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GIS method applied to estimate the cost of dry-built stone retaining masonry walls in application of the Tuscany Rural Development Plan 2007-2013

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Abstract

In compliance with the European Commission Reg.[EC] n°1782/03 articles 4 and 5, aiming at promoting sustainable use of agricultural land, the Tuscany Rural Development Plan [RDP] 2007-2013, includes the rehabilitation of countryside and quality of life in rural areas. The rehabilitation and preservation of retaining stone masonry walls [RSMW] for hydro-geological protection and preservation of local tradition, is one among the active implementations in response to the RDP recommendations. However, rehabilitation costs are very high and difficult to be determined. This paper aims at testing a methodology that allows generating, through Geographic Information System [GIS], a raster map geo-referencing RSMW in order to guide decision makers for a correct allocation of funds. A case study in the area of Pistoia in the region of Tuscany will allow testing the method and RSMW will be classified according to restoration cost.

Keywords: *sustainable rural development, retaining masonry walls, rehabilitation costs*

INTRODUCTION

The role of agricultural rehabilitation works undertaken for hydro-geological protection as well as for the preservation of local traditions is well acknowledged by the most significant documents dealing with rural policies [Pothumus, 2005, Sang-Arun et al. 2005]. Such endeavors are used to try to restore and to recover very important and costly works. This justifies why the rehabilitation of dry-built stone retaining masonry walls is one of the objectives of the Tuscany Rural Development Plan [RDP] 2007-2013. Furthermore, the past rural traditions of Tuscany's region play a part in making the exceptional beauty of its natural vernacular landscape for both tourists and residents.

The RDP includes four principal areas of intervention, and fundamentally aims at improving the environment, the countryside and quality of life in rural areas, and the diversification of rural economy. Particularly, through the second axis, the RDP aims at protecting the land, and preserving and sustaining the areas of substantial environmental value. The presence and state of preservation of a unique landscape, largely man-made, is an important aspect to consider in Tuscany. Urbanization and the expansion of production facilities or tourism are a major threat to Tuscany's landscape. Furthermore, Tuscany's hilly and mountainous topography, and the deteriorating effects of erosion combine to the emergency related to land management [PSR, Tuscany].

More particularly, this axis aims at achieving results able to complement and strengthen the minimum standards of compliance through investments with economic benefits, as well as through the dissemination of elements of the landscape [rows, hedges and small forest formations], of artifacts [non-productive investments] as ditches, and dry masonry retaining walls [PSR, Tuscany].

The demolition of walls and the desire to rehabilitate [renovation] them, as part of hydraulic to agricultural activities going beyond the compliance with the requirements of Rule 1782/03 EC, Art. 4 and 5 is one among the measures aiming at promoting the sustainable use of agricultural land [PSR, Tuscany].

The preservation of such works is undoubtedly important, however, the maintenance costs would be difficult to be determined, and the cost of rebuilding them from scratch is relatively too high [EAO&DO, 2001, Tenge, 2005]. Consistent with the highlighted importance by the PSR, of socio-economic and environmental preservation, this paper focuses on the monetary estimation of restoration costs of dry stone masonry retaining walls. More specifically this work aims at testing a methodology able to estimate restoration costs, through a preliminary measured survey of the dry masonry walls. The survey is based on determining the slope of the land and the type of soil in which these walls are built.

Through the implementation of a Geographic Information System [GIS] the dry stone masonry walls will be geo-referenced, surveyed and then divided according to the cost of their restoration. The aim is to develop a raster map able to guide the decision-maker choices for a correct allocation of funds.

Based upon the work of Bernetti et all. [2003], the work can be subdivided into two principal phases. In the first phase, a standard approach to the survey of terraces is adopted. In the second phase, a case study located in the province of Pistoia, is studied to develop raster maps, in which the terraces will be classified according to the basic cost of restoration.

