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The Medalus project Mediterranean desertification and land use

Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification

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The Medalus project
Mediterranean desertification and land use

Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification

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1. Introduction.

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Desertification is the consequence of a set of important processes which are active in arid and semi-arid environments, where water is the main limiting factor of land use performance in ecosystems. In the context of the EC MEDALUS (Mediterranean Desertification and Land Use), the focus here is primarily on European Mediterranean environments where physical loss of soil by water erosion, and the associated loss of soil nutrient status is identified as the dominant problem. In more arid areas, there is greater concern with wind erosion and salinisation problems, but these are considered to be less significant than water erosion for the northern Mediterranean area.

Environmental systems are generally in a state of dynamic equilibrium with external driving forces. Small changes in the driving forces, such as climate or imposed land use tend to be accommodated partially by a small change in the equilibrium and partially by being absorbed or buffered by the system. For example, an increased rate of soil erosion commonly leads to an increase in soil stoniness both at the surface and within the soil profile. These changes lead to both a greater resistance to erosion due to surface armouring, and to improved water retention as organic matter in concentrated within the fine fractions of the soil. Both of these changes tend to offset and buffer the effects of increased erosion. In many cases, the effects of an external change are also reversible, so that, for example a reduction in erosion will allow coarse material to weather slowly back to finer fractions.

Desertification of an area will proceed if certain land components are brought beyond specific thresholds, beyond which further change produces irreversible change. For example, soils may eventually become so stony that they can only degrade towards scree or bare bedrock. Climate change cannot bring a piece of land to a desertified state by itself, but it may modify the critical thresholds, so that the system can no longer maintain its dynamic equilibrium.

Indicators of Desertification may demonstrate that desertification has already proceeded to its end point of irreversibly infertile soils, for example as rocky deserts or highly sodic soils. The most useful indicators, however, are those which indicate the potential risk of desertification while there is still time and scope for remedial action.

For a European Strategy of Action against desertification, it is essential to adopt a nested approach so that limited resources are applied in a cost effective manner. At the coarsest scales it is essential to adopt a uniform, objective and scientifically based methodology which identifies regions where the risk of desertification is highest. At this scale, it is impossible to identify single fields or communities precisely, but only to identify the regions for which more detailed work is required. These **Regional Indicators** should be based on available international source materials, including remotely sensed images, topographic data (maps or DEM's) climate, soils and geological data, at scales of 1:250 000 to 1 000 000). At these scales the impact of socio-economic drivers is expressed mainly through patterns of land use. Regional Indicators may be used as a base-line for allocation of funds and expertise between countries and between regions within a country. Each Regional Indicator or group of associated indicators should be focused on a single process, for example water erosion. In this way planners and policy makers are able to make informed decisions about the processes in which they seek to intervene.

Once Regions at Risk have been identified, the second nested scale of investigation must lie within each Region. At this second scale, applied to a Province or River catchment (500 - 5 000 km^2), much of the data may still be obtained from maps at 1:25 000 to 1:50 000, but these will need to be substantially supported by field survey. Such intensity of research effort is only justified within Regions at Risk. The proposed methodology at this scale is through the identification of **Environmentally Sensitive Areas (ESA's)** through a multi-factor approach based on both a general and a local knowledge of the environmental processes acting. At this scale it is appropriate and possible to pay much more attention to detailed soil and vegetation properties, and to local topographic factors such as gradient and aspect.

The final nested scale is of local remediation or mitigation action plans. At this scale, the interplay of physical needs and socio-economic possibilities becomes dominant, and can only be carried to a successful conclusion with the full participation of local communities.

This work focuses on the choice of appropriate indicators at the European/National (RDI) and Regional (ESAs) scales; and illustrates their application to identifying ESAs for three target areas defining during the execution of MEDALUS Project and located in Greece (the island of Lesvos), Italy (the Agri basin in Basilicata), and Portugal (Alentejo region).

*1. Introduzione**

La desertificazione è la conseguenza di una serie d'importanti processi che sono attivi in ambienti aridi o semi-aridi, dove l'acqua è il fattore limitante principale per il rendimento del suolo. Nel contesto del Progetto UE Medalus (Mediterranean Desertification And Land Use), l'attenzione è rivolta principalmente agli ambienti del Mediterraneo dove la perdita fisica di suolo, causata dall'erosione idrica e, la conseguente perdita d'elementi nutritivi sono i problemi dominanti. In aree più aride, c'è più interesse per l'erosione eolica e per i problemi di salinizzazione, ma questi sono considerati meno significativi dell'erosione idrica per l'area del nord mediterraneo.

Generalmente i sistemi ambientali sono in uno stato d'equilibrio dinamico con i fattori esterni. Piccoli cambiamenti di questi fattori, come il clima o l'uso del suolo tendono ad essere parzialmente contenuti da un piccolo cambiamento nell'equilibrio e parzialmente assorbito o tamponato dal sistema. Per esempio, un incremento del processo d'erosione di solito porta ad un incremento della pietrosità del suolo conseguente al trasporto delle particelle fertili di suolo superficiale. Questi cambiamenti portano di solito ad una maggiore resistenza dello strato superficiale all'erosione, dovuta alla presenza in superficie di materiale grossolano e alla migliore ritenzione idrica. Entrambi cambiamenti tendono a compensare e tamponare gli effetti dell'aumentata erosione. In molti casi, gli effetti di un cambiamento esterno sono anche reversibili, in modo che, una riduzione dell'erosione permetterà, nel tempo ad una maggiore disgregazione in frazioni più fini del materiale grossolano.

La desertificazione di un'area verificherà se certe componenti del suolo sono portati via oltre specifiche soglie, che potranno produrre cambiamenti irreversibili. Per esempio, suoli possono diventare, a seguito di processi d'erosione tanto pietrosi essi potranno degradare solo verso ghiaioni o verso la roccia madre. Cambiamento nel clima, da se, non può portare alla desertificazione di una superficie di terreno, ma può modificare le soglie critiche in modo che il sistema non può più mantenere il suo equilibrio dinamico.

Gli indicatori di desertificazione potranno dimostrare che la desertificazione è già arrivata al punto d'irreversibilità di alcuni terreni non fertili, per esempio deserti, zone rocciose o suoli con alto contenuto sodico. Comunque, gli indicatori più utili sono quelli che indicano il potenziale rischio di desertificazione quando c'è ancora tempo per azioni di rimedio.

E' essenziale, per gli interventi comunitari contro la desertificazione, di adoperare un approccio chiaro per limitare le risorse da applicare. Sarebbe opportuno adoperare una metodologia uniforme, ed un obiettivo scientifico basato su larga scala che individui regioni dove il rischio di desertificazione è più alto. E' impossibile di identificare campi singoli o comunità in modo preciso a scala ampia, ma sarebbe possibile identificare le regioni dove è richiesta un lavoro più dettagliato. Questi ***Indicatori Regionali (RDI)*** *dovrebbero essere basati su materiali internazionali disponibili, includendo immagini satellitari, dati topografici (mappe e DEMs), dati climatici e geologici e del terreno, alle scale uno: 250 000 a 1 000 000. L'impatto degli aspetti socio-economici, a queste scale, è principalmente espresso attraverso schemi d'utilizzazione del suolo. Gli Indicatori Regionali potranno essere usati come base per l'allocazione dei fondi ed esperienze tra nazioni o tra regioni dentro la nazione. Ognuno degli Indicatori Regionali o gruppi d'indicatori associati dovrebbero essere focalizzati su un singolo processo, per esempio erosione idrica. Questo metterà in grado i pianificatori o politici di prendere decisioni informate sui processi che si vogliono limitare.*

Una volta che le Regioni a rischio sono state identificate, il secondo approccio dovrà essere fattodentro ogni Regione. A questa seconda scala, applicata a livello di bacino o Provinciale (500 – 5 000 km^2), molti dati potranno essere ancora presi da mappe 1: 25 000 a 1:50 000, anche se ci sarà bisogno di supportare il tutto tramite rilievi in pieno campo.

L'intensità di un tale sforzo di ricerca può solo essere giustificata dentro Regioni a rischio. La metodologia proposta, a questa scala, è attraverso l'identificazione d'Aree Ambientali Sensitive tramite un approccio multifattoriale basato sia sulla conoscenza generale sia su quella locale dei processi ambientali in atto. A questa scala è appropriato e possibile rivolgere più attenzione alle proprietà del suolo e della vegetazione in modo dettagliato, ma anche sui fattori topografici locali.

La scala finale a livello locale è per favorire azioni di mitigazione. L'interazione tra fattori fisici e possibilità socio-economiche diventa dominante; questa scala, può essere portata ad un successo solo con la piena partecipazione delle comunità locali.

Questo lavoro focalizza l'attenzione sulla scelta d'indicatori appropriati a scala Europea/Nazionale (RDI) e Regionale (ESAs) e illustra la loro applicazione per identificare ESAs per le tre aree target, definite durante l'esecuzione del Progetto MEDALUS, localizzati in Grecia (Isola Lesvos), Italia (bacino dell'Agri), e Portogallo (regione d'Alentejo).

* The translation into Italian has been made by: Dr. Achille Mastroberti, Universita degli Studi della Basilicata, Dipartimento di Produzione Vegetale.

*1. Εισαγωγή**

Η απερήμωση είναι το αποτέλεσμα μιας σειράς σημαντικών διεργασιών που λαμβάνουν χώρα σε ξηρά και ημίξηρα περιβάλλοντα, όπου το νερό είναι ο κύριος περιοριστικός παράγοντας απόδοσης της γης. Στα πλαίσια του προγράμματος της Ευρωπαϊκής Ένωσης MEDALUS (Μεσογειακή Απερήμωση και Χρήση Γης), η απερήμωση μελετήθηκε κυρίως στα Ευρωπαϊκά Μεσογειακά περιβάλλοντα όπου η απώλεια εδάφους λόγω διάβρωσης και η συνακόλουθη απώλεια εδαφικών θρεπτικών στοιχείων χαρακτηρίζεται σαν η κυριότερη αιτία απερήμωσης. Σε ιδιαίτερα ξηρές περιοχές υπάρχει επίσης το πρόβλημα της αιολικής διάβρωσης και η αύξηση της αλατότητας των εδαφών.

Τα περιβαλλοντικά συστήματα είναι γενικά σε μια κατάσταση δυναμικής ισορροπίας με τις εξωτερικές επιδράσεις που δρουν πάνω τους. Μικρές αλλαγές στις επιδράσει αυτές, όπως το κλίμα ή η χρήση γης τείνουν να εξισορροπηθούν μερικώς με μια μικρή αλλαγή στο σημείο ισορροπίας και μερικώς απορροφούνται ή ρυθμίζονται από το σύστημα. Για παράδειγμα ένας αυξημένος ρυθμός διάβρωσης συχνά οδηγεί σε αύξηση του πετρώδους, τόσο στην επιφάνεια όσο και στο εδαφικό προφίλ. Αυτές οι αλλαγές οδηγούν σε μεγαλύτερη αντίσταση στη διάβρωση λόγω της «θωράκισης» της επιφάνειας και στη βελτίωση συγκράτησης της υγρασίας καθώς η οργανική ουσία συγκεντρώνεται στα λεπτόκοκκα κλάσματα του εδάφους. Και οι δύο αυτές αλλαγές τείνουν να αντισταθμίσουν και να ρυθμίσουν τις συνέπειες της αυξημένης διάβρωσης. Σε πολλές περιπτώσεις οι συνέπειες μιας εξωτερικής μεταβολής είναι αναστρέψιμες έτσι ώστε για παράδειγμα μια μείωση της διάβρωσης να επιτρέψει σε χονδρόκοκκο υλικό να αποσαθρωθεί σταδιακά σε πιο λεπτόκοκκα κλάσματα.

Η απερήμωση μιας περιοχής θα προχωρήσει εάν συγκεκριμένες παράμετροι ξεπεράσουν συγκεκριμένα όρια πέρα από τα οποία κάθε επιπλέον μεταβολή προκαλεί μη αναστρέψιμες αλλαγές. Για παράδειγμα εάν το έδαφος γίνει πολύ πετρώδες τότε η περαιτέρω μεταβολή είναι η μετατροπή σε «σάρες» ή γυμνό μητρικό πέτρωμα. Η αλλαγή του κλίματος δεν μπορεί να φέρει ένα κομμάτι γης σε κατάσταση απερήμωσης από μόνη της, αλλά μπορεί να μεταβάλει τα κρίσιμα όρια, έτσι ώστε το σύστημα να μη μπορεί να διατηρήσει πλέον τη δυναμική του ισορροπία.

Η χρήση των δεικτών απερήμωσης μπορεί να αποδείξει ότι η απερήμωση έχει ήδη προχωρήσει στο τελικό της σημείο των μη αναστρέψιμα άγονων εδαφών, για παράδειγμα πετρώδεις ερήμους ή πολύ αλκαλιωμένα εδάφη. Οι πιο χρήσιμοι δείκτες πάντως είναι αυτοί που δείχνουν τον δυνητικό κίνδυνο της απερήμωσης ενώ υπάρχει ακόμα χρόνος και λόγος για δράσεις αντιμετώπισης.

