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Research Article

Numerical Modelling of Soil Erosion Susceptibility in the Maltese Islands using Geographic Information Systems and the Revised Universal Soil Loss Equation (RUSLE)

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Abstract. The Mediterranean region is subject to various factors that exacerbate soil erosion pressures. Such factors include agricultural land fragmentation and abandonment, unsustainable agricultural practices and rapid urbanisation. Soil erosion in the Maltese Islands has been identified as a predominating land degradation process and a major threat to the sustainability of the agricultural sector. The small scale of the Maltese Islands facilitates an in detail national study of soil erosion processes and contributing socio-economic dynamics. The research methods, erosion rate values and controlling dynamics discussed in this work have a particular relevance to the Mediterranean area.

1 Introduction

Soil erosion is triggered by a combination of natural and anthropogenic factors that include steep slope gradients, intense precipitation, low vegetation cover and inappropriate land use (Renschler, Mannaerts & Diekkrüger, 1999; Wischmeier & Smith, 1978). Prolonged erosion leads to an irreversible loss of ecological and agricultural soil function and associated ecosystems services. Erosion reduces agricultural productivity, posing limitations to sustainable agricultural use. The aspect of soil erosion that causes most concern is the loss of topsoil, the most fertile part of the soil profile (Gobin et al., 2004).

The Global Assessment of Human-induced Soil Degradation (GLASOD) map estimates that 114 million hectares are affected by human-induced soil erosion (Oldeman, Hakkeling & Sombroek, 1991). The principal drivers of soil erosion in the European Union are unsustainable agricultural practices, overgrazing, deforestation and construction activities (Oldeman et al., 1991). The Mediterranean region is particularly susceptible to erosion (EEA, 1999). High erosion rates, in conjunction to slow soil formation, lead to irreversible reductions of Mediterranean soil quality and quantity.

The Maltese Islands (Figure 1) are located in the centre of the Mediterranean Sea. The Islands have a total land area of 316 km^2 and comprise three main islands, Malta, Gozo and Comino, and a number of outlying islets.

Figure 1: Map of the Maltese Islands (from (Ezilon, 2009))

The Maltese Islands have a semi-arid Mediterranean climate, with mild, wet winters and hot, dry summers. The average annual rainfall is around 524 mm and the average yearly temperature is 22.5 °C. Rainfall is characterised by storms of high intensity and relatively short duration (Government of Malta, 2002).

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The Maltese Islands, and indeed the rest of the Mediterranean, are subject to various local factors which exacerbate soil erosion pressures. Such factors include agricultural land fragmentation and abandonment, limited soil agriculture suitability, unsustainable agricultural practice, rapid urbanisation, limited water resources and rapidly modernising social structure. As a consequence of the above interacting factors, soil erosion has been identified as a predominating land degradation process and a major threat to the sustainability of the agricultural sector (Tanti, Role, Borg & Calleja, 2002).

Maltese soil erosion risk modelling predating this article consisted of a numerical model developed by Tanti et al. (2002) assessing the northwestern region of Malta. The model identified areas threatened by soil erosion on the basis of geological substrate, slope, retaining rubble walls state and land cover. Model results clearly indicated that the assessed area was subject to high soil erosion rates (Tanti et al., 2002).

Presently, a large variety of empirical, semi-empirical, and physical process-based soil erosion risk models are available (Gitas, Douros, Minakou & Silleos, 2009; Erkal & Yildirim, 2012). The most widely applied empirical model (Fistikoglu & Harmancioglu, 2002) for assessing soil erosion by water driven mechanisms is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978). The USLE and its revision RUSLE (Renard, Foster, Weesies, McCool & Yoder, 1997) apply more than 40 years of experimental field observations gathered by the Agricultural Research Service of the USDA (Novotny & Olem, 1994). The RUSLE is applied is this study.

The dynamic relationship between human activities and resulting soil erosion requires that erosion be monitored. Regular monitoring allows competent authorities to appreciate the influence policy and land use change mechanisms have on soil erosion. Our study aims to provide quantitative estimates of soil erosion by water of the Maltese Islands for the year 2013. The discussion section examines the interaction between the socio-economic situation and consequent effects on soil erosion. This approach ties environmental science to policy issues and provides an integrated approach through which professionals and government may prioritise and present context specific erosion control measures. In this framework, high erosion risk areas are singled out, the physical, socio-economic and policy mechanisms influencing the area identified, and erosion control measures, via policy and physical intervention, suggested and implemented to reduce risk.