MATERIAL & METHODS

The equation used to determine the width EH [formula 2] of the wall is directly proportional to the height and indirectly proportional to the slope of the land. Although, in reality this measure is uncertain since it tends to match the width of the dry masonry walls with the width of the property or with those of the slopes [5 Terre National Park, 2004].

$$EH = EV\ 100/D \qquad [2]$$

Where
EH = horizontal dimension [width]
To complete the survey of the wall the thickness [s] is to be measured. Based on the literature this dimension varies between 50 and 80 centimeters depending on the slope of the land [AA.VV, 1993]
Therefore, the volume of the walls is determined applying formula number 3:

$$Vm = [s \cdot EH \cdot EV] \qquad [3]$$

Where
Vm = volume of the retaining wall
s = thickness of the wall
EH = width of the wall
EV = height of the wall

Finally, to estimate the restoration cost of the wall, the cost of restoration per square meter must be multiplied by the volume of the same wall [formula 4].

$$C = Ci \cdot Vm \qquad [4]$$

Where
C = unit cost of wall restoration
Ci = cost of one cubic meter of restoration
Vm = volume of the wall

The implemented methodology tries to adapt the measured survey of the dry masonry wall proposed by Bertoni, Lomabrdi Neto, including within the cost of restoration of the wall the volume of the backfill soil, which also involves land movement and settlement, and are part of the terrace [figure 1].

Remodeling the land is a fundamental operation, and requires the calculation of an additional value, indicated with S. To develop a profitable agricultural surface, it is necessary to alter the surface of the topsoil through a series of cut and fill operations. The section of the terrace shows, in the backfill of the retaining wall, two layers of soil: the topsoil which was affected by the construction of the wall [cohesive and compact], and a layer of loose material made of excavation debris and replaced at the end [Parco Nazionale delle 5 terre].

Taking into consideration the above factor, the terrace could be approximated into the geometric figure below [figure2] representing a rectangular prism defined by the height of the wall [EV], the width of the wall [EH], and the depth of the terrace [S].

The adopted method is based on the formula developed by Bertoni and Lombardi in 1990. The method examines the slope of the land and the type of the soil in which the dry masonry walls were built. More specifically, it consists of an equation allowing to determine the height of the retaining wall EV [formula 1] and its width [EH].

Where [1]
EV = vertical dimension [height]
D = slope
K = coefficient defining the pedology or soil study [table 1]

The depth S of the terrace [formula 5] is a function of the slope of the land as the height of the wall.

$$S = EV \cdot tg\ \alpha \qquad [5]$$

Where
S = depth of the terrace
EV = height of the retaining wall
α = angle opposite to the slope of the land [γ] expressed in degrees

Introducing this parameter enables to extend the investigation beyond the cost of the single terrace. The cost of a single hectare of terraces' restoration could therefore be quantified: calculating the number of terraces in one hectare [formula 6] multiplied by the unit cost of terrace's restoration [formula 7].

$$N = 10000/A \qquad [6]$$

Where
N = number of terraces per one hectare
A = area of terrace [$S \cdot EH$]

$$Cha = C \cdot N \qquad [7]$$

Where
Cha = cost per hectare of terraces
C = unit cost of terrace's restoration
N = number of terraces per hectare

Moreover, it is possible to estimate the annual cost of terraces by applying the financial compensation mathematical formula [for an in depth study refer to Michieli 2002] taking into consideration a determined sample of relevance and a maximum durability of the same terrace [formula 8].

$$Cha/year = Cha \qquad [8]$$

Where
Cha/year = annual cost per hectare of terraces
r = relevant sample
q = 1+r
n = durability per number of years of the terraces
Case Study: geo-referencing the cost of restoration of retaining walls using GIS methodology.

Description of the area

The area of study is located to the North of Pistoia District, an area that underwent agricultural and rural exodus following the Second World War.

