx_{ij} = \frac{Su_{ij}}{S_{ij}}$$

where: Suij = sum of the urban areas falling within the class j of category i;
Sij = sum of the areas belonging to the class j of category i.

Since our goal is that of defining a settlement risk index (Six) which takes into account the sensitivity indices for all the categories, it is reasonable to associate to an area characterized by three class attributes, one for each category, a settlement risk index which is the weighted sum with respect to i of the corresponding Ssxij i.e.

$$Six = \sum_{i=1}^{3} Ssx_{ij} \cdot \alpha_i$$

where $\alpha_i>0$, for any i and $\alpha_1+\alpha_2+\alpha_3=1$.

The coefficient α_i is a measure of the influence of category *i* over the settlement distribution and is function of technical aspects (e.g. we expect that the settlement percentage is zero when the slope is over a given threshold), of climatic, historic and socio-economic factors. Our idea is that of considering the variance v_i of indices Ssx_{ij}, $j=1..c_i$. In fact the higher is the variance, the higher is the influence of category *i*. When variance is *0*, then ther is no influence. The coefficient α_i is defined as:

$\alpha_i = vi/(v1+v2+v3)$
where we assume that $v_1+v_2+v_3>0$ and so the value of Six is between *0* and *1*.

The thresholds between categories and classes is shown in Table 2.

Morphological categories (Ci)		Classes (Cij)
C1	Altitude (m above sea level)	< 300 between 300 and 600 between 600 and 800 between 800 and 1000 >1000

C2	Acclivity (slope)	< 5% between 5 and 10% between 10 and 20% between 20 and 50% > 50%
C3	Aspect	NW-NE NE-SE SE-SW SW-NW

Table 2 | Categories and classes

More in details, for a certain category, the study territory is subdivided into zones, each of a certain class. By putting all categories together, we obtain a detailed picture of sub-zones, each with a class value for each category. In each of these sub-zones, the value of the index Six of overall sensibility to urbanisation can be computed.Of course, the precision of the result depends on the level of detail of the available DTM model (Digital Terrain Model 3D). As for the meaning of the index, under the hypothesis that social behaviour so far measured remains unchanged in the future, Six describes a scenario, and we could assume that its value, associated to an area, represents the possible urbanization rate for that area, within a sufficient long time horizon (at least 30 years). Considering the real values obtained applying the methodology to the study regions the final index have been ranked as follow:

Six < 0,05 (low risk)
0,05 < Six < 0,10 (medium risk)
0,10 < Six < 0,25 (high risk)
Six > 0,25 (very high risk)

This ranking is also referred to the national average of urban rate in Italy that is estimate about 10%. As already remarked in other sections of this paper, urbanisation phenomena are also determined by other factors, as infrastructures and proximity to other urban areas. Since these factors can be designed by the planning tools, the knowledge of Six gives an important tool to increase or decrease the urbanisation pressure, defined on the basis of morphological factors.

		Abruzzo	Lazio	Marche	Molise	Umbria	Veneto
Categories	Classes	Percentage of urbanised areas per class (Six_{ij})					
ALTITUDE	< 300 m a.s.l.	0,08	0,13	0,08	0,03	0,07	0,15
	300-600 m a.s.l.	0,04	0,05	0,03	0,02	0,03	0,08
	600-800 m a.s.l.	0,06	0,02	0,01	0,03	0,01	0,04
	800-1000 m a.s.l.	0,02	0,01	0,01	0,01	0,01	0,04
	> 1000 m a.s.l.	0,00	0,00	0,00	0,00	0,00	0,01
ASPECT	Flat	0,05	0,09	0,06	0,03	0,04	0,10
	NW-NE	0,03	0,06	0,04	0,03	0,03	0,02
	NE-SE	0,04	0,04	0,06	0,02	0,03	0,11
	SE-SW	0,03	0,12	0,04	0,02	0,02	0,12
	SW-NW	0,02	0,08	0,02	0,02	0,02	0,04
SLOPE	0-5%	0,17	0,15	0,12	0,05	0,06	0,12
	5-10%	0,06	0,08	0,07	0,03	0,04	0,14
	10-20%	0,02	0,02	0,03	0,01	0,02	0,06
	20-50%	0,01	0,00	0,01	0,01	0,00	0,01
	>50%	0,00	0,00	0,01	0,00	0,00	0,00