2 Methods

The RUSLE technique was applied and built into a GIS-based model. Relevant model input parameters were prepared separately and stored as GIS vector layers. Five vector layers, each representative of RUSLE factors, were converted to raster layers with a grid resolution of 50 metres. Each cell has a value representative of the area's factor value. Each raster layer was then combined in the GIS model to calculate soil loss for each cell in the study area for the year 2013. The predicted soil losses were verified against field observations of soil erosion made at the end of the 2013 winter season. The section below discusses the method followed to obtain the five RUSLE factor values.

2.1 RUSLE factors

The factors assessed in the RUSLE are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management practices (C) and conservation practices (P) (Wischmeier & Smith, 1978). These factors are combined in a numerical formula (equation 1). The computation returns soil loss per unit area, equivalent to predicted erosion in $\mathrm{ton\,hectare^{-1}\,year^{-1}}$ (Gitas et al., 2009).

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A = average annual soil loss ($\mathrm{t\,ha^{-1}\,yr^{-1}}$), R = rainfall/runoff erosivity ($\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}yr^{-1}}$), K = soil erodibility ($\mathrm{t\,h\,MJ^{-1}mm^{-1}}$), LS = slope length and steepness (dimensionless), C = cover management (dimensionless), P = support practice (dimensionless)

2.1.1 Rainfall Erosivity (R factor)

Rainfall erosivity is a climatic factor that takes into account the erosive capacity of rainfall (D'Odorico, Yoo & Over, 2001; Le Bissonnais, Montier, Jamagne, Daroussin & King, 2002). The factor is determined as a function of total storm kinetic energy (E) and its maximum 30-min intensity (Imax30) (Wischmeier, 1959; Wischmeier & Smith, 1958).

The authors refer to the method employed by (Iraldo et al., 2013) in the calculation of the Maltese R factor. Iraldo et al. (2013) applied a modification of the Fournier index F, developed by (Arnoldus, 1980), the modified F index (F_F) (Ferro, Porto & Yu, 1999) (equation 2). The method uses average monthly ($\mathrm{p_{ij}}$) and annual precipitation (P). This approach is thought to be better correlated with rainfall erosivity.

$$F_F = \frac{1}{N}\sum_{j=1}^{N}\sum_{i=1}^{12}\left(\frac{\mathrm{p_{ij}^2}}{\mathrm{P_j}}\right) \tag{2}$$

where $\mathrm{p_{ij}}$ is the rainfall in month (mm) of the year j and P is the total rainfall per year.

Iraldo et al. (2013) calculate the F_F index using rainfall data for Malta (http://www.maltaweather.com) over the period 1985–2012. The R value was estimated using the average of R: F_F relationships adapted for Sicily (Ferro et al., 1999; Renard & Freimund, 1994). $R = 0.612\,F^{1.56}$ (Sicily). The R factor value defined by Iraldo et al. (2013) for Malta was 832.16 MJ mm $\text{ha}^{-1}\,\text{h}^{-1}\,\text{yr}^{-1}$.

2.1.2 Soil erodibility (K factor)

Soil erodibility expresses the intrinsic capacity of the soil to be eroded and reflects the effect of the average long-term soil profile response to rainfall and runoff erosion. The main soil properties affecting K are soil texture, organic matter, structure, and soil permeability (Erkal & Yildirim, 2012). High organic content decreases soil erodibility (F.A.O, 1996).

An extensive national soil survey, assessing over three hundred data points in a grid distribution of 1 km spacing, was carried out in 2002 (MALta Soil Information System, 2003). Amongst other soil parameters, the survey defined organic matter content and texture. Following Table 1, the MALSIS (2002) data set was used to define two hundred and sixty eight K factor values (Figure 2) for the Maltese Islands. Soil erodibility factor (K) value varies from 0.12 to 0.6 t ha h $\text{MJ}^{-1}\,\text{mm}^{-1}$ and the mean value is 0.29 t ha h $\text{MJ}^{-1}\,\text{mm}^{-1}$.