The territory of Pistoia is composed of three homogeneous geographic systems. These are referred to as the valley, the hill and the mountain. The hill and the mountain occupy a significant portion of the territory, 70% of the total administrative surface. The rest of the territory is occupied by the valley of the Ombrone Pistoiese River. The territorial land use is strongly conditioned by the geomorphologic nature of the different sites. Valleys are mainly occupied by Nurseries, an important economic activity of Pistoia. In addition, a considerable variety of forms and productive systems are found in the area's territorial structure, of valleys, hills, and mountains, which are strong elements of diversification and classification.

Nowadays, there are still activities related to the phenomenon of part-time, which over the years have allowed the preservation of agricultural practices, forestry and animal husbandry, of less economic importance, but essential in ensuring the conservation and protection of territory and local landscapes. Olive crop is among these, the most interesting; sharing an agricultural useable surface [SAU] equal to the surface of nurseries, and witnessing a substantial historical vocation of agriculture in the hills of the area of Pistoia. The landscape of the olive crop area is almost entirely made of terraces and occupied with small scale agriculture agencies of family scale. The Total Agricultural Surface [SAT] is approximately the 70% of the whole district surface. While, the cultivated agricultural area [SAU] is 47%, the rest of the area corresponds to the percentage of forests.

At the district level, nursing is a strongly entrenched activity covering approximately 32% of the total SAU, and having a considerable economic impact. It is also important to highlight that olive crop, which traditionally covered hilly areas, is maintained considerably in comparison to nursing activity [34% of the SAU]. 10% of the valley that used to be cultivated with sorghum, foxtail, millet and wheat is now cultivated with corn.

The hilly strip is characterized by moderate and steep slopes, rocky soil, shallow depth, often dry and low fertility soil. It is accordingly developed in terraces, and covered by traditional agriculture, prevalently intended for owners' families' consumption. Olive crop are the predominant agriculture, with irregular presence of meadow and arable land. The fields with olive trees extending over the entire surface of the area and reaching the edge of the forest, and the terraces supported by dry masonry walls and stepped embankments, all contribute noticeably to the definition of the hilly landscape.

The hilly areas are mainly covered by woodland. Chestnut cultivation for chestnut flour production is the most abundant species. The rest of the woodland heritage is concerned with biomass production. Though with some delay, the primary sector of Pistoia district is experiencing innovative agricultural activity with the proliferation of eco-friendly and organic farms. However, this phenomenon is still at its early stages and is minimally perceived within the hilly and mountainous structures of production, allowing for huge future expansion, and good prospects for marginal areas. Currently this process does not have any effect on the downward trends in the industry. Moreover, in the last decade the agricultural surface used has decreased lightly, along with the neglect of agricultural wood yards [especially olives] . Both the hydro-geological balance and the aesthetic values of the rural landscape are being endangered by this phenomenon. This is how the restoration of the terraces, though would seem to be costly, is variedly significant in securing hydro-geological protection, preservation of rural traditions, and territorial safeguard.

Terrace dimensioning

The implementation of a Geographical Information System [GIS] requires the use of thematic maps: The eco-pedologic map of the case study area, and the Digital Model of the Land [DTM] with a 20 meters pixel resolution. This is how the terraces were georeferenced and categorized according to their slope. As suggested by Landi [1999], the analysis considered exclusively the terraces included in typical slopes' arrangements varying between 25% and 50% [figure 3]. Approximately 468 hectares of terraced areas were examined.

In order to estimate the volume of terraces [Vm], the height [EV] of the dry masonry walls was calculated by applying the formulas proposed in section 2. To calculate the width [EH] of the walls, the pixel resolution scale was used. In other words 20 meters, considering that measure to be equal to the slope's width. The thickness of the dry wall [s] was measured in relation to the slope. The thickness of 0.5 meters was assigned to the walls reaching 30% slope, and 0.8 meters to those reaching 50% slope [table 2].

The 468 hectares of terraced areas analysed show that the height of terraces varies between 1.54 meters and 2.32 meters, characteristic of areas with steep slope [around 50%]. 79% of the latter [369 hectares] are less than 2 meters high while the remaining 21% [98 hectares] are more than 2 meters high. These values are considered in function of the slope of the area being studied, where 80% of the territory has a slope that varies between 25% and 405 [375 ha] while the remaining 20% [approximately 92 ha] slopes more than 40% [only 2.8 hectares have a slope of 50%].