Για μια Ευρωπαϊκή Στρατηγική Δράσης ενάντια στην απερήμωση είναι απαραίτητο να υιοθετηθεί μια απλή προσέγγιση έτσι ώστε η χρήση περιορισμένου αριθμού δεδομένων να είναι αποτελεσματική στο συγκεκριμένο θέμα μελέτης. Σε μεγαλύτερες κλίμακες είναι απαραίτητο να υιοθετηθεί μια ενιαία, αντικειμενική και επιστημονικά τεκμηριωμένη μεθοδολογία που να αναγνωρίζει περιοχές όπου ο κίνδυνος της απερήμωσης είναι μέγιστος. Σ' αυτή την κλίμακα είναι αδύνατο να αναγνωριστούν μεμονωμένα πεδία ή κοινότητες με ακρίβεια αλλά μόνο να αναγνωριστούν οι περιοχές όπου χρειάζεται πιο λεπτομερής δουλειά. Αυτοί οι Περιφερειακοί Δείκτες (RDI) θα πρέπει να βασίζονται σε διεθνώς διαθέσιμο υλικό, συμπεριλαμβανομένων δορυφορικών εικόνων, τοπογραφικών δεδομένων (χάρτες ή ψηφιακά υψομετρικά μοντέλα – DEM), κλιματικών, εδαφολογικών και γεωλογικών δεδομένων σε κλίμακες 1:250.000 έως 1:1.000.000. Σ' αυτές τις κλίμακες η επίδραση των κοινωνικό-οικονομικών δυνάμεων εκφράζεται κυρίως μέσω μοντέλων χρήσης γης. Περιφερειακοί δείκτες μπορούν να χρησιμοποιηθούν σαν βάση για τη κατανομή κονδυλίων και τεχνογνωσίας μεταξύ χωρών και μεταξύ περιοχών της ίδιας χώρας. Κάθε Περιφερειακός Δείκτης ή ομάδα σχετιζόμενων μεταξύ τους δεικτών θα πρέπει να εστιάζονται σε μια μοναδική διαδικασία, για παράδειγμα η υδατική διάβρωση. Μ' αυτόν τον τρόπο οι σχεδιαστές διαχείρισης και οι *πολιτικοί θα είναι σε θέση να λαμβάνουν ορθές αποφάσεις για τις διαδικασίες στις οποίες επιδιώκουν να παρέμβουν.*

Από τη στιγμή που αναγνωριστούν οι περιοχές που κινδυνεύουν η επόμενη κλίμακα της έρευνας πρέπει να βρίσκεται μέσα στην περιοχή. Σ' αυτή τη δεύτερη κλίμακα που εφαρμόζεται σε μια περιφέρεια ή μια λεκάνη απορροής (500 – 5.000 km^2), πολλά από τα δεδομένα μπορούν ακόμα να εξαχθούν από χάρτες κλίμακας 1:25.000 έως 1:50.000 αλλά αυτά θα πρέπει να υποστηριχτούν ουσιαστικά από έρευνες πεδίου. Τέτοια εντατική έρευνα μπορεί να δικαιολογηθεί μόνο στα όρια των περιοχών που κινδυνεύουν. Η προτεινόμενη μεθοδολογία σ' αυτή την κλίμακα είναι η αναγνώριση των Περιβαλλοντικά Ευαίσθητων Περιοχών (ESAs) μέσα από μία πολυπαραμετρική προσέγγιση βασισμένη τόσο σε μια γενική όσο και σε μια τοπική γνώση των περιβαλλοντικών διαδικασιών που λαμβάνουν χώρα. Σ' αυτή την κλίμακα είναι καταλληλότερο και δυνατό να δοθεί περισσότερη προσοχή σε λεπτομερείς ιδιότητες του εδάφους και της βλάστησης και σε τοπικούς τοπογραφικούς παράγοντες όπως η κλίση και η έκθεση.

Η τελευταία κλίμακα είναι αυτή των τοπικών σχεδίων δράσης αποκατάστασης ή αντιμετώπισης. Σ' αυτή την κλίμακα η διαπλοκή των φυσικών αναγκών και των κοινωνικο-οικονομικών δυνατοτήτων γίνεται κυρίαρχη και μπορεί να οδηγηθεί σε ένα επιτυχές αποτέλεσμα μόνο με την πλήρη συμμετοχή των τοπικών κοινοτήτων.

Η παρούσα εργασία εστιάζεται στην επιλογή των κατάλληλων δεικτών σε Ευρωπαϊκή/Εθνική (RDI) και τοπική (ESAs) κλίμακα και παρουσιάζει την εφαρμογή τους στην αναγνώριση Περιβαλλοντικά Ευαίσθητων Περιοχών (ESAs) για τρεις πιλοτικές περιοχές που καθορίστηκαν κατά την εκτέλεση του προγράμματος MEDALUS και βρίσκονται στην Ελλάδα (Λέσβος), την Ιταλία (η λεκάνη του Agri στα Βασιλικάτα) και την Πορτογαλία (η περιφέρεια Alentejo).

* The translation into Greek has been made by: Dr. V. Detsis, Agricultural University of Athens, Laboratory of Soils and Agricultural Chemstry.

1. ***Introdução****

A Desertificação é a consequência de um conjunto de importantes processos que actuam em ambientes áridos e semi-áridos, onde a água é o principal factor limitante para diferentes usos do solo e nos ecossistemas. No contexto do Projecto da União Europeia – MEDALUS (Mediterranean Desertification and Land Use), a abordagem deste problema centra-se sobretudo nos diferentes ambientes da Europa Mediterrânica, onde o processo físico de perda de solo por erosão hídrica e os processos de perda de nutrientes e fertilidade associados, são identificados como os problemas fundamentais. Nas áreas mais áridas existe uma preocupação crescente com os problemas da erosão eólica e da salinização dos solos, que são, no entanto, menos significativos que a erosão hídrica para a Europa Mediterrânica.

Os sistemas ambientais estão geralmente em estado de equilíbrio com as forças externas que os condicionam. Pequenas mudanças nestas forças externas, tais como o clima ou usos de solo impostos pelo Homem, tendem a ser acompanhadas, por um lado, por pequenas mudanças no equilíbrio do sistema e, por outro, por uma absorção ou assimilação dessa perturbação no interior do sistema. Por exemplo, um aumento no coeficiente de perda de solo por erosão hídrica conduz a um aumento da percentagem de fragmentos rochosos no solo («quando o solo morre as pedras nascem…!») tanto à superfície como ao longo do perfil dos horizontes do solo. Estas mudanças conduzem a uma maior resistência à erosão, devido à protecção dada pelas pedras («armadura» do solo) e a um aumento da capacidade de retenção de água já que a matéria orgânica se concentra na fracção mais fina do solo. Ambas estas mudanças tendem a atenuar os efeitos de um aumento da erosão. Em muitos casos, os efeitos provocados por uma perturbação exterior são também reversíveis, de forma que, por exemplo, uma redução na erosão permitirá que o material mais grosseiro possa ser meteorizado lentamente até integrar de novo as fracções mais finas do solo.

A desertificação de uma área continuará se determinadas componentes do sistema bioprodutivo terrestre forem sistematicamente ultrapassadas nos seus limites, para além dos quais, qualquer mudança produzirá alterações irreversíveis. Por exemplo, os solos podem eventualmente tornar-se tão pedregosos que apenas se podem degradar no sentido de um rególito (solo pedregoso) ou da rocha-mãe. A alteração climática não pode por si só tornar uma área desertificada, mas pode modificar os limiares críticos de mudança e absorção, de forma que o sistema não pode mais manter o seu estado de equilíbrio.

Os indicadores de desertificação podem demonstrar que este fenómeno atingiu já um ponto final, tornando-se os solos irreversivelmente inférteis, como por exemplo os desertos rochosos ou solos altamente sódicos. Os indicadores mais úteis são, no entanto, aqueles que indicam o risco potencial de desertificação, enquanto existe tempo e possibilidades de empreender acções para remediar o processo.

Para uma Estratégia Europeia de Acção de luta contra a desertificação é essencial a adopção de uma abordagem concentrada na génese do problema, de forma que recursos limitados possam ser aplicados de uma maneira efectiva em termos de custos. A uma escala mais alargada é essencial adoptar uma metodologia uniforme, objectiva e de base científica, que identifique as regiões onde o risco de desertificação é mais elevado. A esta escala é impossível identificar pequenas áreas ou comunidades afectadas de forma precisa, sendo apenas possível a identificação de regiões para as quais é necessário um diagnóstico mais detalhado. Estes ***Indicadores Regionais de Desertificação (RDIs)*** *devem basear-se em fontes de informação disponíveis internacionalmente, incluindo imagens de satélite, informação topográfica (mapas e Modelos Digitais de Terreno – DEMs), clima, solos e informação sobre a geologia, coberto vegetal e uso do solo, a escalas entre 1:250 000 e 1:1 000 000). A estas escalas, o impacto dos factores socioeconómicos é expresso sobretudo através dos padrões de usos do solo. Os indicadores regionais podem ser utilizados como uma base para a alocação de fundos e recursos técnicos entre países e entre regiões dentro do mesmo país. Cada*

Indicador Regional ou grupo de indicadores associados deverá reflectir um determinado processo, como por exemplo a erosão hídrica. Desta forma, as autoridades com responsabilidades no planeamento e na decisão política, poderão ser capazes de tomar decisões fundamentadas acerca dos processos nos quais desejam intervir.

Uma vez que estejam identificadas as regiões em risco, a segunda escala de investigação tem de basear-se em cada região. Nesta segunda escala, aplicada à Província ou bacia hidrográfica (500 – 5 000 km^2) grande parte da informação pode ainda ser obtida dos mapas à escala 1:25 000 ou 1:50 000, mas esta tarefa deverá ser substancialmente complementada com trabalho de reconhecimento de campo. Um tal esforço de investigação só é justificado para Regiões em Risco. A metodologia proposta a esta escala baseia-se na identificação de ***Áreas Ambientalmente Sensíveis (ESAs)****, através de uma análise multi-factorial baseada simultaneamente num conhecimento geral e local dos processos actuantes. A esta escala é apropriado e possível prestar muito mais atenção e analisar com maior detalhe as propriedades do solo e da vegetação e a aspectos da topografia local como o declive ou a exposição das vertentes.*

A última escala de análise integrada concentra-se em planos locais de acção de combate e mitigação da desertificação. A esta escala as interacções entre as necessidades físicas e as possibilidades socioeconómicas tornam-se centrais e podem apenas ser conduzidas e concluídas com sucesso com a total participação das comunidades locais.

Este trabalho concentra-se na escolha de indicadores apropriados, à escala Europeia/Nacional (RDI) e Regional (ESA); e ilustra a sua aplicação na identificação de ESAs para três áreas de estudo definidas durante a execução do Projecto MEDALUS, localizadas na Grécia (ilha de Lesvos), Itália (a bacia do Agri, Basilicata), e em Portugal (região Alentejo, concelho de Mértola).

* The translation into Portuguese has been made by: Dr. Jorge Mourao, Universidade Nova de Lisboa, Departamento de Geografia e Planeamento Regional, Faculdade de Ciencias e Humanas.

*1. Introducción**

La desertificación es la consecuencia de un conjunto de importantes procesos activos en ambientes áridos y semiáridos, dónde el agua es el principal factor limitante de la productividad en los ecosistemas. En el contexto del Proyecto MEDALUS (Desertificación y Uso del Suelo en el Mediterráneo) de la UE, el punto de atención básico son los ecosistemas de la Europa mediterránea, dónde la pérdida de suelo por erosión hídrica, y la pérdida asociada de nutrientes se identifica como el problema dominante. En áreas más áridas hay una mayor preocupación en la erosión eólica y la salinización, que se consideran menos significativas que la erosión hídrica en el área del Mediterráneo norte.

Los sistemas medioambientales están generalmente en un estado de equilibrio dinámico con las fuerzas conductoras externas. Ccambios pequeños en estas fuerzas conductoras, tales como el clima o un uso del suelo impuesto tienden a ser ajustados en parte por un pequeño cambio en el estado de equilibrio y en parte son absorbidos o amortiguados por el sistema. Por ejemplo, un incremento en tasa de erosión del suelo lleva a un incremento de la pedregosidad tanto en la superficie como en el perfil. Estos cambios conducen a una mayor resistencia a la erosión debido al encostramiento, y a una retención mejorada del agua ya que la materia órganica se concentra en las fracciones finas del suelo. Ambos cambios tienden a compensar y amortiguar los efectos del incremento de erosión. En muchos casos, los efectos de un cambio externo son también reversibles, de modo que, por ejemplo, una reducción en la erosión permitirá que el material grueso se meteorice lentamente en fracciones más finas.

La desertificación de un área ocurrirá si ciertos componentes del sistema son llevados más allá de umbrales específicos, más allá de los cuales un cambio posterior es irreversible. Por ejemplo, el suelo puede finalmente llegar a ser tan pedregoso que sólo se puede degradar hacia un canchal o roca madre desnuda. El cambio del clima no puede llevar a un área al estado desertificado por sí mismo, pero pudiera modificar los umbrales críticos, de manera que el sistema no puede mantener su equilibrio dinámico.

Los indicadores de desertificación pueden demostrar que la desertificación está ya operando hacia suelos irreversiblemente infértiles, su punto final, por ejemplo en forma de desiertos rocosos o suelos altamente sódicos. Los indicadores más útiles, sin embargo, son aquellos que indican el riesgo potencial de desertificación mientras que aún haya tiempo y oportunidad para acciones de rehabilitación.