Table 1: K values as they were calibrated according to specific soil parameters

Textural classes	Organic matter less than 2 %	Organic matter more than 2 %
Clay	0.24	0.21
Clay Loam	0.33	0.28
Coarse Sand Loam	/	0.07
Fine Sand	0.09	0.06
Fine Sandy Loam	0.22	0.17
Heavy Clay	0.19	0.15
Loam	0.34	0.26
Loamy Fine Sand	0.15	0.09
Loamy Sand	0.05	0.04
Loamy Very Fine Sand	0.44	0.25
Sand	0.03	0.01
Sandy Clay Loam	/	0.20
Sandy Loam	0.14	0.12
Silty Loam	0.41	0.37
Silty Clay	0.27	0.26
Silty Clay Loam	0.35	0.30
Very Fine Sand	0.46	0.37
Very Fine Sandy Loam	0.41	0.30
Loamy sand	0.05	0.04
Silt	0.43	0.60
Sandy clay	0.10	0.14
Clay and heavy clay	0.24	0.21

The data points were then interpolated following GIS kriging method. The resulting GIS layer was converted to a raster map with a grid resolution of 50 metres. Each cell has a value representative of the area's K factor value (Figure 2).

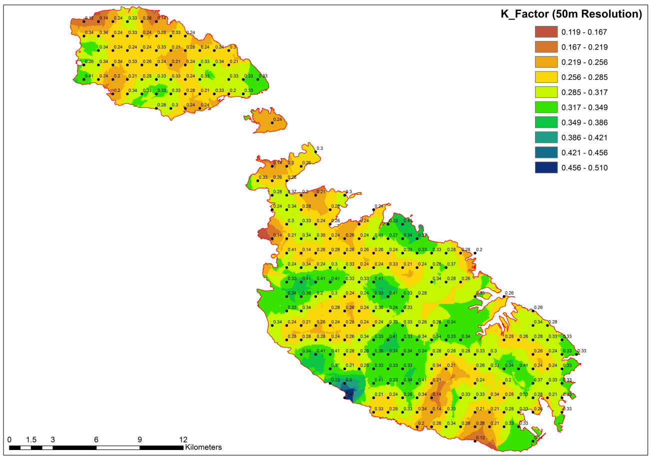


Figure 2: K factor raster map showing K factor values.

2.1.3 Slope length and steepness (LS factor)

Slope length and steepness reflect the proportional effect topography has on erosion (Foster & Wischmeier, 1974; Wischmeier & Smith, 1978). For this study, the LS factor was computed from a Digital Elevation Model (DEM) with the ArcGIS Spatial Analyst extension. The LS factor was calculated at a 10 m horizontal spacing from a 1:1500 scale topographic DEM following equation 3.

$$LS = \left(\frac{\text{Slope} - \text{length}}{22.1}\right)^{0.5} 0.065 + 0.0456(\text{slope}) + 0.00654(\text{slope})^2 \tag{3}$$

where Slope−length is in meters and slope is in %.

The computed LS factor GIS layer was converted to a raster map with a grid resolution of 50 metres. Each cell has a value representative of the area's LS factor value (Figure 3).

2.1.4 Crop and Vegetation management (C factor)

The management factor reflects the effect cropping and management practices have on erosion rates. The C factor is closely linked to land-use types and is a factor in soil erosion vulnerability (Wischmeier & Smith, 1978; Beskow et al., 2009). For this study, the C factor of the study area was obtained from a high resolution aerial orthophoto set produced in June 2012. The orthophoto data set was manually interpreted by the author, a land cover expert (Figure 4). Ground truthing surveys and

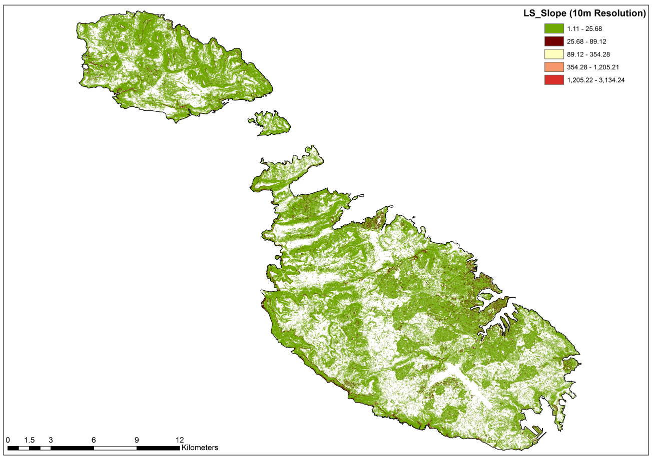


Figure 3: *LS* factor raster map.

land cover reports were consulted as a means of ensuring correct orthophoto land cover interpretation. A minimum mapping unit of 10.000 m^2 was applied following a classification system compliant to the CLC 2006 technical guidelines. A number of additional layers were defined in view of the large scale of orthophoto interpretation (1:5000). Maltese Island cover was divided into twenty two land-use types (Figure 4).