The calculation of terraces' volume was used to determine the unit cost of the terraces [C]. A superimposition of the thematic layers was applied to calculate the depth of the terraces [S]. For that purpose, the maps representing the slope of the terraced zones and height of the terraces [EV] were used.

Looking into the Tuscany Region 2010 price list reference book, the cost of restoration of a retaining wall ranges between 60 and 80 euro per cubic meters. The cost includes workmanship, the reparation works of the wall [not to be considered built ex-novo due to the high cost] and the restoration works of the terraces above [essentially ground movements or settlements].

Restoration cost estimation

The cost of terraces per hectare [Cha] was calculated, by computing the number of terraces [N] through their area [A]. Table 3 shows examples relative to three different slopes of sandy soil.

Considering the width of a terrace equal to 20 meters, the table shows that the wall is estimated 1.54 meters high and 7.72 meters deep for a 25% slope. A volume estimated approximately 15.36 cubic has a unit cost of 921 euro, while the unit cost per hectares, taking into consideration 64 terraces around 154 square meters wide, is almost 59000 euro. It is obvious that on steeper slopes the cost would result sensibly higher: on a slope of 50%, the walls' height may reach 2.30 meters, a smaller depth of terraces [5.54 m], however, the resulting volume is larger [36.73 cm], and the unit cost of restoration is 2203 euro. Considering an area for each terrace of approximately 110 square meters, summing-up 90 terraces per hectare, the total cost per hectare would be over 198000 euro.

Finally, the depreciation that is expected, considering the duration of adjustments of 60 years and at an interest rate of 3.5% [as for example] was calculated. The cost of restoration of the terraces per hectare, per year was also calculated. This example is illustrated in figure 4 and table 4 including the three precedent examples already represented in table 3.

Table 4 shows for example the annual cost of a terrace on a 25% slope, taking into consideration the unit cost equal to 921 euro, would be annually 2364 euro per hectare. For a 50% the terrace annual cost would increase to 88.35 euro, and the annual cost per hectare 7951 euro.

CONCLUSION

The rural territory of Tuscany, as well as the rural national territory, play a very fundamental role from different points of view, ranging from the landscape to the prevention of hydro geological risks. The linear elements making this landscape are included within internal politics of agricultural heritage preservation, in the aim of combining the local traditions with the inevitable human progress. Retaining dry masonry walls, being considered as valuable landscape elements, find within the Rural Development Plan measures aiming at their maintenance, preservation, and recovery.

More particularly and as per the D.G.R. n. 923/06 within the development plan zone ZPS it is forbidden: removing traditional natural and semi-natural elements of the agro-ecosystems such as ponds, drinking pits, ditches, dry stone walls, hedges, rows of trees, reeds, springs, and fountains [PSR Tuscany]. The implementation of such measures, in the case of dry retaining masonry walls, wakes it expensive and difficult for the decision maker to properly allocate available financial resources.

This work aims at quantifying the restoration and maintenance cost of dry retaining masonry walls, through the application of a Territorial Information System. The development of thematic maps allowed to automatically calculate the dimensions of the dry retaining masonry walls. The overall aim is to classify the restoration works based on their cost of recovery, by overlapping the thematic layers. More specifically, in the present case study, 468 hectares terraced areas in the province of Pistoia have been georeferenced. The cost of restoration was estimated to vary between 58970 euro per hectare to exceed 198000 euro per hectare on extreme slopes [50%].