*Para una Estrategia Europea de Acción contra la desertificación, es esencial adoptar una aproximación anidada de modo que los recursos limitados sean utilizados de manera rentable. A las escalas de grano grueso es esencial adoptar una metodología, uniforme, objetiva y sustentada científicamente que identifique las regiones dónde el riesgo de desertificación es más elevado. A esta escala, es imposible identificar campos individuales o comunidades con precisión, pero es posible identificar las regiones de las que se requiere un trabajo más detallado. Estos **Indicadores Regionales (IRD)** deberían estar basados en materiales disponibles internacionalmente, incluyendo imágenes de teledetección, datos topográficos (mapas o MDE), clima, suelos y datos geológicos a escalas de 1:250.000 a 1:1.000.000. A estas escalas el impacto de las fuerzas socioeconómicas se expresa principalmente en los patrones de uso del suelo. Los Indicadores Regionales pueden usarse como línea de base para la distribución de fondos y conocimientos técnicos entre países y entre regiones dentro de un país. Cada Indicador Regional o grupo de indicadores asociados debería enfocarse sobre procesos individuales, por ejemplo erosión hídrica. De este modo los planificadores y decisores políticos podrán tomar decisiones bien informadas sobre los procesos en los que pretenden intervenir.*

Una vez que la Regiones en Riesgo han sido identificadas, la segunda escala anidada de investigación debe ser cada Region. A esta segunda escala, una Provincia o cuenca *hidrológica (500-5.000 km^2), muchos de los datos se pueden obtener aún de mapas, a escalas 1:25.000 a 1:50.000, pero se necesitará un apoyo sustancial de la investigación de campo. Tal intensidad en el esfuerzo investigador sólo se justifica dentro de las Regiones en Riesgo. La metodología propuesta a esta escala es la identificación de* ***Areas Medioambientalmente Sensibles (AMS)*** *a través de una aproximación multifactorial basada tanto en conocimientos generales como locales de los procesos ambientales actuantes. A esta escala es apropiado y posible prestar gran atención a propiedades detalladas del suelo y la vegetación, y a los factores topográficos locales tales como la pendiente y la exposición.*

La última escala anidada es la de los planes locales de rehabilitación o mitigación. A esta escala el juego entre las necesidades físicas y las posibilidades socioeconómicas llega a ser dominante y sólo puede ser llevado a cabo con éxito con la participación plena de las comunidades locales.

Este trabajo está enfocado en la elección de indicadores apropiados a las escalas Europea/Nacional (IRD) y Regional (AMS); e ilustra su aplicación para identificar las AMS para tres áreas objetivo definidas durante la ejecución del Proyecto MEDALUS, y localizadas en Grecia (la isla de Lesvos), Italia (la cuenca del Agri en Basilicata) y Portugal (la región de Alentejo).

*The translation into Spanish has been made by: Dr. Gonzalo Gonzalez-Barbera, Universidad de Murcia, Area de Geografia Fisca.

A. KEY INDICATORS OF DESERTIFICATION AT THE ESA SCALE

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Desertification is the consequence of a set of important degradation processes in the Mediterranean environments, especially in semi-arid and arid regions, where water is the main limiting factor of land use performance on ecosystems. Environmentally Sensitive Areas (ESAs) to desertification around the Mediterranean region exhibit different sensitivity to desertification for various reasons. For example there are areas presenting high sensitivity to low rainfall and extreme events due to low vegetation cover, low resistance of vegetation to drought, steep slopes, highly erodible parent materials, etc. High sensitivity can be also related to the type of land use for the cases that it promotes desertification in climatically and topographically marginal areas. For example cereals cultivated in hilly areas with soils formed on marl present a serious threat for desertification. Furthermore, there are areas which are sensitive to desertification for special reasons, such as fire risk, which is likely to generate runoff and erosion problems for some years; rambla and flood plain environments, where fluctuating phreatic levels may show salinization and toxicity problems; and exotic tree plantations, where poor ground cover and autotoxicity may lead to higher runoff and sediment yields.

The various types of ESAs to desertification can be distinguished and mapped by using certain key indicators for assessing the land capability to withstand further degradation, or the land suitability for supporting specific types of land use. The key indicators for defining ESAs to desertification, which can be used at regional or national level, can be divided into four broad categories defining the qualities of soil, climate, vegetation, and management (stressor indicators). This approach includes parameters which can be easily found in existing soil, vegetation, and climate reports.

A. I NDICATORI CHIAVI PER LA DESERTIFICAZIONE A LIVELLO ESAS

La desertificazione è la conseguenza di una serie d'importanti processi di degradazione del suolo in ambiente Mediterraneo, specialmente nelle regioni aride e semi-aride, dove l'acqua è il fattore limitante principale per il rendimento dell'uso del suolo. Aree Ambientali Sensitive (ESAs) alla desertificazione nella regione del Mediterraneo mostrano una diversa sensibilità alla desertificazione per vari motivi. Per esempio, ci sono aree che presentano un'elevata sensibilità alla bassa piovosità ed ad eventi piovosi di elevata intensità che favoriscono il processo erosive di aree a scarsa copertura vegetale, con pendenze elevate, e su suolo molto erosivo, ecc. L'alta sensibilità può anche essere riferita al tipo di utilizzazione del suolo che porta alla desertificazione in aree climaticamente e topograficamente marginali. Per esempio, cereali coltivati in aree collinari con suoli formati su marna presentano una minaccia seria alla desertificazione. Inoltre, ci sono aree che sono sensibili alla desertificazione per ragioni speciali, come il rischio d'incendi, che sicuramente genera problemi di deflusso e d'erosione per alcuni anni; ambienti rambla e pianure alluvionali, dove il variare del livello freatico potrebbe mostrare problemi di salinizzazione e di tossicità; piantagioni d'alberi esotici, dove la scarsa copertura del suolo e l'auto-tossicità potrebbero portare a deflussi e sedimenti più alti.

I vari tipi d'ESAs alla desertificazione possono essere distinti e mappate usando degli indicatori chiavi per la stima della capacità del suolo a resistere a processi di degradazione, oppure l'idoneità del suolo di supportare specifici usi. Gli indicatori per definire ESAs alla desertificazione sia a livello regionale sia a livello nazionale possono essere divisi in quattro categorie definendo la qualità del suolo, la qualità del clima, la qualità della vegetazione e la qualità della gestione *(indicatori di stress). Quest'approccio include parametri che possono essere facilmente trovati nelle relazioni esistenti sul suolo, sulla vegetazione e sul clima.*

Α. ΔΕΙΚΤΕΣ ΑΠΕΡΗΜΩΣΗΣ ΣΕ ΚΛΙΜΑΚΑ ΠΕΠ

Η απερήμωση είναι η συνέπεια μιας σειράς από σημαντικές διαδικασίες υποβάθμισης στα μεσογειακά περιβάλλοντα, ειδικά στις ημίξηρες και ξηρές περιοχές, όπου το νερό είναι ο κύριος περιοριστικός παράγοντας του δυναμικού των οικοσυστημάτων. Οι Περιβαλλοντικά Ευαίσθητες Περιοχές (ΠΕΠ) στην απερήμωση στην περιοχή της Μεσογείου παρουσιάζουν διαφορετική ευαισθησία στην απερήμωση για διάφορους λόγους. Για παράδειγμα υπάρχουν περιοχές που παρουσιάζουν υψηλή ευαισθησία στη χαμηλή βροχόπτωση και τα ακραία φαινόμενα εξαιτίας της μικρής φυτοκάλυψης, της μικρής αντοχής της βλάστησης στην ξηρασία, των απότομων κλίσεων, της υψηλής διαβρωσιμότητας του μητρικού υλικού κλπ. Η υψηλή ευαισθησία μπορεί επίσης να σχετίζεται με τον τύπο της χρήσης γης στην περίπτωση που υποβοηθά την απερήμωση σε κλιματικά και τοπογραφικά οριακές περιοχές. Για παράδειγμα σιτηρά που καλλιεργούνται σε λοφώδεις περιοχές με εδάφη σχηματισμένα από μάργα είναι ένας σοβαρός κίνδυνος για απερήμωση. Επίσης υπάρχουν περιοχές που είναι ευαίσθητες στην απερήμωση για ειδικούς λόγους, όπως ο κίνδυνος πυρκαγιάς, που είναι πιθανό να δημιουργήσει προβλήματα επιφανειακής απορροής και διάβρωσης για μερικά χρόνια, υποβαθμισμένες περιοχές και περιοχές που πλημμυρίζουν περιοδικά, όπου η διακύμανση του υδροφόρου ορίζοντα μπορεί να οδηγήσει σε προβλήματα αλάτωσης και τοξικότητας, φυτείες εξωτικών ειδών όπου η φτωχή κάλυψη του εδάφους και η αυτοτοξικότητα μπορεί να οδηγήσει σε υψηλότερη επιφανειακή απορροή και παραγωγή ιζήματος.

Οι διάφορες κατηγορίες των ΠΕΠ για την απερήμωση μπορούν να διακριθούν και να χαρτογραφηθούν χρησιμοποιώντας συγκεκριμένους δείκτες-κλειδιά για να εκτιμήσουμε την ικανότητα ενός τόπου να αντισταθεί στην παραπέρα υποβάθμιση ή την καταλληλότητά του για διάφορους τύπους χρήσεων γης. Οι δείκτες κλειδιά για την διάκριση των ΠΕΠ για την απερήμωση, οι οποίοι μπορούν να χρησιμοποιηθούν σε τοπικό ή εθνικό επίπεδο, μπορούν να διαιρεθούν σε τέσσερεις ευρείες κατηγορίες που προσδιορίζουν τις ιδιότητες του εδάφους, του κλίματος, της βλάστησης και της διαχείρισης (δείκτες πίεσης). Αυτή η προσέγγιση περιλαμβάνει παραμέτρους που μπορούν να βρεθούν εύκολα σε διαθέσιμες εκθέσεις για το έδαφος, τη βλάστηση και το κλίμα.

A. INDICATORES -CHAVE DE DESERTIFICACAO A ESCALA DAS ESA

A Desertificação é consequência de um conjunto importante de processos de degradação em ambientes mediterrâneos, especialmente em regiões áridas e semi-áridas, onde a água é o principal factor limitante nos diferentes usos do solo e nos ecossistemas. As Áreas Ambientalmente Sensíveis à desertificação ao longo das regiões mediterrâneas, apresentam diferentes sensibilidades à desertificação por várias razões. Por exemplo, existem áreas que apresentam uma elevada sensibilidade à escassez de precipitação e à ocorrência de fenómenos climáticos extremos, devido a uma escassez do coberto vegetal, baixa resistência da vegetação à secura, vertentes declivosas, grande erodibilidade dos materiais rochosos, etc. Uma elevada sensibilidade pode também estar relacionada com o tipo de uso do solo que em determinados casos promovem a desertificação em áreas marginais do ponto de vista climático e topográfico. Por exemplo, os cereais cultivados em áreas de relevo movimentado, com vertentes declivosas e solos margosos, apresentam elevado risco de desertificação. Por outro lado existem áreas que são bastante sensíveis à desertificação por razões especiais, tais como áreas de risco de incêndio, com problemas de erosão e drenagem; vales e planícies aluviais, onde as flutuações no nível freático podem fazer surgir problemas de salinização e contaminação dos solos; e plantações de essências arbóreas exóticas, onde a pobreza do sub-coberto e problemas de auto-toxicidade podem conduzir a valores mais elevados de escorrência superficial e perda de solo.

Os vários tipos de ESAs no contexto da desertificação podem ser identificadas e cartografadas, mediante a utilização de indicadores-chave para o diagnóstico das capacidades dos recursos naturais para resistir à degradação, ou ainda a adequação das terras para suportarem determinados usos de solo. Os indicadores-chave na definição das ESAs no contexto da desertificação, que podem ser utilizados à escala regional ou a nível nacional, podem dividir-se em quatro grandes categorias que são definidas pelas qualidades do solo, do clima, da vegetação e pelas *qualidades de gestão (indicadores de pressão). Esta abordagem inclui parâmetros que podem ser facilmente acessíveis em estatísticas e fontes de informação sobre solos, clima e vegetação.*

A. INDICATORES CLAVE DE DESERTIFICATION A LA ESCALA DE AMS

La desertificación es la consecuencia de un importante conjunto de procesos de degradación en lo ecosistemas mediterráneos, especialmente en las regiones semiáridas y áridas, dónde el agua es el principal factor limitante en la productividad de los ecosistemas. Las Areas Medioambientalmente Sensibles (AMS) a la desertificación situadas en la región mediterránea exhiben una diferente sensibilidad a la desertificación por varias razones. Por ejemplo, hay areas que presentan alta sensibilidad a la baja precipitación y los eventos extremos debido a una baja cobertura vegetal, escasa resistencia de la vegetación a la sequía, altas pendientes, materiales altamente erosionables, etc. La sensibilidad alta se puede relacionar también con el tipo de uso del suelo en los casos que este uso promueva la desertificación en áreas climática y topográficamente marginales. Por ejemplo, los cereales cultivados en areas montañosas sobre margas presentan una seria amenaza de desertificación. Más aún, hay áreas que son sensibles a la desertificación por razones especiales, tales como el riesgo de incendios, proceso que puede generar problemas de escorrentía y erosión durante algunos años; ecosistemas de rambla y llanuras de inundación, dónde la fluctuación de niveles freáticos puede inducir problemas de salinización y toxicidad; y la plantación de árboles exóticos, dónde una pobre cobertura y la autotoxicidad pueden llevar a mayor escorrentía y producción de sedimentos.

Los diversos tipos de AMS a la desertificación pueden ser distinguidas y cartografiadas mediante el uso de ciertos indicadores clave para evaluar la capacidad de la tierra para resistir más degradación, o su potencialidad para soportar tipos específicos de usos del suelo. Los indicadores clave para definir AMS a la desertificación, que se pueden utilizar a nivel regional o nacional, se pueden dividir en cuatro amplias categorías que definen la calidad del suelo, la calidad del clima, la calidad de la vegetación y la calidad de la gestión (indicadores de estrés). Esta aproximación incluye parámetros que se pueden encontrar fácilmente en los informes existentes sobre suelo, vegetación y clima.