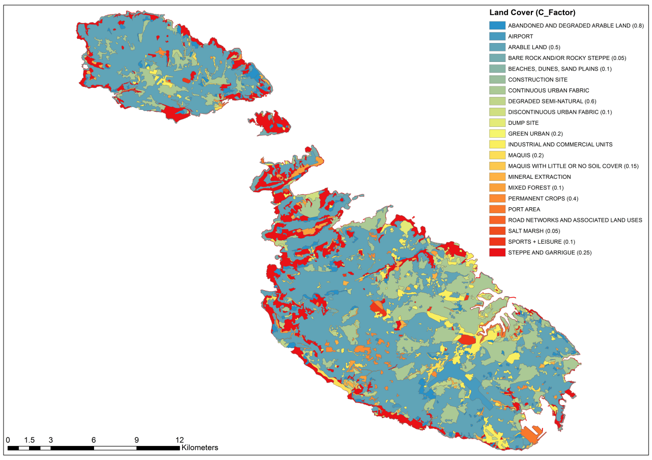


Figure 4: Detailed map showing spatial distribution of land use and cover in the Maltese Islands.

C factor values, corresponding to land cover classes (Table 2), were defined following expert defined descriptions (e.g., Wischmeier and Smith (1978), Morgan (1995), Pasák, Janeček and Šabata (1983), Alena (1991), Malíšek (1992). The classification scheme excludes urbanised areas, bare rocks and water surfaces from evaluation since these surfaces contain no soil. Discontinuous urban, green urban (semi-permeable surfaces), mixed forest (moderate soil cover), maquis (with little to no soil cover), beaches, dunes, sand plains, rocky steppe and salt marshes as cover types of good management practice with a *C* factor value of less than 0.1. Maquis (with moderate soil cover), green urban (semi-permeable surfaces), sports and leisure (semi-permeable surfaces), pastures and permanent crops are categorised as land cover of moderate management practice with a designated *C* factor value between 0.11 and 0.4. Arable land, abandoned and degraded agricultural areas, and degraded semi-natural areas are categorised as land cover or low management practice of *C* factor values between 0.41 and 0.8. Land-use classes were allocated *C* values without considering seasonal variance.

Agricultural practice is of particular relevance when defining agricultural *C* factor. A large portion of Maltese arable soils are exposed, have no vegetation cover, and are deep-ploughed in anticipation of the first torrential September rains (RDP, 2007–2013). This agricultural practice intensifies water erosion and, as a consequence, a high *C* factor value was assigned to areas covered by arable land. Abandoned/ degraded agricultural areas and degraded semi-natural areas have the highest *K* factor values. Vegetation cover in these areas is often entirely removed to accommodate bird trapping, parking and other such activities that contribute towards accelerated soil erosion.

The land cover dependent *C* factor values were mapped in GIS. The resulting layer was converted to a raster map with a grid resolution of 50 metres. Each cell has a value representative of the area's C factor value (Figure 5).

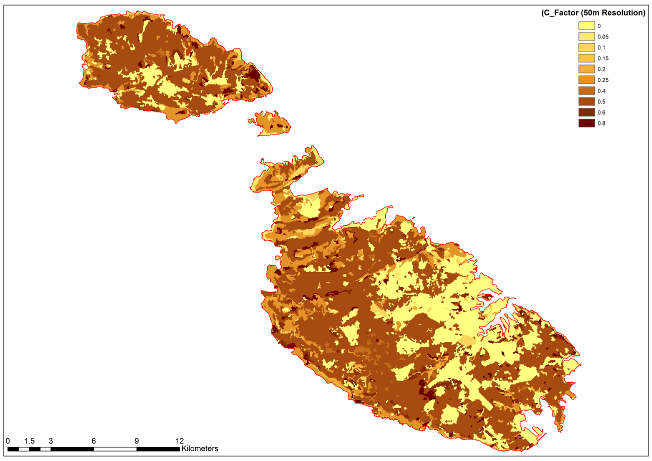


Figure 5: *C* factor raster map.