This estimation could play a key role in the allocation of funds considering the recent developments in EU policies. Particularly, the Rural Development Plan anticipates agro-environmental payments focused on the environmental development and its aesthetic component-the landscape. This can be achieved by acting on the agricultural land uses that play a principal role in the developmental scenarios of the territory. The preservation and restoration of the dry masonry retaining walls is in line with the PSR measures, by preventing hydro-geological soil settlements, participating to the stability of the slopes, limiting soil erosion, and safeguarding soil's fertility [PSR, Tuscany]. Furthermore, these measures add value to the landscape, becoming part of the evolution history of a determined territory, and conserving the Tuscan landscape, which is always under threat of degradation. The threat is the same in other territories, and is due to the oversimplification of production systems, and neglect of farming activity in marginal areas [PSR, Tuscany]. The payments mentioned previously are intended to be compensated to agricultural investors for the management of the territory and the implementation of five years basis interventions, necessary to achieve the above objectives. Lump-sum payments are paid on a yearly basis to compensate for any loss of revenues or increased costs.

The present work within this perspective stands as a possible tool supporting decisions giving the possibility to estimate recovery costs and especially to highlight areas where these costs are greater.

REFERENCE

AA.VV. 1993 - Manuale tecnico di ingegneria naturalistica. Regione Emilia Romagna, Regione Veneto.

Bagnaresi U., 2000 - La valutazione del paesaggio rurale - Terra e vita n°5, pp 69-72.

Bernetti I., Franciosi C., Lombardi G. V., 2003 - Il contributo dell'agricoltura multifunzionale alla conservazione dell'equilibrio idrogeologico - Atti del XL convegno Sidea "La liberalizzazione degli scambi dei prodotti agricoli tra conflitti e accordi. Il ruolo dell'Italia", Padova 18-20 settembre, pp 397-409.

Bernetti I., 2006 – Modelli di valutazione ambientale – in "Risorse naturali e ambiente" a cura di Silvio Menghini, AdArnum, Franco Angeli editore.

Bernetti I., Fagarazzi C., 2002 - L'impiego dei modelli multicriteriali geografici nella pianificazione territoriale – Aestimum dicembre 41, pp 1-26.

Bertoni, J, Lobardi Neto, F., 1990 - Conservação do Solo - São Paulo: Iconi, 3a edição. 355 p.

Brunori G., 1995 - La valutazione degli spazi rurali: una strategia di intervento - Genio Rurale n°11.

Cortellessa C. M., 1994 - Breve Corso sul GIS - Supplemento ai numeri 5/93, 1/94, 2/94, 3/94, 4/94 di Mondo AutoCAD.

Distasio M., 1997-1998 - L'economia del paesaggio rurale - Agrobusiness Paesaggio & ambiente n°1.

Environmental Affairs Office and Design Office, 2001 – A Case of Benefit-Cost Analysis : Soil Bioengineering as an Alternative for Roadside Management - Washington State Department for Transportation.

Falqui E., 1990 - Verso la pianificazione ambientale - Angelo Guerini e associati s.r.l. editore pp 115-173.

Ferrucci D., 1999 - Applicazione di un GIS per il confronto e l'integrazione di cartografie di uso del suolo - Genio Rurale n°5, pp 55-63.

Landi R.,1999 - Agronomia e ambiente - Edagricole, Bologna.

Maciocco G., 1991 - La pianificazione ambientale del paesaggio - Franco Angeli editore, cap 1, 2.

Michieli I., Michieli M., 2002 - Trattato di estimo - Edagricole, Bologna.

Parco Nazionale delle 5 terre, 2004 – Manuale per la costruzione dei muri a secco – (On line) Progetto LIFE 00 ENV/IT/000191 PROSIT, Pianificazione e recupero delle opere di sistemazione del territorio costiero delle Cinque Terre, Website http://www.alpter.net/IMG/pdf/MANUALE-2.pdf (retrieved on 7 october 2010).

Pearce D., Turner, K., 1991 – Economia delle risorse naturali e dell'ambiente – Il Mulino editore.

Posthumus E., 2005 – Adoption of terraces in the Peruvian Andes - Website http://library.wur.nl/wda/dissertations/dis3843.pdf (retrieved on 26 october 2010).

Regione Toscana, 2010 - Ambiente e territorio: difesa del suolo - Website http://webtrial.regione.toscana.it/WebEP/GetProvincePrezziario.do?prezcod=1 (retrieved on 11 october 2010).