1. Soil quality indicators

Soil is a dominant factor of the terrestrial ecosystems in the semi-arid and dry sub-humid zones, particularly through it's effect on biomass production. Desertification will proceed, in a certain landscape, when the soil is not able to provide the plants with rooting space and/or water and nutrients. In the semi-arid and the sub-humid zones, the land becomes irreversibly desertified when the rootable soil depth is not capable to sustain a certain minimum vegetation cover. There are cases that desertification proceeds in deep soils, when their water balance is incapable to meet the needs of the plants. In these cases the phenomenon is reversible. Nutrient supply to plants seldom becomes critical in the two climatic zones mentioned above.

Soil quality indicators for mapping ESAs can be related to (a) water availability, and (b) erosion resistance. These qualities can b evaluated by using simple soil properties or characteristics given in regular soil survey reports such as soil depth, soil texture, drainage, parent material, slope grade, stoniness, etc. The use of these properties for defining and mapping ESAs requires the definition of distinct classes with respect to degree of land protection from desertification. The definition of classes requires the study of relations such as: (a) soil depth and plant cover under various climatic, lithological, and topographical conditions, (b) parent material and water availability, (c) soil water holding capacity and soil texture.

1.1 Parent material

Soils derived from different parent materials react differently to soil erosion, vegetation and desertification. Limestone produces shallow soils with a relatively dry moisture regime. In the opposite, as Plate 1 (left photograph) shows, soils formed in flysch are deep, well vegetated. Areas with soils in limestone are characterised by high erodibility and slow vegetation recovery (Plate 1). Several areas on limestone formations in the Mediterranean region are already desertified with the soil mantle eroded, and the vegetation cover completely removed. Under Mediterranean climatic conditions, regeneration of soils and vegetation is impossible, and desertification is irreversible. Similarly, acid igneous parent materials such as pyroclastics (Plate 1) produce shallow soils with high erodibility and high desertification risk.

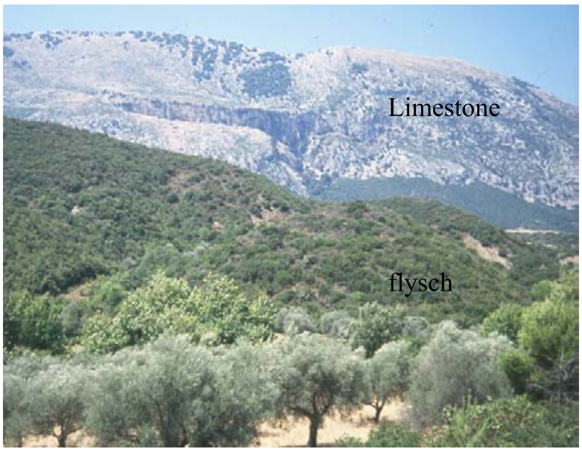


Plate 1. Areas highly eroded and desertified with soils formed in limestone (upper part, left photograph) and pyroclastics (right photograph) and areas well vegetated with deep soils formed in flysch (lower part, left photograph) (Photo by C. Kosmas).

Extensive areas on hilly agricultural lands in the semi-arid zone of the Mediterranean region are cultivated with rainfed cereals. Areas with soils formed in marl are very susceptible to desertification. Such soils cannot support any annual vegetation in particularly dry years, despite their considerable depth and high productivity in normal and wet years (Kosmas *et al*., 1993). On the contrary, soils formed on shale-sandstone, conglomerates, basic igneous rocks, etc. despite their normally low productivity in wet years, may supply appreciable amounts of previously stored water to the stressed plants and to secure a not negligible biomass production even in dry years.

The presence of cracks or fractures and faults into the bedrock favours the soil formation by weathering or the removal of soil aggregates into the cracks by gravity. The formed 'tube' type soils are well protected from erosion and the percolating water can be stored into and protected from evaporation. The presence of deep soils in cracks and faults is of great ecological importance, supporting relatively well the natural vegetation under Mediterranean climatic conditions and preventing large hilly areas from desertification (Plate 2).

1.2 Rock fragments

Rock fragments have a great but variable effect on runoff and soil erosion (Poesen *et al*. 1994; Danalatos *et al*., 1995), soil moisture conservation (van Wesemael, *et al*., 1995; Moustakas *et al*., 1995) and biomass production (Poesen and Lavee, 1994), so playing an important role on land protection in the Mediterranean region. Generally, runoff and sediment loss are greater from stony than stone-free soils, apart from soils rich in coarse gravel (Fig. 1) on the surface subjected to heavy and prolonged showers. Bunte and Poesen (1993) found that interill sediment loss increased with increasing rock fragment percentage up to about 20%. Beyond this value, the limited space between fragments prevents development of scour holes and thus limits soil loss. For sheet and rill erosion, however, rock fragments cover always reduces sediment production in an exponential way (Poesen et al., 1994) (Fig. 2).

Plate 3. Cracks (hilly area in Sardinia) and dikes (hilly area in Lesvos) present into the bedrock favouring the growth of natural vegetation under adverse climatic conditions (photo by C. Kosmas).

Despite increasing runoff and erosion, cobbles have a beneficial effect on soil moisture conservation under conditions of moderate water stress such as those prevailing in spring and early summer, the most crucial periods for the productivity of winter crops. The presence of cobbles can be very valuable, particularly in dry years, by conserving appreciable amounts of water stored in previous times or adsorbed at night, thus protecting arge areas from desertification (Kosmas *et al*., 1998).

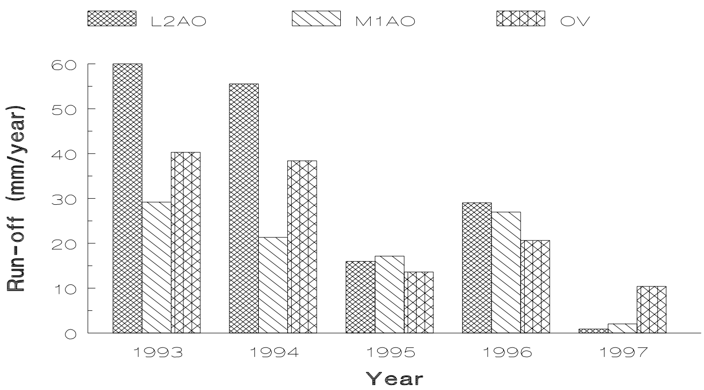


Fig. 1. Annual water run-off measured in bare plots covered with cobbles (L2AO), coarse gravel (M1AO), and vegetated but stone-free soil (OV) (source: C. Kosmas).

Stony soils along slope catenas of parent materials rich in rock fragments such as conglomerates, shale-sandstone, etc., despite their normally low productivity, may supply appreciable amounts of previously stored water to the stressed plants and ensure an adequate biomass production in dry years (Kosmas *et al*., 1993). As Fig.3 illustrates, the biomass production of wheat growing under water- limiting conditions was reduced by 10-30% in plots in which the rock fragments were removed from the soil surface during cultivation, as compared with the stony plots of the same soils along hillslope catenas. Soils formed on marl are free of rock fragments and despite their considerable depth and high productivity in normal and wet years, they are susceptible to desertification in particularly dry years. In such dry years, they are unable to support any vegetation due to adverse soil hydraulic properties and the absence of gravel and stone mulching.

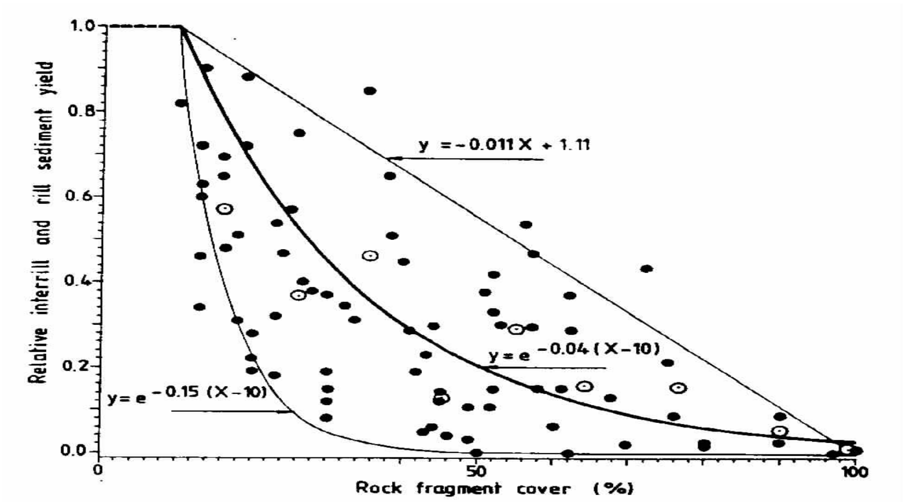


Fig. 2. Effect of rock fragment cover at the soil surface on relative interill and rill sediment yield (Poesen *et. al*., 1994).

1.3 Soil depth

Dryland soils on hilly areas are particularly vulnerable to erosion, especially when their vegetation cover has been degraded. Soils on Tertiary and Quaternary consolidated formations usually have a restricted effective soil depth due to erosion and limiting subsurface layers such as petrocalcic horizon, gravely and stony layer, and/or shallow bedrock. Therefore, the tolerance of these soils to erosion is low and, under hot and dry climatic conditions and severe soil erosion, rainfed vegetation can no longer be supported, leading to desertification.

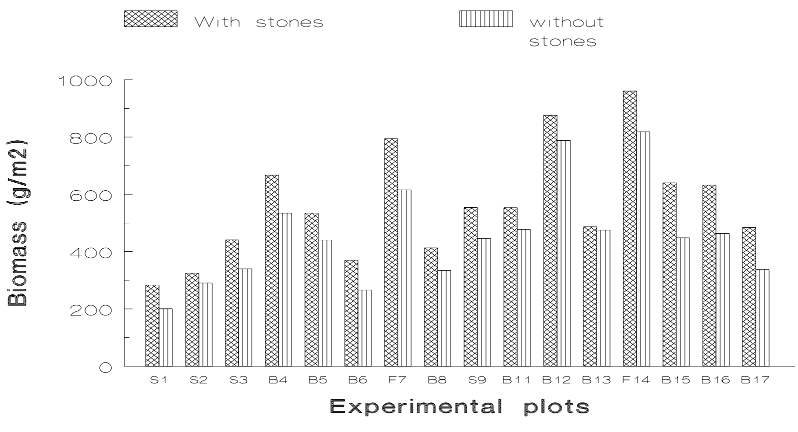


Fig. 3. Wheat biomass production measured along catenas in nearby plots with and without rock fragments in the soil surface (source: C. Kosmas).

Soils formed in various parent materials show different ability to support a considerable vegetation cover for erosion protection under given climatic conditions. Soils formed in pyroclastics (Fig. 4) are the most sensitive in supporting adequate macchia vegetation with a crucial depth of 10 cm under which the existing vegetation can not longer survive (Kosmas *et al*., 1998). Below that crucial depth, all the perennial vegetation disappears and only some annual plant species can survive. The erosion rates below that critical depth are very high, favouring the appearance of the underlying bedrock on the soil surface. Soils formed in schist-marble metamorphic rocks have a higher ability to support perennial vegetation under the same climatic conditions with crucial depth around 4-5 cm.

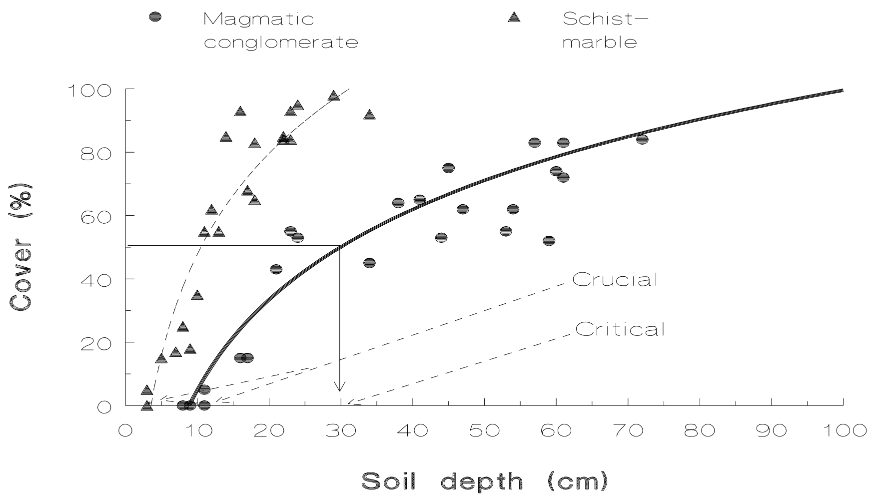


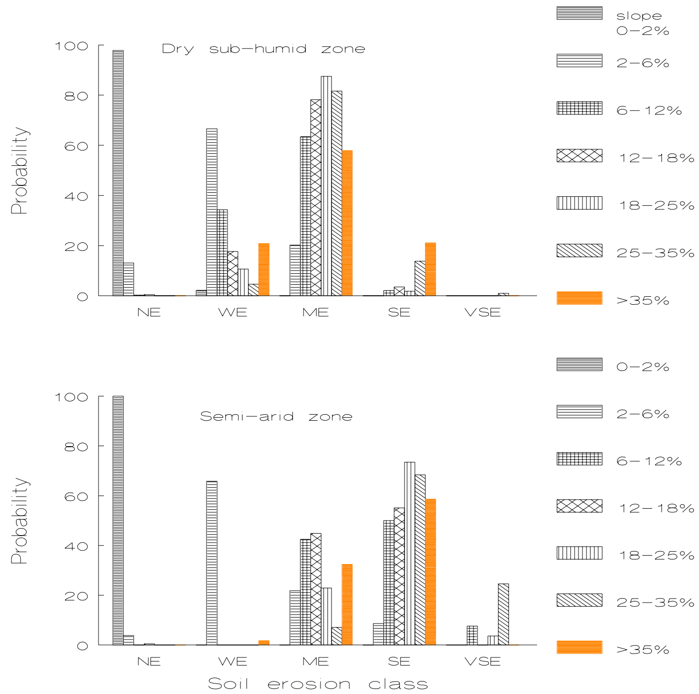
Fig. 4. Relation of percentage vegetation cover of *Sarcopoterium sp* and soil depth measured in areas with soils formed in pyroclastics (magmatic conglomerates) and schist-marble (Kosmas *et al*., 1998).