2.1.5 Erosion control (*P* factor)

Erosion control represents the effects various practices have on preventing soil erosion by water runoff. Wischmeier and Smith (1978) discuss that control structures, which include *inter alia* improved tillage

Table 2: Land-use classes, cover in km^2 and allocated C value (land-use listed below only includes those with a C value)

Land cover type	Cover km^2 (% of total land)	C factor value
Discontinuous urban	3.36 (1.06%)	0.10
Green urban (semi-permeable surfaces)	0.26 (0.08%)	0.15
Sports + Leisure (semi-permeable surfaces)	1.95 (0.62%)	0.20
Arable land	164.50 (52.1%)	0.50
Permanent crops	2.91 (0.92%)	0.40
Abandoned + Degraded Agricultural areas	9.56 (3.03%)	0.80
Mixed forest (moderate soil cover)	4.20 (1.33%)	0.10
Steppe + Garrigue	36.07 (11.42%)	0.25
Maquis (with moderate soil cover)	4.69 (1.49%)	0.20
Maquis (with little to no soil cover)	0.08 (0.03%)	0.15
Beaches, dunes, sand plains	0.12 (0.04%)	0.10
Bare rock / rocky steppe (little to no soil cover)	5.83 (1.83%)	0.05
Degraded semi-natural areas	7.28 (2.31%)	0.60
Salt marshes	0.15 (0.05%)	0.05

practices, strip cropping and terraces, should significantly contribute towards erosion control and frequently provide the major control in a farmer's field. The lower the P values, the more effective the conservation practice is deemed to be in reducing soil erosion (Erkal & Yildirim, 2012).

Appropriate farming practices may positively influence countryside and landscape quality, and sustain key environmental resources such as biodiversity, soil and water. Terraced agricultural fields are recognised as a characteristic feature of Mediterranean landscapes (Whitelaw & French, 1999; Frederick & Krahtopoulou, 2000; Grove & Rackham, 2001; Price & Nixon, 2005). Terraces adjust hillslopes into stepped, contour parallel, agricultural units of relatively flat ground suitable for cultivation. In the Mediterranean, terrace construction has typically involved the use of interlocked dry stone risers, rubble walls. These walls act as retainers to support back-lying beds of level soil. Although the original purpose of terrace construction is the increase of agricultural areas, these structures provide a necessary means of soil erosion control (Bevan & Conolly, 2011).

Maltese agricultural practices have significant control on agricultural land susceptibility to degradation and soil erosion. Tanti et al. (2002) identify retaining rubble walls in terraced fields as the most important water and soil erosion control method structures in the Maltese Islands (Tanti et al., 2002). Contour ploughing was also identified as a key erosion mitigation practice.

A national survey was conducted by the author over four months, starting in June 2013. The survey assessed rubble wall state following a classification scheme consisting of three potential rubble wall states. In this classification scheme, rubble walls in a good state contain a maximum of 1 breach showing half of the soil profile; rubble walls in moderate state contain more than 1 breach, but no more than 3, showing half of the soil profile, and rubble walls in a poor state contain more than 3 breaches showing half of the soil profile or 1 or more that show the whole soil profile. Each state is attributed P factor values; good state P factor value 0.3, moderate state P factor value 0.5, and poor state P factor value 0.7. The resulting GIS rubble wall state layer was converted to a raster map with a grid resolution of 50 metres. Each cell has a value representative of the area's P factor value (Figure 6).

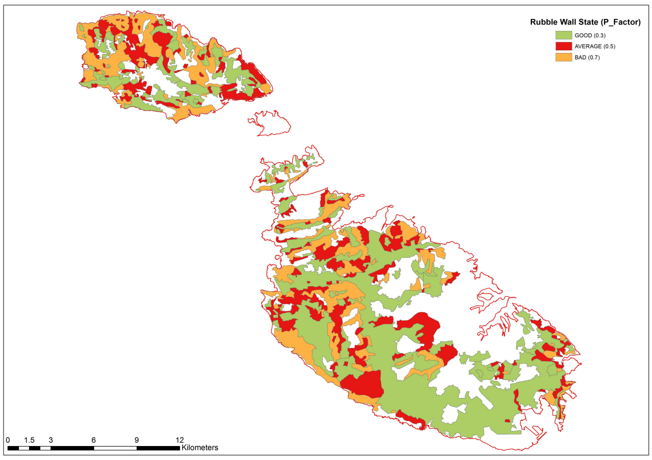


Figure 6: P factor raster map. Blank (white) areas represent urban areas or areas that contain no rubble walls.