Regione Toscana, 2005 - Programma di sviluppo rurale della regione toscana per il periodo 2007/13 – Firenze.

Sang-Arun J. et al., 2005 – Soil Erosion and Participatory Remediation Strategy for Bench terraces in Northern Tthailand – Website http://www.elesevier.com/locate/apgeog, Applied Georgraphy 25 348-366 (retrieved on 26 october 2010).

Schenone C., 1997 - Sistemi Informativi Territoriali - Gruppo Editoriale Futura Milano.

Tenge A. J. et al., 2005 – Financial Efficiency of Major Soil and Water Conservation Measures in West Usambara Highlands, Tanzania – Website http://www.elesevier.com/locate/apgeog, Applied Georgraphy 25 348-366 (retrieved on 26 october 2010).

Table 1.coefficient defining the pedology

TYPE OF SOIL	K
SAND SOILS	0.835
CLAY SOILS	0.954
RED SOILS	1.212

Table 2. Wall section as per slope

Slope (%)	Thickness of wall (meters)
25	0.5
30	0.5
35	0.6
40	0.7
45	0.8
50	0.8

Table 3. Computation of the cost of dry retaining masonry wall built on sandy soil

Slope *D (%)*	**Weight** *EV(m)*	**Width of terrace** *EH (m)*	**Depth** *S (m)*	**Area** *A (sqm)*	**Volume** *Vm (cm)*	**Unit cost** *C (€)*	**Number per hectare** *N (n/ha)*	**Cost per hectare** *Cha (€/ha)*
25	1.54	20.00	7.72	154.41	15.36	921.41	64.00	58.970.17
35	1.87	20.00	6.62	132.37	29.87	1.791.95	75.00	134.396.49
50	2.30	20.00	5.54	110.84	36.73	2.203.79	90.00	198.340.91

Table 4. Annual cost of dry retaining masonry wall built on sandy soil

Slope *D (%)*	**Unit cost** *C (€)*	**Terrace annual cost** *€/year/terrace*	**Cost per hectare** *Cha (€/ha)*	**Annual cost per hectare** *€/year/terrace*
25	921,41	36,94	58.970,17	2.364,03
35	1.791,95	71,84	134.396,49	5.387,77
50	2.203,79	88,35	198.340,91	7.951,21

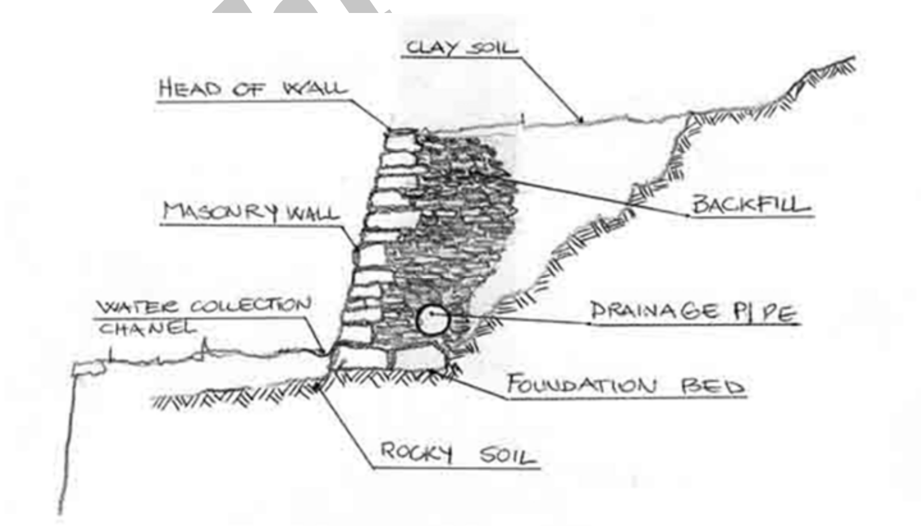

Fig1. Transversal section of a retaining dry wall *Source: Parco Nazionale delle 5 Terr Manuale per la costruzione dei muri a secco*