Given certain physical characteristics and underlying parent material, two soil depths, very important for land protection, can be distinguished, the critical and the crucial depth (Fig. 4). The critical depth can be defined as the soil depth in which plant cover achieves values above 40%. On soil less than that depth the recovery of the natural perennial vegetation is very low and the erosional processes may be very active resulting in further degradation and desertification of the land. When a hilly landscape of marginal capability is cultivated, agriculture should be abandoned before the soil reaches the critical depth. While the critical depth is a limit to cultivation, the crucial depth can be defined as a lesser soil depth on which the perennial vegetation can no longer be supported, and the whole soil structure is rapidly washed out by wind or water erosion. This is an irreversible process.

1.4 Slope gradient

Slope angle and generally topography are undoubtedly important determinants of soil erosion. Erosion becomes acute when slope angle exceeds a critical value and then increases logarithmically. Soil survey data of the island of Lesvos shows that slope grade has a variable effect in the different climatic zones, depending on annual rainfall. The probability of appearance of high erosion degree decreased with increasing rainfall for the same slope classes (Fig. 5). Severely eroded soils are present in the semi-arid zone with slopes greater than 12%, while slightly to moderately eroded soils are found in the dry sub-humid zone under the same slope classes. As Fig. 5 shows, the probability of finding severely eroded soils on moderately steep to very steep slopes is rather high in the semi-arid zone. On the opposite, moderately eroded soils have the highest probability of occurrence under similar slopes in the dry sub-humid zone.

Fig. 5. Probability of appearance of various degrees of erosion under different slope



classes in the semi-arid and dry sub-humid climatic zones of the island of Lesvos (NE=no erosion, WE=slight erosion, ME=moderate erosion, SE=severe erosion, VSE=very severe erosion) (Kosmas *et al.*, 1998).

1.5 Soil structure decline

Soil structure stability is affected by various factors such as change in organic matter content, use of heavy machinery, irrigation with poor quality of water, etc. Large scale deforestation of hilly areas around the Mediterranean, intensive cultivation, and burning of the vegetation results in a drastic reduction of the organic matter content and the aggregate stability of the surface soil horizon. Cultivation of the Thessaly hilly areas (Greece) brought about a decrease of organic matter content to less than 2.5% as compared with an excess of 5% occurring some 40 years ago due to water and wind erosion and frequently burning of the crop residues (Danalatos, 1993).

Land use change greatly affects organic matter content and aggregate stability. For example the shift from olive trees to vine cropping had a degrading effect on the organic matter content and the aggregate stability. Data collected along two catenas in Attica demonstrated that the organic matter content decreased by about 33% and the aggregate size by about 10 times in 12-years period of cultivation with vines as compared with the soils under olives (Kosmas *et al.*, 1995).

1.6 Salinization

The transport and distribution of salts within a landscape and in a soil profile reflect the prevailing water balance conditions, and the depth of the groundwater. Therefore, precipitation and evapotranspiration together with soil profile characteristics are important for the distribution of salts in a landscape and in a soil profile. A general decrease in precipitation and/or an increase in evapotranspiration will cause an increase of soils affected by saline or sodic conditions around the Mediterranean region. This is because in those regions with high evaporation rates, capillary rise is accelerated and salts accumulate residually, where drainage is nearly absent. The extent to which this will happen at a local scale will depend on various factors controlled by the water balance, soil type, and by the total salt and sodium inputs. Salinity problems will be most severe in areas receiving rainfall between 300 and 600 mm. The increasing concentrations of salts result in radical changes in the water economy of the soil, creating a potentially adverse ecological environment for native vegetation or agricultural crops leading to desertification (Plate 3).

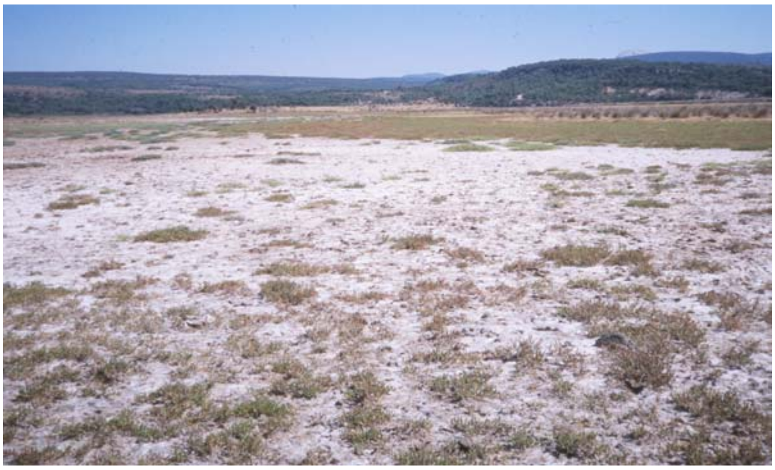


Plate 3. Flat area located along the seashore of Lesvos with very poorly drained soils and very shallow water table facing severe problems of salinization and desertification (photo by C. Kosmas, August 1997).

2. Climate quality

The uneven annual and interannual distribution of rainfall, the extreme events and the out of phase of rainy and vegetative seasons in the semi-arid and arid zones of the Mediterranean are the main climatic attributes that contribute to the degradation of land. Land in the above two climatic zones is unstable and desertification processes are triggered only if the other land components cross specific thresholds. Global climate change is expected to widen the present geography of the vulnerable zones in the Mediterranean. In a number of years, the prevailing weather conditions during the growing period of annual crops may be so adverse that the soils remain bare, creating favourable conditions for overland flow and erosion. Any loss of volume from these marginal lands greatly reduces the potential for biomass production, ultimately leading to desertification. Desertification at present threatens only the shallow and severely eroded soils. Global change may threaten the majority of them.

2.1 Precipitation

The atmospheric conditions that characterise a desert climate are those that create large water deficits, that is, potential evapotranspiration (ETo) much greater than precipitation (P). These conditions are evaluated by a variety of indices. One of these is the FAO-UNESCO (1977) bioclimatic index: P/ETo. Areas which are sensitive to desertification can be divided into the following categories:

- The arid zone : 0.03<P/ETo<0.20
- The semi-arid zone: 0.20<P/ETo<0.50
- The sub-humid zone: 0.50<P/ETo<0.75.

An area becomes naturally desertified when the ratio: P/ETo acquires values below a certain threshold, regardless of the other components. In contrast, when the ratio exceeds an upper threshold, desertification does not advance (FAO-UNESCO, 1977). The following scheme is proposed for the threat of desertification induced by the climate:

(DESERTIFICATION) 0.03 > P/ETo > 0.75 (NO DESERTIFICATION)

Erosion data collected in various sites along the Mediterranean region shows that the amount of annual rainfall of 280-300 mm is very crucial (Fig. 6). There is a tendency of increasing runoff and sediment loss with decreasing rainfall in hilly Mediterranean shrublands, especially in the region where rainfall is greater than 300 mm/year. Below to that limit, runoff and sediment loss decreases with decreasing rainfall.

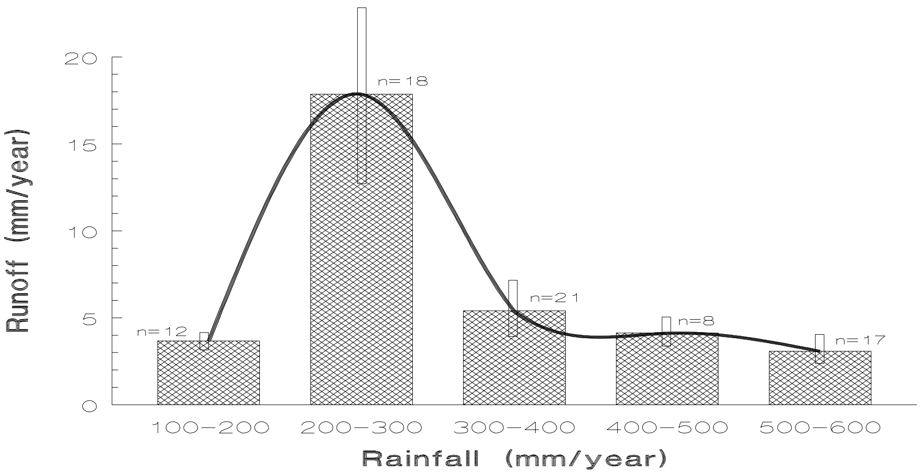


Fig. 6. Runoff-annual precipitation relationships measured in four Mediterranean sites under shrubland (Kosmas *et al*., 1997).

Rainfall amount and distribution are the major determinants of biomass production on hilly lands under Mediterranean conditions. Decreasing amounts of rainfall combined with high rates of evapotranspiration drastically reduce the soil moisture content available for plant growth. Reduced biomass production, in turn, directly affects the organic matter content of the soil and the aggregation and stability of the surface horizon to erosion. Studies on the effect of diminishing soil moisture on soil properties and biomass production of rainfed wheat in rainfall exclusion experiment showed that the total above ground biomass production was proportionally reduced with the amount of rainfall excluded (Kosmas *et al*., 1993). Reductions in biomass of 90%, 71.4%, and 53.4% were measured in the experimental plots in which rainfall was reduced by 65%, 50% and 30%, respectively (total amount of rain falling in the open field during the growing period R=361 mm). As Figure 7 shows, the leaf area index (LAI) of the crop was also greatly affected throughout the growing period. The maximum LAI-values measured in the plots of 100%, 70%, 50% and 35% rain interception were 5.2, 3.7, 2.9 and 1.6, respectively.

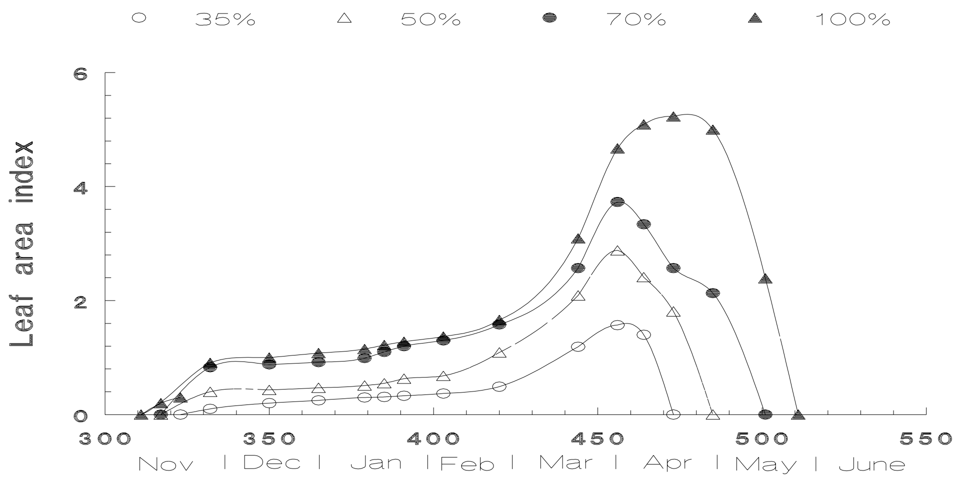


Fig. 7. The change in leaf area index of rainfed wheat grown in plots with 35%, 50%, 70% and 100% rain interception (Kosmas *et al.*, 1993).

2.2 Aridity

Aridity is a critical environmental factor in determining the evolution of natural vegetation by considering the water stress which may occur reducing vegetation cover. However, the existing Mediterranean vegetation presents a great capacity of adaptation and resistance to dry conditions, which most of these species can survive under prolonged droughts with soil moisture content below the theoretical wilting point for many months.

The effect of aridity on vegetation characteristics can be clearly demonstrated by the distribution of vegetation in the various climatic zones of Lesvos. The climate of the island of Lesvos can be divided into two major climatic zones defined as semi-arid and dry sub-humid. The great reduction in rainfall for about 45% combined with the high evapotranspiraton demands has greatly affected the vegetation performance. Due to the lack of available soil water, the semi-arid part of the island is dominated by poor *maquis* vegetation (Fig. 8), while olive trees, oak and pine forests prevail in the dry sub-humid part under similar topographical and geomorphological conditions with the previous zone. Vegetation cover increases with increasing soil depth and decreasing aridity.

In a comparative analysis of the Agri basin (Italy) and the Lesvos island indicated that the greatest part of the island (74%) is characterised as very dry with a Bagnouls-Gaussen bioclimatic aridity index greater than 150. In the opposite 48% of the Agri basin is characterised as moist with an aridity index less than 50. The rest of the Agri basin is characterised as dry with an aridity index ranging from 50 to 125. The greater aridity index of climate in Lesvos resulted in vegetation of higher resistance to drought than the vegetation existing in the Agri basin. Extensive pine (*Pinus sp*) forests and olive groves are dominant in the island. In contrast, 52% of the Agri basin is covered with vegetation of low to very low resistance to drought such as deciduous forest.

2.3 Aspect

Slope aspect is considered an important factor for land degradation processes. Aspect affects the microclimate by regulating isolation. The angle and the duration at which the sun rays strikes the surface of the soil depends on the slope aspect. In the Mediterranean region lands with southern and western aspects are warmer and have higher evaporation rates and lower water storage capacity than northern and eastern aspects. So a slower recovery of vegetation is expected in southern and western aspects and higher erosion rates than in northern and eastern aspects. As a consequence, southern exposed slopes usually have a lower vegetation cover than northern exposed slopes (Poesen *et al*., 1998)higher As Fig. 9 shows, the degree of erosion measured along north- and south-facing hillslopes is twice as much as or even higher in the south-facing slopes under various types of vegetation cover.