Table 3 | Urban sensibility of morphological classes

	Abruzzo	Lazio	Marche	Molise	Umbria	Veneto
Categories	Normalised Variance per categories (Vn_i)					
ALTITUDE	0,10	0,27	0,25	0,03	0,22	0,13
ASPECT	0,02	0,02	0,02	0,01	0,02	0,05
SLOPE	0,27	0,17	0,16	0,16	0,15	0,13

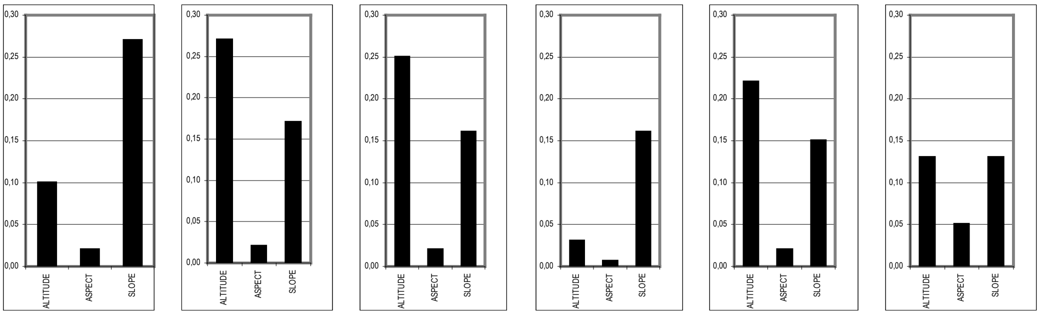

Table 4 | Urban sensibility of morphological categories

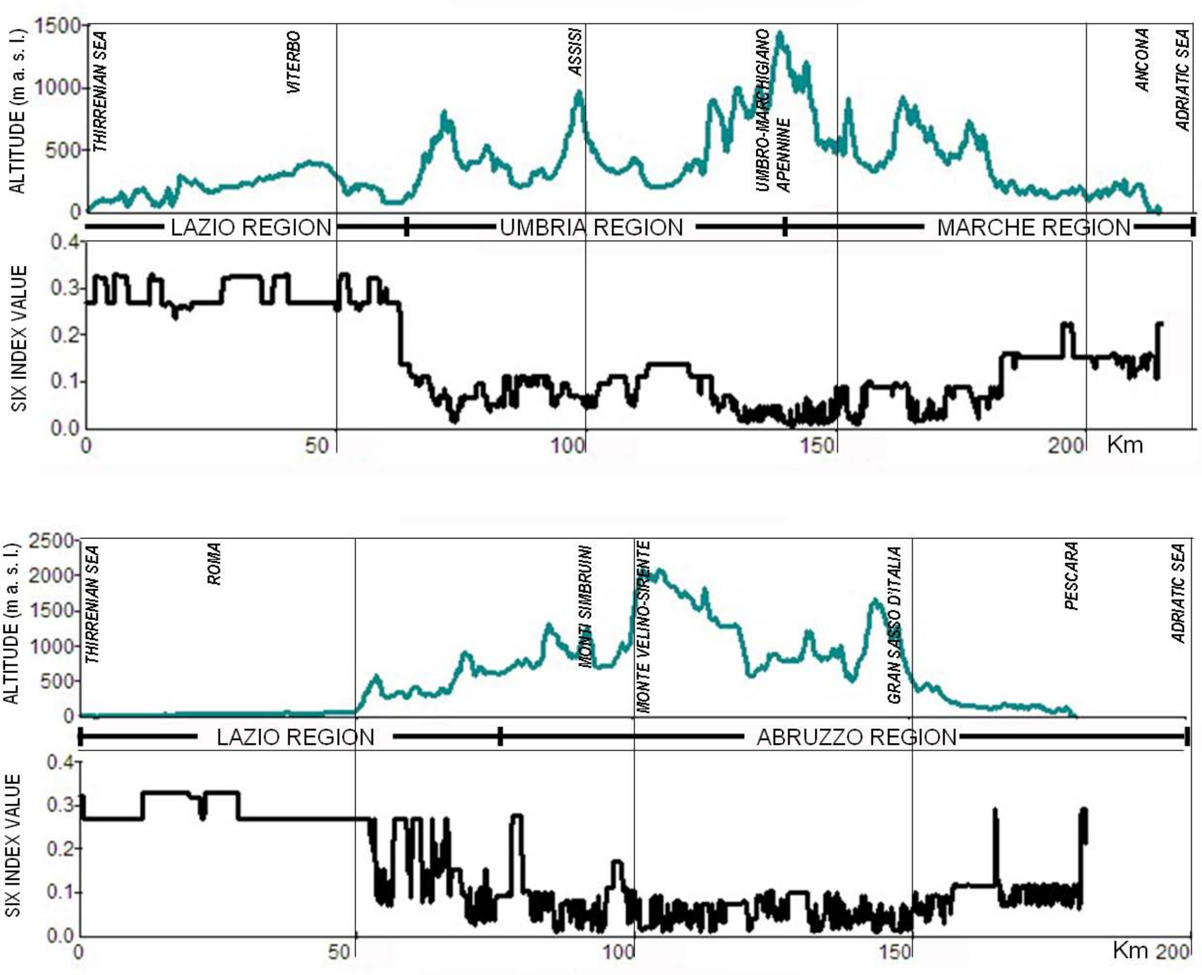

Figure 2 | Urbanisation sensibility along two morphological transects of Central Italy expressed by Six Index

A high settlement risk (Six>0,10) refers to those areas which are extremely vulnerable to urbanisation and not only to building. Urban areas include the portion of land occupied by buildings but also by surfaces around buildings with ancillary functions, such as carparks and technological equipments, which take up soil and cause soil sealing, as buildings do.
Tables 3 and 4 and Figure 2 show that different territories, such as the study Italian regions, have varying susceptibility to urbanisation. In the case of Lazio, Marche and Umbria, altimetry plays a more important role in the location and densification of settlements than in Abruzzo and Molise. Generally, slope aspects has limited influence over settlements in all study cases, showing to be a territorial aspect that does not have a significant impact on the distribution of urban structures.
The amount of information obtained in calculating the settlement risk index for all those parts of the territory which have the same features and proven to be better suited to urban settlement, shows that we can ascribe settlement risk to these features, as expressed in Figure 3. In this figure, which shows adjacent study regions in central Italy only, the maximum levels of the risk of land consumption due to urbanisation are concentrated in the flat areas and along the coastal lines or along river valley floors, but also in the broader valleys of inland areas. It is only too clear that, where settlement risk is high, it leads to building and urban saturation for the flat morphologies. This in turn leads to severe isolation of mountain areas where the most important natural ecosystems are concentrated, which lose their interaction opportunities, thus damaging the fauna of international conservation interest in the Apennines.
A further consideration is the loss of flat land that could be used for farming. Much has already been lost, while the current trend is marked by urban expansion in hilly areas too, particularly in the coastal hinterland. These areas support important specialised crops, such as olive groves, vineyards and large areas of grazing land which form a landscape of high aesthetic value.