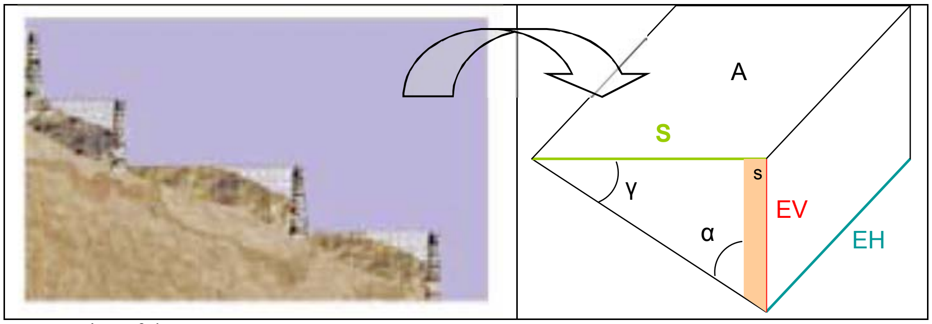

Fig2. Geometric representation of the terrace

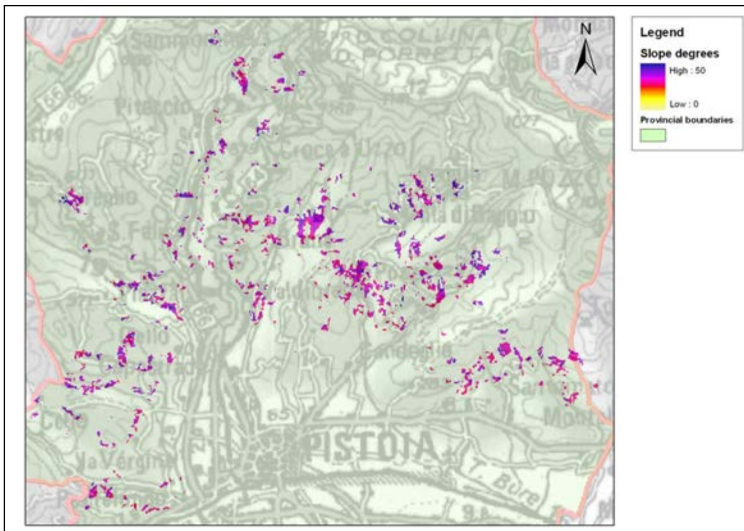

Fig3. Subdivision of terraces according to slope percentage

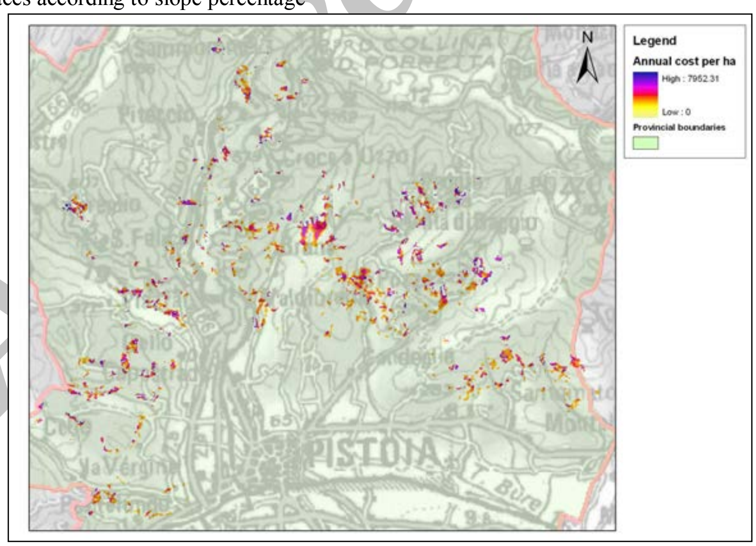

Fig4. Cost of terraces per hectare