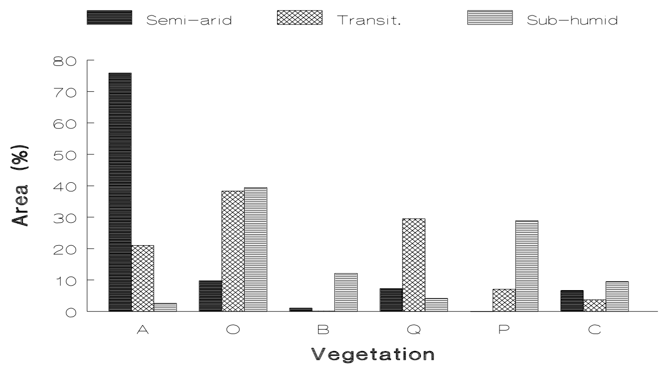


Fig. 8. Dominant vegetation present in the three climatic zones of Lesvos (A=sclerophylous, O=olives, B=evergreen oak, Q=deciduous oak, P=pines, C=annual crops).

3. Vegetation quality

The dominant biotic land component in terms of desertification is the vegetative cover of the land. Vegetation cover is very crucial for run-off generation and can be readily altered along the Mediterranean hilly areas depending on the climatic conditions and the period of the year. In areas with annual precipitation less than 300 mm and high evapotranspiration rate, the soil water available to the plants is reduced drastically and the soil remains relatively bare favouring overland water flow. Key indicators of desertification related to the existing natural or agricultural vegetation can be considered in relation to: (a) fire risk and ability to recover, (b) erosion protection offered to the soil, (c) drought resistance, and (d) percentage plant cover.

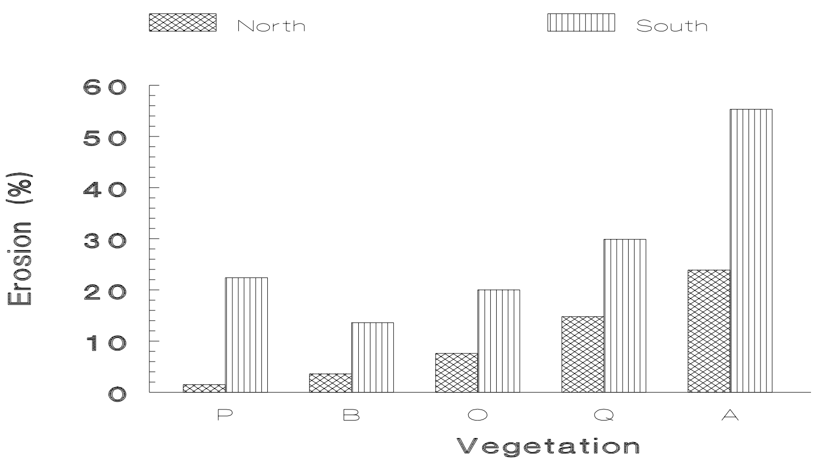


Fig. 9. Distinct erosion patches measured along hilslopes with various types of vegetation located at north and south-facing slopes (P=pines, B=evergreen oak, O=olives, Q=deciduous oak, A=perennial shrubs).

3.1 Fire risk and ability to recover

Forest fires is of the most important cause of land degradation in hilly areas of the Mediterranean region. Fires have become very frequent especially in the pine dominated forests (Fig. 10) during the last decades with dramatic consequences in soil erosion rates and biodiversity losses. The frequency of fire occurrence is lower in grasslands, and mixed Mediterranean macchia with evergreen forests. Also, Mediterranean pastures are frequently subjected to man-induced fires in order to renew the biomass production. The Mediterranean vegetation type is highly flammable and combustible due to the existence of species with high content of resins or essential oils.

Plants react to fire in very different ways. They possess numerous fire-related adaptations. For any given species, there is a range of fire-resistance possibilities which vary according to fire intensity (Trabaud, 1981). These possibilities may vary with growing season and maturity. For example, observations show that winter or spring fires do not harm subsequent development of sprouts of Quercus ilex or Quercus coccifera, while fires in summer or autumn which are more intense, decrease sprouting ability.

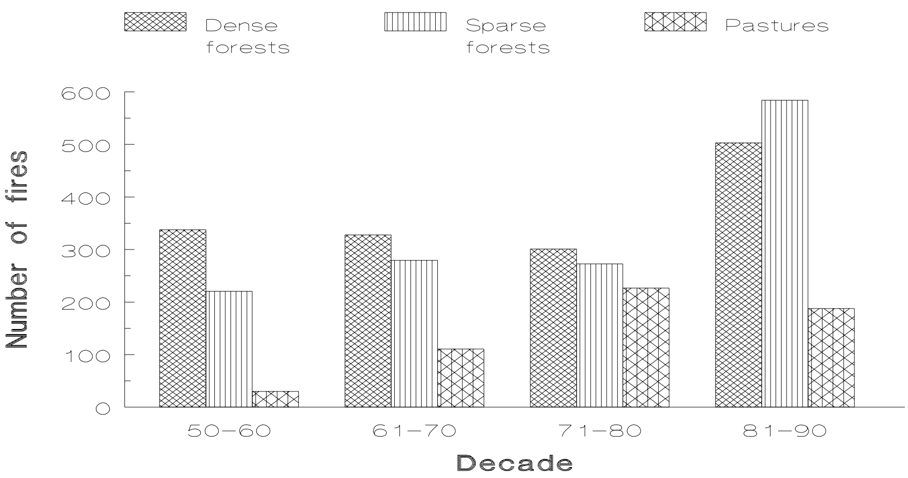


Fig. 10. Average fire frequency occurring in areas covered mainly with pine forests, mixed deciduous and evergreen oak forests, and pastures measured in Greece in the last three decades (Greek Ministry of Agriculture).

The Mediterrananean vegetation is known to have a high ability to recover after fire (Trabaud, 1993) and the environmental problems related to fire normally last for only a limited number of years after the fire occurred. Mediterranean ecosystems are well-adapted to fire, which can even be beneficial under certain conditions. There is no succession, in the strict sense of the term, sfter a fire incidence, since all the species, which constitute the mature plant community, are present already in the first year after the fire. There is an initial increase in plant diversity followed by a decrease as the regeneration process advances. (Trabaud, 1980). All this is true if no mismanagement takes place, which unfortunately is the case more often than not.

There are several parameters, which affect the process of recovery, apart from the fire and site characterisitics, which can be both natural and anthropogenic. Years of unusual drought (Mazzoleni and Esposito, 1993) or sites that can't be affected from the moist sea winds during summer (Saracino and Leone, 1993) ahow a slower rate of recovery. Human interference such as livestock grazing or change in the land use pattern may damage irreversibly the recovering vegetation (Clark, 1996). Particularly important are the time intervals between two subsequent fires. The ability of the ecosystems to recover is not unlimited and a fire frequency beyond a certain threshold can also lead to a degraded stage (Trabaud, 1980). This can be due both to the nutrient and seed bank depletions and to increased erosion. These processes have already led to severe degradation and desertification of extensive hilly areas in the Mediterranean region.

There are two main strategies of survival for plants in fire-prone ecosystems: resprouting and germinating. In the first case the plants resprout from the undergraound parts of them, which survive the fire due to soil protection. In the second case the seeds are bale to withstand the high temperatures and in some cases the germnation rate is drastically increased. part of the soil seed bank is destroyed by fire and the propostion becaomes greater with increasing fire intensity (Cancio *et al.,* 1993). The same is true for resprouters; the more severe the fire the deeper down are the intact plant parts that must resprout (Clark, 1996).

3.2 Soil erosion protection

Vegetation and land use are clearly important factors controlling the intensity and the frequency of overland flow and surface wash erosion (Bryan and Campbell, 1986; Mitchell, 1990). Extensive areas cultivated with rainfed crops such as cereals, vines, almonds and olives are mainly confined to hilly lands with shallow soils very sensitive to erosion. These areas become vulnerable to erosion and desertification because of the decreased protection by vegetation cover in reducing effective rainfall intensity at the ground surface (Faulkner, 1990). Perennial crops such as almonds, and olives have largely expanded in Mediterranean hilly areas, while vines have declined during the last decades (Grove, 1996). These crops require frequent removal of annual vegetation using pesticides or by tillage. Actually, such soils remain almost bare during the whole year, creating favourable conditions for overland flow and soil erosion.

Erosion data measured in eight sites along the northern Mediterranean region and the Atlantic coastline located in Portugal, Spain, France, Italy and Greece in a variety of landscapes and under a number of land-uses representative of the Mediterranean region, such as agricultural land with rainfed cereals, vines, olives, eucalyptus plantation or natural vegetation (shrubland) showed that the greatest rates of runoff and sediment loss were measured in hilly areas under vines (Fig. 11). Areas cultivated with wheat are sensitive to erosion, especially during winter, generating intermediate amounts of runoff and sediment loss especially under rainfalls higher than 380 mm per year. Olives grown under semi-natural conditions, as for example with an understory of vegetation of annual plants greatly restrict soil loss to nil values. Erosion in shrublands increased with decreasing annual rainfall to values in the range 280-300 mm and then it decreased with decreasing rainfall.

Several hilly areas under natural forests around the Mediterranean region have reforested with exotic species such as *eucalyptus.* Such soils are undergoing intense erosion as compared with soils left under natural vegetation (Aru and Barrocu, 1993). However, the measured rates of erosion under *eucalyptus* are relatively lower than those measured under vines, almonds and cereals.

Soil erosion data measured under various types of vegetation and certain physiographic conditions in the island of Lesvos showed that the best protection from erosion was measured in areas with a dominant vegetation of evergreen oaks, pines and olive trees under semi-natural condition (Fig. 9). Pines have lower ability to protect the soils in southern aspects due to the higher rate of litter decomposition and restrict growth of understory vegetation. Deciduous oak trees offered relatively low protection from erosion in cases that the falling leaves do not cover the whole soil surface.

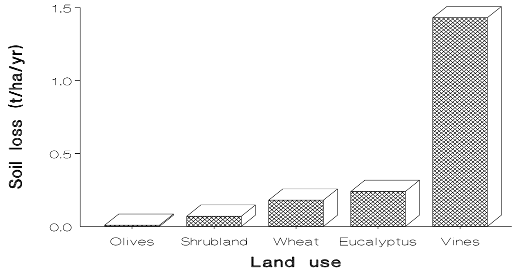


Fig. 11. Average annual erosion rates measured in various types of land uses in runoff plots located along the northern Mediterranean region (C. Kosmas *et al*., 1997).

3.4 Drought resistance

The main factors affecting the evolution of the Mediterranean vegetation, in the long term, are related to the irregular and often inadequate supply of water, the long length of the dry season, and perhaps fire and grazing (Clark, 1996). According to the types of leaf generation, the following two major groups of vegetation can be distinguished (Clark, 1996): (a) deciduous and drought avoiding with a large photosynthetic capacity but no resistance to desiccation; and (b) evergreen (sclerophyllous) and drought enduring with low rates of photosynthesis. The main response of the plants to increased aridity is the reduction in leaf area index. Severe droughts that cause a reduction in leaf area index may be beneficial in the short term as it reduces transpiration, but such drought will increase the probability of enchanced soil erosion when rain eventually falls, as protective vegetation cover is reduced.

The various ecosystems present in the Mediterranean region presents a great capacity of adaptation and resistance in aridity which most of the species existing under Mediterranean climatic conditions have to survive under long droughts and soil moisture contents below the theoretical wilting point for many months (Table 1). Probably the expected changes in the vegetation performance, resulted from a gradual precipitation decrease, could be only noticed after a critical minimum number of years.

Table 1. Classification of the dominant Mediterranean vegetation according to a decreasing rate of drought resistance.

Cla	*Types of vegetation*
1	Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia
2	Conifers, permanent grassland
3	Evergreen perennial agricultural trees
4	Deciduous perennial agricultural trees
5	Deciduous forests
6	Annual agricultural crops, annual grasslands

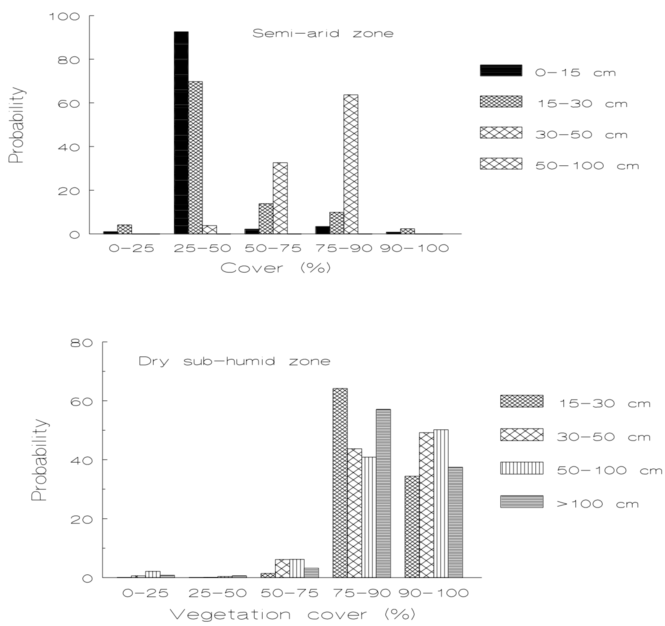
Among the prevailing perennial agricultural crops in the Mediterranean, olive trees present a particularly high adaptation and resistance to long term droughts and support a remarkable diversity of flora and fauna (Plate 5) even higher than some natural ecosystems (Margaris, 1995). Under these conditions, annual vegetation and plant residues form a high soil surface cover, preventing surface sealing and minimising the velocity of the overland run-off water (Plate 5). In the case that the land is intensively cultivated, then high erosion rates are expected. The olive groves can be considered as a natural forest highly adapted in dry Mediterranean conditions, with lower vulnerability to fires as compared to pine forests, protecting hilly areas from desertification.