3 Results

3.1 Computed soil loss

The average annual soil loss was computed on a cell-by-cell basis following equation 1. The five factor raster maps representing R, K, LS, C and P factors, were overlain and multiplied with the ArcGIS Spatial Analyst extension. The erosion map (Figure 7) shows the spatial distribution of soil loss in the Maltese Islands expressed as annual average soil loss in tonnes per hectare per year. The values should however be considered in a comparative manner rather than absolute values. This is due to the generalisation of the used input data as well as the nature of the model.

In order to obtain a better general understanding and be able to carry out a National comparison, the quantitative output of soil loss prediction was classified in eight categories of increasing soil loss severity: < 1 (none), 1 to 2, 2 to 5 (very low), 5 to 10 (low), 10 to 25 (moderate), 25 to 45 (high), 45 to 75 (very high), $> 75\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ (severe). Erosion severity thresholds are consistent with those presented by various experts (e.g., Iraldo et al. (2013)). Such a classification is consistent with the RUSLE model's role as a conservation management tool, where relative comparisons among areas are more significant than any assessment of the absolute soil loss in a particular location.

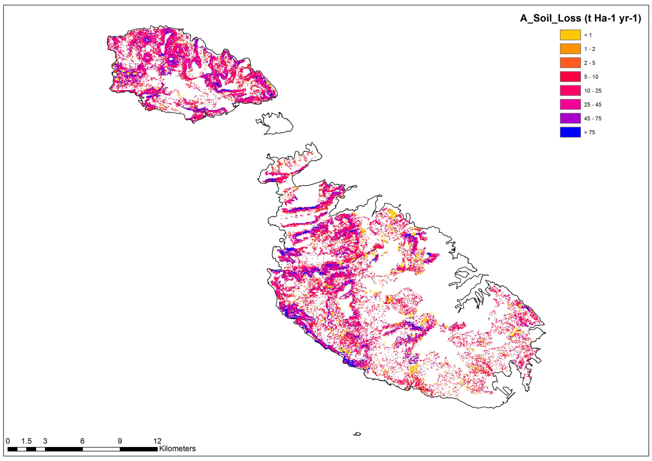
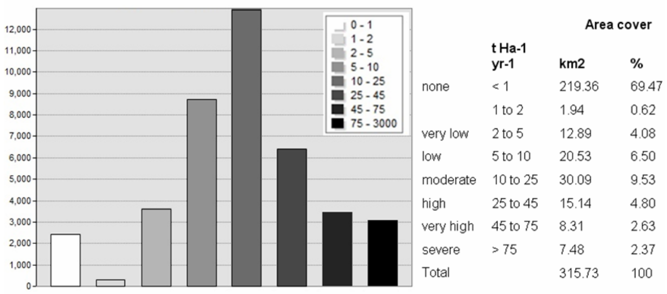


Figure 7: Average annual soil loss ($\mathrm{t\,ha^{-1}\,yr^{-1}}$) in the Maltese Islands following RUSLE equation.

3.2 Areas at risk

Calculated National annual soil loss (Figure 7 and 8) indicates that $61.01\,\mathrm{km^2}$, $19.33\,\%$ of total National land area, are at risk of moderate (10 to $25\,\mathrm{t\,ha^{-1}\,yr^{-1}}$) to severe ($> 75\,\mathrm{t\,ha^{-1}\,yr^{-1}}$) soil erosion.



		Area cover	
	t Ha-1 yr-1	km2	%
none	< 1	219.36	69.47
	1 to 2	1.94	0.62
very low	2 to 5	12.89	4.08
low	5 to 10	20.53	6.50
moderate	10 to 25	30.09	9.53
high	25 to 45	15.14	4.80
very high	45 to 75	8.31	2.63
severe	> 75	7.48	2.37
Total		315.73	100

Figure 8: Soil loss potential histogram. X-axis number of cells ($2500\,\mathrm{m^2}$) showing erosion values that fall within erosion rate categories, Y-axis soil erosion rate categories.