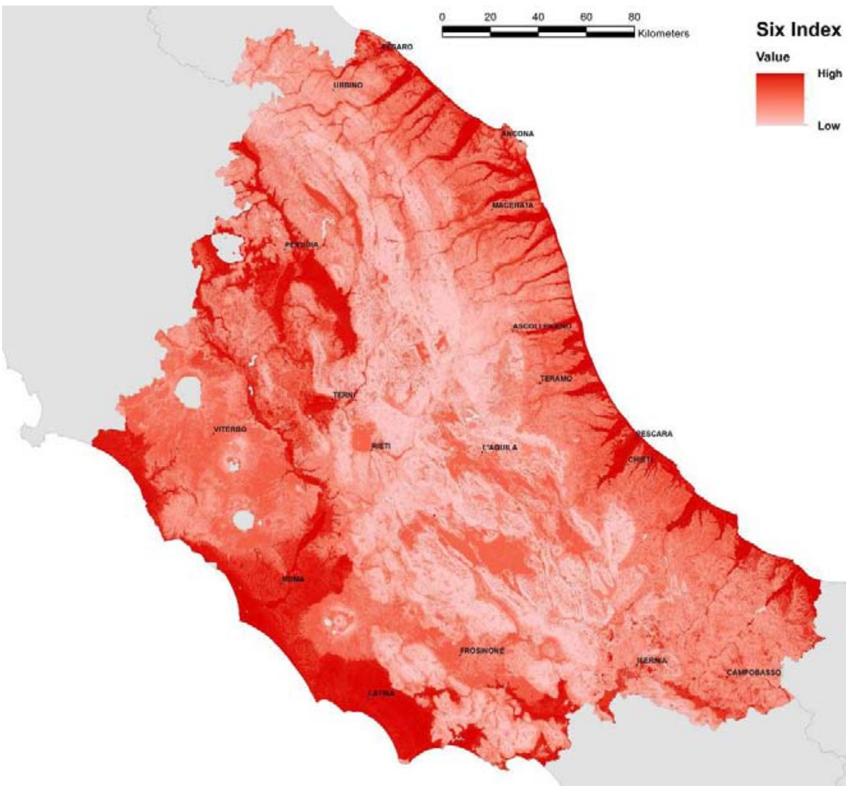

Figure 3 | Geographical result of settlement sensibility assessment on the study areas in Central Italy expressed by values of Six Index.

Conclusions

The geographical information derived from the calculation of the settlement risk may be useful to planners in order to identify trends. These can inform the use of town planning capabilities in order to exert greater control and implement containment policies (Wassmer, 2006; Boyle & Mohamed, 2007) through more incisive laws than in the past (Colding, 2007). The debate on how to "compact" urban areas remains open, considering that this solution too needs to be put in practice using reasonable criteria which vary between geographical areas. It does not lend itself to simplistic generalizations (Jenks, Burton & Williams, 1996) due to many interrelations between conurbations and their adjacency matrix (Forman, 2008).

Moreover, as mentioned earlier, we should not forget that the categories which should be used to calculate the settlement risk index may be far more numerous than the morphological ones discussed in this paper. Unfortunately, homogenous and extended layers of information were unavailable for the study regions considered. Future urban distribution is dependent on geo-lithologic characteristics, the road network and existing conurbations. Geological parameters are important nowadays and it is actually considered by urban planners and managers in defining the trend of urban growing. But it was not the same in the past: a lot of municipalities were founded on weak rocks and unstable terrains and, during the times, they enlarged their boundaries over even worse terrain, if possible.

In the case of geo-lithology, we can consider variously grouped classes. One possibility is to restrict ourselves to the main features shown in structural schemes. Alternatively we could use the units derived from stratigraphic and tectonic discontinuity and the formations into which the latter are broken down for a more detailed scale (Fiorini & Romano, 2007). The choice largely depends on the size of the territory where the index is used and on the geological complexity of the setting considered.

The choice of classes is easier in the case of proximity to roads, where it is possible to identify road-side strips of a constant width (e.g. 50, 100, 150, 200 m).

Assuming that in the Italian experience the morphological factors have been the main drivers of urban placement, in particular in the last forty years, a more sophisticated methodology is the one used to measure the "urban around the urban", that is to say the positive feedback effect that urban areas produce in adjacent territories, by attracting new urbanisation (Murgante, Las Casas & Danese, 2007; Murgante, Borruso & Lapucci, 2011). In this case, it would be necessary to have as data about settlement development spread over as many points in time as possible. However, these are databases which are not yet very widespread in Italy and they are hardly homogeneous from a chronological viewpoint. This analysis could, however, be very significant, if implemented in areas surrounding conurbations which we can classify as "urban concentrators", that is to say more attractive for new settlements, being close to services and rich in employment possibilities.

The model described in this research could be useful in territories around the world, in particular where the urban pressure is high and the morphology has a strong impact.

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