Plate 5. Olive groves (a) with understorey of annual vegetation (Lesvos), well-protected from erosion (left) and (b) intensively cultivated (Cordoba), and severely eroded (right) (photo by C. Kosmas, spring 1997).

3.5 Plant cover

Many studies showed that the variation in runoff and sediment yields in drainage basins is attributed to the vegetation cover and land use management changes (Douglas, 1969; Reed, 1971; Williams and Reed, 1972; Patton and Schumm, 1975; Newson, 1985; Bryan and Campbell, 1986). Many authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Elwell and Stocking, 1976; Lee and Skogerboe, 1985; Francis and Thornes, 1990). A piece of land is considered desertified when the biomass productivity drops below a certain threshold value. A value of 40% vegetative cover is considered critical below which accelerated erosion dominates in a sloping land (Thornes, 1988). This threshold may be modified for different types of vegetation, rain intensity and land attributes. It shows, however, that degradation begins only when a large portion of the land's surface is denuded, then it proceeds with an accelerated mode, that cannot be arrested by land resistance alone. Deep soils on unconsolidated parent materials show slow rates of degradation and loss of their biomass production potential. In contrast, shallow soils with lithic contact on steep slopes have low productivity, and low erosion tolerance if they are not protected by vegetation.

Fig. 12 Probability of appearance of percentage cover in various soil depth classes measured in two climatic zones of the island of Lesvos



Soil and vegetation survey data of the island of Lesvos clearly indicated that the percentage cover was greatly affected by the soil depth in the various climatic zones (Kosmas *et al*., 1998). Fig. 12 shows the frequency of appearance of the various classes of vegetation cover present in the three climatic zones of the island of Lesvos. Vegetation cover increased with increasing soil depth and decreasing drought. In the soil depth class of 15-30 cm, the vegetation cover class of 25-50% had the maximum frequency of appearance (93%) in the semi-arid zone, whereas areas with soils having the same soil depth class had a higher vegetation cover with a 64% maximum frequency of appearance of the cover class 75-90% cover in the dry sub-humid zone.

4. Management quality and human factors

The definition of ESAs to desertification requires both key indicators related to the physical environment and to the human-induced stress. A piece of land, irrespective of its size, is characterised by a particular use. This use is associated with a given type of management which is dictated by and changes under the influence of environmental, social, economic, technological and political factors. Depending on the particular type of management, land resources are subject to a given degree of stress. Moreover, the existence of environmental policies which apply to a certain area moderate the anticipated impacts of a given land use type compared to the situation where no such policies are in effect.

4.1 Land use and intensity of land use

The extensive deforestation of hilly areas and intensive cultivation with rainfed cereals in the Mediterranean has already led to accelerated erosion and degradation in the last century. The erosion risk is especially high in areas cultivated with rainfed cereals (Plate 6). For one or two months after sowing winter cereals the land remains almost bare, and the erosion risk is high considering that rains of high intensity and occasionally long duration occur during that period. The sloping lands of the Thessaly plain, the greatest lowland of Greece, were for centuries under grazing especially in winter by transhuman flocks and herds. The rapid increase in population due to immigration in early 1920's resulted in the sharp increase of the areas which were brought under wheat cultivation. Erosion experiments and estimations from the exposure of tree roots demonstrated that erosion on these areas has proceeded at rates of 1.2-1.7 cm soil per year since the introduction of wheat. The hilly soils on Tertiary and Quaternary hilly landforms usually have limiting subsurface layers, such as petrocalcic horizons or bedrock, and under high erosion rates and hot and dry climatic conditions, growth of cereals produces increasingly poor yields and the cultivated land is abandoned.

Plate. 6. Hilly areas (a) cultivated with cereals and subjected to accelerated erosion (left, Cordoba Spain) and abandoned after long period cultivation with wheat highly degraded (right, Thiva Greece) under high desertification risk (photo by C. Kosmas).

Many hilly areas around the Mediterranean are experiencing abandonment at an increasing rate.

Land abandonment may lead to a deteriorating or improving phase of the soils, depending on the particular land and climatic conditions of the area. Hilly areas that can support sufficient plant cover may improve with time by accumulating organic materials, increasing floral and faunal activity, improving soil structure, increasing in infiltration capacity and therefore, causing a decrease in the erosion potential (Kosmas *et al*. 1995). In cases of poor plant cover, the erosional processes may be very active and the regeneration of these lands may be irreversible. In cases of land partially covered by annual or perennial vegetation, the remaining bare land with soils of low permeability (clays) creates favourable conditions for overland flow, soil erosion and land degradation (Plate 6).

4.2 Overgrazing

Wheat production in hilly Mediterranean areas has drastically declined during the last few decades and the intensity of grazing has increased at the same time (Fig.13). Shepherds usually damage the natural vegetation by deliberately setting fires to eradicate the vegetation and encourage the growth of grass, which they then overgraze. Once the land is bare of its vegetative cover and the soil is loosened, the torrential rains of autumn and winter begin to wash away the topsoil. The process of land degradation can be greatly accelerated by high densities of livestock which lead to vegetation degradation and, in turn, to soil compaction. An obvious consequence of overgrazing is the increase in soil erosion, since the gradual denudation of the landscape exposes the soil to water and wind erosion. Under such management conditions and hot and dry climatic conditions, soils of these areas cannot economically support a sufficient vegetative cover, leading to desertification (Plate 7). Overgrazing of this climatically and topographically marginal areas, accompanying by fires, constitutes a desertification-promoting land use, further deteriorating the existing land resources.

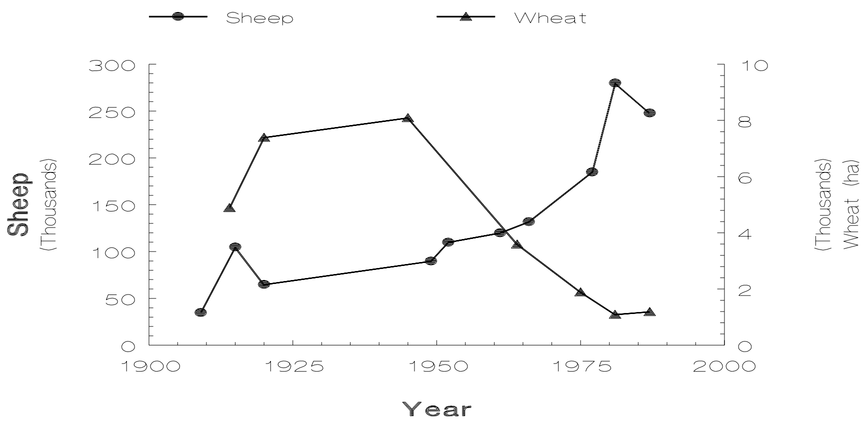


Fig. 13. Change in the number of sheep grazing in the island of Lesvos and the total area cultivated with cereals during the last 90 years (Kosmas, 1997).

4.3 Abandonment of terraced land

In the last decades, favourable soil and climatic conditions and the availability of ground or surface water has resulted in intensive farming of the lowlands of the Mediterranean region. The development of high input agriculture in the plains provided much higher net outputs than those obtained from terracing agriculture. Furthermore, in the last decades, the value of such terraces has markedly decline because of low accessibility by tractors. At present, most of these areas have been abandoned, and the terraces have been collapsed causing a rapid removal of the soil by the runoff water, apart from some cases that the stone walls are protected by the roots of fast growing shrubs and trees. Maintaining such terraces appears a very expensive practice comparing to most other alternatives for soil erosion control (Plate 8). Considering that such terraces protect very valuable soil for preserving the natural vegetation, these agricultural structures should be ameliorated with the aid of the national consolidation schemes, particularly in the environmentally sensitive areas.

Plate 7. Badly degraded area (Lesvos) due to adverse climatic conditions, intensive cultivation in the past and overgrazing accompanying with fires today (photo by C. Kosmas, October 1996).

4.4 Fires

The recent number and the extent of forest fires occurring in the Mediterranean region are amongst the most serious environmental problems. In addition to the loss of vegetation, forest fires induce changes in physico-chemical properties of soils such as water repellency, loss in nutrients and increased runoff and erosion. They also extinguish wildlife habitat, cause loss of human life and damage infrastructure. The loss of vegetation after fire and the progressive inability of soils to regenerate adequate vegetation cover due to erosion has already led to severe degradation and desertification of extensive hilly areas in the Mediterranean region.

Plate 8. A typical example of an abandoned terraced area (Peloponnesus, Greece), in which terraces have collapsed resulting washing out of the soil (photo by C. Kosmas).

Fires have become frequent in the pine dominated forests during the last fifty years. Most of the fires can be attributed to the people carelessness. The majority of fires occur in areas with high xerothermic indices and moisture deficits. Soil dryness and wind speed are the principal factors of fire evolution. The areas affected by forest fires are increasing dramatically throughout the Mediterranean basin. In the period from1960 to 1975, the average rate of burned area was 200 000 ha/yr, from 1975 to 1980 470 000 ha/yr, and 660 000 ha/yr from 1981 to 1985 (Conacher and Sala, 1998). Since 1960s, 1 144 710 hectares have been burned in Greece. Considering that the forest land in Greece covers about 8 200 000 ha, therefore 14% of that area has been affected by fires in the last 38 years. Similar conditions have been reported for other areas of the Mediterranean region. For example 9.4% of the forested area has been affected by fires in Spain during the last 12 years.

Erosion rates seem to be enhanced after fires. The increased erosion rates are only partly due to the removal of vegetation. More important seems to be the forming of an impermeable subsurface layer, which decreases infiltration rates, while causing a quick saturation of the upper layers leading to overland flow and erosion (Giovannini and Lucchesi, 1993). In contrast aggregate stabiloity increases after fire and that increase is more pronoiunced after severe burns (Molina, 1993).

B. METHODOLOGY FOR MAPPING ENVIRONMENTALLY SENSITIVE AREAS (ESAs) TO DESERTIFICATION

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1. Definition of ESAs

The different types of ESAs to desertification can be analysed in relation to various parameters such as landforms, soil, geology, vegetation, climate, and human action. Each of these parameters is grouped into various uniform classes with respect the its behaviour on desertification and weighting factors are assigned in each class. Then the following four qualities are evaluated (a) soil quality, (b) climate quality, (c) vegetation quality, and (d) management quality. After the computation of four indices for each quality, the ESAs to desertification are defined by combining them (Fig. 14). All the data defining the four qualities are introduced in a regional geographical information system (GIS), and overlaid in accordance with the developed algorithm and maps of ESAs to desertification are compiled. This approach includes parameters which can be easily found in existing soil, vegetation, and climate reports of an area.

Three general types of Environmentally Sensitive Areas (ESAs) to desertification can be distinguished based on the stage of land degradation:

Type A: Areas already highly degraded through past misuse, presenting a threat to the environment of the surrounding areas. For example, badly eroded areas subject to high runoff and sediment loss. This may cause appreciable flooding downstream and reservoir sedimentation. These are ***critical*** **ESAs**.

Type B: Areas in which any change in the delicate balance of natural and human activity is likely to bring about desertification. For example, the impact of predicted climate change due to greenhouse warming is likely to enchance reduction in the biological potential due to drought causing areas to lose their vegetation cover, subject to greater erosion, and finally shift to the Type A category. A land use change, as for example, a shift towards cereals cultivation, on sensitive soils might produce immediate increase in runoff and erosion, and perhaps pesticide and fertiliser pollution downstream. These are ***fragile*** **ESAs**.

Type C: Areas threatened by desertification under significant climate change, if a particular combination of land use is implemented or where offsite impacts will produce severe problems elsewhere, for example pesticide transfer to downslope or downstream areas under variable land use or socio-economic conditions. This would also include abandoned land which is not properly managed. This is a less severe form of Type B, for which nevertheless planning is necessary. These are ***potential ESAs***.

Areas with deep to very deep, nearly flat, well drained, coarse-textured or finer soils, under semi-arid or wetter climatic conditions, independently of vegetation are considered as ***non-threatened by desertification.***

B. METODOLOGIA PER MAPPARE ESAS

1. Definizione delle ESAs

I diversi tipi d'ESAs alla desertificazione possono essere analizzati in relazione ai vari parametri come morfologia del suolo, profondità del suolo, composizione geologica, vegetazione, clima o azioni umane. Ognuno di questi parametri è raggruppato in vari classi uniformi in relazione alla sua influenza sulla desertificazione, e di pesi assegnati ad ogni classe. In seguito sono valutati quattro parametri: (a) la qualità del terreno, (b) la qualità del clima, (c) la qualità della vegetazione e (d) la qualità della gestione. Dopo aver calcolato quattro indici per ciascun qualità del suolo, si procede alla definizione delle ESAs alla desertificazione combinando i quattro indici (Fig. 14). Tutti i dati che definiscono i quattro parametri del suolo sono introdotti in un GIS regionale, e sovrapposti secondo gli algoritmi sviluppati, quindi sono prodotte le mappe delle ESAs alla desertificazione.