4 Discussion

Maltese central and north-eastern areas show the lowest erosion risk. These areas are characterised by relatively flat topographies, good land management and erosion control measures. Maltese north-western and Gozitan areas are characterised by a large range in erosion rates. Within this area, low erosion risk occurs in plateaus comprising low topographic gradients, and the application of good land management and erosion control measures. Plateau flanks typically consist of exceptionally high erosion rates, characterised by high topographic gradients, inappropriate cultivation practices and poor erosion control measures. Steeply inclined plateau flanks demonstrating low erosion risk are associated with areas demonstrating adequate vegetation cover, and effective management and conservation practices.

The spatial pattern of modelled potential soil erosion (Figure 7) is clearly proportional to slope gradient. Field work and national reports also identify land use (C factor) and control measures (P factor) as being critical. The highest estimates of quantitatively measured and predicted erosion rates occur in steeply inclined arable land where poor management and conservation practices are applied (e.g., Tanti et al. (2002).

A large portion of Maltese arable soils are exposed, all vegetation cover is removed and deep-ploughed in anticipation of the first torrential September rains. This agricultural practice intensifies water erosion. The author proposes that strip contour ploughing, where vegetation cover is retained between ploughed areas, is applied to reduce water induced soil erosion. Field evidence also clearly identifies agriculture retaining rubble walls as a key soil erosion control method in steeply inclined agriculture areas. The reasons leading to inappropriate agricultural practices, and consequent soil erosion, are closely tied to the National socio-economic situation often common to the Mediterranean region.

Agricultural land ownership is a key issue in the

Maltese Islands. Two thirds of the agricultural land is owned by the State and the remaining one-third by the private sector. Eighty percent of cultivated agricultural land is rented and twenty percent is occupied by owners or under a freehold basis (National Statistics Office, 2003). In accordance with the Agricultural Leases (Re-letting) Act drawn up in 1967, government and privately owned land is automatically re-let to the existing tenant or descendants. Law impedes the eviction of tenants or any substantial increases of rent, even on privately owned land. Given the low prices at which land is rented and prospects of strong land speculation, both tenants and private landowners tend to hold on to leased land. This situation has significant national consequences. Should leased agricultural land not provide a significant source of income, the arable land may be disused or used for other purposes. This process leads to accelerated land degradation and reduces the economies of scale potential, reduced production, of the Maltese agricultural sector (Rural Development Plan, 2007–2013).

Statistical results from the 2010 census indicate that seventy four percent (9.203 ha) of all agricultural holdings cover less than one hectare (census, 2010). Significantly contributing to this issue is land fragmentation, brought about by inheritance and parcel sale. This process significantly reduces the total exploitable land and thus diminishes economic viability of agriculture production. This may consequentially lead to land abandonment or change in land use.

Land abandonment may also be the consequence of increased international agricultural product cost competitiveness. Mediterranean agriculture is faced with severe limitations in this area. Naveh (1991) estimates that more than half of Mediterranean land is of marginal economic agricultural potential, characterised by steep, rocky uplands and poor soils. This setting often presents insurmountable economic obstacles for the introduction of modern agricultural techniques necessary in modern markets (Pinto Correia, 1993). For the Mediterranean regions, the trend towards land abandonment is accentuated by increasing competition with the highly productive agriculture of northwestern Europe (Pinto Correia, 1993). Agricultural activity survived in the Maltese Islands in the past fifty years as a result of protective measures, namely price guarantees and quota restrictions on imports, aimed at encouraging production by ensuring a regular income flow for local farmers. Maltese entry to the EU (2004) led to the dismantling of various protective levies and extensive sector restructuring to adhere to EU legislation (RDP, 2007–2013). These developments adversely influenced net farmer income. As a consequence, landowners may have to sustain net income through alternative employment, leading to reduced land management and land degradation. When agricultural exploits do not produce a source of revenue, farmers may also resign and abandon the area altogether.

The socio-economic conditions discussed above, agricultural land ownership, increased international agricultural product cost, agricultural holding size and land fragmentation, constrain net farm income. The generation of income via agricultural practices is central to understanding whether agricultural land is used and invested upon or abandoned and erosion processes potentially intensified.

The effects of land abandonment on soil quality and soil erosion may be either positive or negative. The key control on soil regenerative capacity is vegetation cover, controlled by climatic conditions and soil quality. Numerous authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (e.g., Elwell and Stocking (1976), Lee and Skogerboe (1985), Francis and Thornes (1990). Consequently, should the applied agricultural management practices have been unfavourable, the re-establishment of natural vegetation cover may reduce soil erosion. Central Mediterranean climatic conditions, dry summers reduce vegetation cover and winter flash floods exacerbate soil erosion, however do not favour natural vegetation reclamation. Another key parameter, significantly contributing to soil erosion in terraced fields, is the degradation of soil retaining rubble walls.

Soil retaining rubble walls in terraced fields are anthropogenic structures characteristic of sloped Mediterranean agricultural areas. Although the original purpose of terrace construction is the increase of agricultural areas, these structures provide a necessary means of soil erosion control (Bevan & Conolly, 2011). In Malta, significant expanses of garrigue were reclaimed for agricultural use; rubble material was used for levelling, topped-off with soil and retained by rubble walls (Rural Development Plan, 2004-2007). Under natural conditions, these soils would not accumulate in such areas, and given the opportunity, gravitational processes would transport soils to more stable areas. Unfavourable climatic conditions hinder natural vegetation reclamation and as a consequence, once rubble walls are breached and not restored, intensive soil erosion occurs.

The Maltese National survey, carried out by the author assessing land use (Figure 4) and rubble wall state (Figure 6), concludes that the majority of agricultural terraces on inclined surfaces are disused and retaining rubble walls in a derelict state. These steeply inclined agricultural fields show the highest National soil erosion rates (Figure 7). These areas are subject to various socio-economic conditions that constrain net farm income. Such hindering conditions include agricultural land ownership legislation, increased international agricultural competition, agricultural holding size and land fragmentation. In the Maltese Islands, these fields, of limited size, low accessibility, and requiring high rubble wall maintenance, may have once been economically exploitable. However, with changes in socio-economic dynamics, the economic incentive for tending these marginal fields was lost and the fields abandoned. It is proposed that in most cases, these socio-economic factors, common to Mediterranean countries, significantly contributed towards agricultural land disuse and dilapidation of soil retaining structures. These conditions are the main drivers leading to accelerated soil loss. The socio-economic dynamics, and the consequent effects on agricultural practices and soil erosion processes discussed in this study are characteristic of the Mediterranean region.

There is an urgent need for an update of national legislation to alleviate the adverse effects socio-economic parameters have on agricultural practices. The author proposes that ameliorating net farmer income will directly increase agricultural land use, reversing the current abandonment trend. This mechanism will indirectly increase the maintenance of key soil erosion control structures, the terraced field rubble wall, and reduce the current alarming rate of soil erosion.

5 Conclusion

Calculated National annual soil loss (Figure 7) indicates that $61.01\,\mathrm{km}^2$, $19.33\,\%$ of total National land area, are at risk of moderate to severe soil erosion. Maltese central and north-eastern areas show the lowest erosion risk. These areas are characterised by relatively flat topographies, good land management and erosion control measures. Maltese north-western and Gozitan areas are characterised by a large range in erosion rates. Within this area, low erosion risk occurs in plateaus comprising low topographic gradients, and the application of good land management and erosion control measures. Plateau flanks typically consist of exceptionally high erosion rates, characterised by high topographic gradients, inappropriate cultivation practices and poor erosion control measures. Steeply inclined plateau flanks demonstrating low erosion risk are associated with areas demonstrating adequate vegetation cover, and effective management and conservation practices.

Analysis of the Maltese National land cover (Figure 4) and rubble wall state (Figure 6) survey, carried out by the authors, concludes that the majority of agricultural terraces on inclined surfaces are in a derelict state and in most cases disused. These steeply inclined agricultural fields show the highest National soil erosion rates (Figure 7). These areas are subject to various socio-economic conditions that constrain net farm income. We propose that in most cases socio-economic factors, common to Mediterranean countries, significantly contribute towards agricultural land disuse, dilapidation of soil retaining structures and accelerated soil erosion.

Soil is a limited resource in the Mediterranean area both in terms of quantity and quality. Soil resources support agriculture, maintain ecosystem health and are central to hydrological processes. Although of great importance, soil resources are relatively mismanaged and are threatened by accelerated erosion rates. There is an urgent need for an update of national legislation to alleviate the adverse effects socio-economic parameters have on agricultural practices. Ameliorating Mediterranean net farmer income will directly increase agricultural land use, reversing the current abandonment trend. This mechanism will indirectly increase the maintenance of key soil erosion control structures, the terraced field rubble wall, and reduce the current alarming rate of soil erosion.

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