Si possono distinguere tre tipi generali d'ESAs alla desertificazione in base al grado di degradazione del suolo:

***Tipo A:** Aree già altamente degradate tramite il cattivo uso del terreno, che presenta una minaccia all'ambiente delle aree circostante. Per esempio, aree molto erose soggette ad un'alto deflusso e perdita di sedimenti. Queste aree sono denominate **ESAs critiche**.*

***Tipo B:** Aree dove qualsiasi cambiamento del delicato equilibrio delle attività naturali o umane molto probabilmente porterà alla desertificazione. Per esempio, l'impatto del previsto cambiamento climatico causato dall'effetto serra probabilmente determinerà una riduzione del potenziale biologico causata dalla siccità provocando la perdita della copertura vegetale in molte aree, che saranno soggette ad una maggiore erosione, e diventeranno di Tipo A. Un cambiamento nell'uso del suolo, per esempio uno spostamento verso la coltivazione di cereali su suoli sensibili potrebbe produrre un immediato aumento del deflusso e dell'erosione, e forse l'inquinamento a valle da parte di pesticidi e fertilizzanti. Queste aree sono denominate **ESAs fragili**.*

Tipo C:** Aree minacciate dalla desertificazione sono soggette ad un significativo cambiamento climatico; se una particolare utilizzazione del suolo è praticata con criteri gestionali non corretti si potranno creare seri problemi, per esempio il scorrimento di pesticidi lungo la pendice e deposito a valle dei principi attivi nocivi alla vegetazione. Questo tipo è meno severo del precedente, ma ciò nonostante è necessaria attuare una pianificazione delle aree. Queste aree sono denominate **ESAs potenziali.

*Aree profonde o molto profonde, pianeggiati, ben drenati, e con tessitura grossolana o suoli con particelle più fini, soggette a condizioni semi-aride o con condizioni climatiche più umide, indipendentemente della loro copertura vegetale sono considerate come aree non soggette a desertificazione o comunque soggetti al lento processo di **degradazione e comunque stabili.***

Β. ΜΕΘΟΔΟΛΟΓΙΑ ΧΑΡΤΟΓΡΑΦΗΣΗΣ ΠΕΠ ΣΤΗΝ ΑΠΕΡΗΜΩΣΗ

2. Ορισμός των ΠΕΠ

Οι διαφορετικές κατηγορίες των ΠΕΠ για την απερήμωση μπορούν να αναλυθούν σε σχέση με διάφορες παραμέτρους όπως η γεωμορφολογία, το έδαφος, η γεωλογία, η βλάστηση, το κλίμα και οι ανθρώπινες δραστηριότητες. Κάθε μια από αυτές τις παραμέτρους ομαδοποιείται σε διάφορες ομοιογενείς κατηγορίες σε σχέση με τη συμπεριφορά της προς την απερήμωση και σε κάθε κατηγορία δίνονται συντελεστές βαρύτητας. Μετά οι ακόλουθες τέσσερεις ποιότητες αξιολογούνται: (α) ποιότητα εδάφους, (β) ποιότητα κλίματος, (γ) ποιότητα βλάστησης και (δ) ποιότητα διαχείρισης. Μετά από τον υπολογισμό των τεσσάρων δεικτών (ενός για κάθε κατηγορία) οι ΠΕΠ για την απερήμωση προσδιορίζονται από το συνδυασμό τους. (Εικ. 14). Όλα τα δεδομένα που προσδιορίζουν τις τέσσερεις ποιότητες εισάγονται σε ένα γεωγραφικό πληροφοριακό σύστημα και γίνονται διαδοχικές επιθέσεις με βάση τον αλγόριθμο που αναπτύχθηκε οπότε και φτιάχνονται οι χάρτες των ΠΕΠ. Αυτή η προσέγγιση περιλαμβάνει παραμέτρους που μπορούν να βρεθούν εύκολα σε διαθέσιμες εκθέσεις για το έδαφος, το κλίμα και τη βλάστηση μιας περιοχής.
Τρεις γενικές κατηγορίες Περιβαλλοντικά Ευαίσθητων Περιοχών (ΠΕΠ) για την απερήμωση μπορούν να διακριθούν με βάση το στάδιο της υποβάθμισης:

Κατηγορία Α: *Περιοχές ήδη υποβαθμισμένες λόγω κακής χρήσης στο παρελθόν που παρουσιάζουν κινδύνους για το περιβάλλον γειτονικών περιοχών. Για παράδειγμα έντονα διαβρωμένες περιοχές που υπόκεινται σε υψηλή επιφανειακή απορροή και απώλεια ιζήματος. Αυτό μπορεί να προκαλέσει σημαντικά πλημμυρικά φαινόμενα στα κατάντη και πρόσχωση των φραγμάτων. Αυτές είναι οι* ***κρίσιμες ΠΕΠ****.*

Κατηγορία Β: *Περιοχές στις οποίες κάθε αλλαγή στην λεπτή ισορροπία φυσικής και ανθρώπινης δραστηριότητας είναι πιθανόν να προκαλέσει απερήμωση. Για παράδειγμα η επίδραση της προβλεφθείσας κλιματικής αλλαγής λόγω του φαινομένου του θερμοκηπίου είναι πιθανόν να προκαλέσει μείωση του βιολογικού δυναμικού λόγω της ξηρασίας που θα οδηγήσει στην απώλεια της φυτοκάλυψης από ορισμένες περιοχές, θα τις εκθέσει έτσι σε μεγαλύτερη διάβρωση και τελικά θα τις μετατοπίσει στην κατηγορία Α. Μια αλλαγή της χρήσης γης, όπως για παράδειγμα μια μετατόπιση προς την καλλιέργεια σιτηρών σε ευαίσθητα εδάφη μπορεί να προκαλέσει άμεση αύξηση στην απορροή και τη διάβρωση και ίσως μόλυνση από φυτοφάρμακα και λιπάσματα στα κατάντη. Αυτές είναι* ***ευαίσθητες ΠΕΠ****.*

Κατηγορία Γ: *Περιοχές που απειλούνται από την απερήμωση κάτω από σημαντική κλιματική αλλαγή, αν εφαρμοστεί κάποιος ειδικός συνδυασμός χρήσεων γης ή εκεί όπου δημιουργούνται έντονα προβλήματα από επιδράσεις που ξεκινούν από αλλού, για παράδειγμα η μεταφορά σε χαμηλότερες περιοχές φυτοφαρμάκων που χρησιμοποιήθηκαν ψηλότερα κάτω από διαφορετικές χρήσεις γης ή κοινωνικοοικονομικές συνθήκες. Αυτό θα περιλάμβανε ακόμα εγκαταλελειμμένη γη η οποία δε διαχειρίζεται σωστά. Αυτή είναι μια λιγότερο σοβαρή περίπτωση από την κατηγορία Β, για την οποία όμως είναι απαραίτητος ο σχεδιασμός. Αυτές είναι οι* ***δυνητικές ΠΕΠ****.*

Περιοχές με βαθιά ως πολύ βαθιά, σχεδόν επίπεδα, καλά αποστραγγιζόμενα, χονδρόκοκκα ή και πιο λεπτόκκοκα εδάφη κάτω από ημίξηρες ή και πιο υγρές κλιματικές συνθήκες ανεξάρτητα από τη βλάστηση θεωρούνται σαν ***μη απειλούμενες*** *από την απερήμωση.*

B. METODOLOGIA PARA A CARTOGRAFIA DAS ESAs

2. Definição de ESAs

Os diferentes tipos de ESAs no contexto da desertificação podem ser analisados relativamente a vários parâmetros, tais como morfologia, solos, geologia, coberto vegetal, clima, e acção antrópica. Cada um destes parâmetros é agrupado em diferentes classes uniformes que reflectem o seu comportamento relativamente à desertificação, sendo atribuídos factores de ponderação para cada classe. Seguidamente, as quatro qualidades dos recursos da terra são avaliadas: (a) qualidade de solo. (b) qualidade de clima. (c) qualidade de vegetação e (d) qualidade de gestão. Depois do tratamento informático dos quatro índices para cada qualidade, as ESAs são definidas pelo cruzamento dessas qualidades (Fig. 14). Toda a informação relativa às diferentes qualidades dos recursos da terra é introduzida num Sistema de Informação Geográfica (SIG) de base regional, sendo sobrepostos os diferentes níveis de informação de acordo com um algoritmo matemático, de modo a produzir mapas de Áreas Ambientalmente Sensíveis (ESAs) no contexto da desertificação. Esta abordagem inclui parâmetros que podem ser facilmente acessíveis em estatísticas e fontes de informação sobre solos, clima e vegetação.

Podem distinguir-se, deste modo, três tipos principais de ESAs no contexto da desertificação, baseadas no seu estado de degradação:

Tipo A: *Áreas já bastante degradadas devido a uma incorrecta utilização no passado, constituindo uma ameaça para o ambiente das áreas envolventes. Por exemplo, áreas severamente erodidas, sujeitas a elevados índices de escorrência superficial e de perda de solo. Neste caso podem ocorrer a jusante inundações com alguma gravidade e a sedimentação das albufeiras. Estas são as* ***ESAs Críticas.***

Tipo B: *Áreas onde qualquer alteração no delicado equilíbrio entre o meio natural e as actividades humanas pode conduzir o ecossistema no sentido da desertificação. Por exemplo, o impacto da previsível alteração climática devido ao aquecimento global (efeito de estufa) pode potenciar uma redução do potencial biológico devido à ocorrência de secas, causando uma redução do coberto vegetal, um aumento da erosão do solo e por fim uma mudança para a categoria do Tipo A. Uma mudança do uso do solo, por exemplo no sentido do cultivo de cereais, em áreas de solos com elevada sensibilidade, pode produzir um aumento imediato nos fenómenos de escorrência superficial e na erosão hídrica, e talvez ainda problemas de poluição a jusante devido ao arrastamento de pesticidas e fertilizantes. Estas são* ***ESAs Frágeis****.*

Tipo C: *Áreas ameaçadas pela desertificação em face de uma significativa alteração climática, se uma particular combinação de usos do solo for implementada e onde impactos externos podem produzir graves problemas, como por exemplo a transferência de pesticidas ao longo das vertentes e cursos de água para áreas a jusante, sujeitas a uma variedade de usos de solo e condições socioeconómicas. Esta situação inclui também as terras que são abandonadas e não devidamente geridas posteriormente. Trata-se de uma forma menos severa que o Tipo B, para a qual, no entanto, é necessário ordenamento e gestão. Estas são as* ***ESAs Potenciais****.*

As áreas com solos profundos ou muito profundos, quase planos, bem drenados, com textura grosseira ou mais fina, sob condições climáticas semi-áridas ou mais húmidas, independentemente do coberto vegetal, são consideradas como não ameaçadas ou ***não afectadas pela desertificação.***

B. METODOLOGIA PARA LA CARTOGRAFIA DE LAS AMS

1. Definición de AMS

Los diferentes tipos de AMS a la desertificación pueden ser analizados en relación a varios parámetros como geoformas, suelo, geología, vegetación, clima y acción humana. Cada uno de estos parámetros se agrupa dentro de varias clases uniformes con respecto a su comportamiento sobre el proceso de desertificación y se les asignan factores de ponderación dentro de cada clase. Se pueden evaluar las siguientes cuatro calidades de la tierra: (a) calidad del suelo, (b) calidad del clima, (c) calidad de la vegetación y (d) calidad de la gestión. Tras la computación de los cuatro índices para cada calidad de la tierra, las ASM a la desertificación son definidas por la combinación de estos índices (Fig. 14). Todos los datos que definen las cuatro calidades de la tierra se introducen en un sistema de información geográfica (SIG) regional, se superponen de acuerdo con el algoritmo desarrollado, y los mapas de las AMS a la desertificación son compilados. Esta aproximación incluye parámetros que se pueden encontrar fácilmente en los informes existentes sobre suelo, vegetación y clima de un área.

Se pueden distinguir tres tipos diferentes de Areas Medioambientalmente Sensibles (AMS) a la desertificación, sobre la base del estado de degradación de la tierra:

Tipo A: *Areas que ya están altamente degradadas por el mal uso pasado, que presentan una amenaza para el medio ambiente de las áreas adyacentes. Por ejemplo, areas muy erosionadas sujetas a alta escorrentía y alta producción de sedimentos, que pueden causar inundaciones aguas abajo y colmatación de embalses. Son las **AMS críticas**.*

Tipo B: *Areas en las cuales cualquier cambio en el delicado balance entre la naturaleza y la actividad humana puede, verosílmente, causar desertificación. Por ejemplo, el impacto del cambio climático que se predice debido al efecto invernadero verosílmente intensificará la reducción del potencial biológico debido a que la sequía causará la pérdida de la cobertura vegetal en ciertas áreas, que sufrirán mayor erosión y finalmente cambiarán a la categoría de Tipo A. Un cambio en el uso del suelo, como por ejemplo un cambio hacia el cultivo del cereal, sobre suelos sensibles pudiera producir un incremento inmediato en la ecorrentía y la erosión, y quizá contaminación por pesticidas y fertilizantes aguas abajo. Estas áreas son las **AMS frágiles**.*

Tipo C: *Areas amenazadas por desertificación ante un cambio climático significativo, si se implementa una combinación particular de usos del suelo o dónde los impactos no locales (aquellos que son inducidos por la AMS sobre zonas adyacentes o lejanas) producen problemas severos en otras áreas, por ejemplo pesticidas transferidos hacia áreas ladera y aguas abajo, bajo condiciones de uso del suelo y socioeconómicas variables. También se incluirían campos abandonados que no son apropiadamente gestionados. Es una forma menos severa del Tipo B, ante la cual, no obstante, es necesaria una planificación. Son las **AMS potenciales.***

*Areas con suelos profundos o muy profundos, casi llanas, bien drenadas, de textura gruesa o más fina, bajo condiciones climáticas semiáridas o más humedas, independientemente de su vegetación se consideran como **no amenzadas por desertificación.***

2. Data collection

The following data of the physical environment and land management characteristics are required for the definition of ESAs to desertification: (a) soil data, (b) vegetation data, (c) climate data, and (d) land management characteristics (Fig. 14).

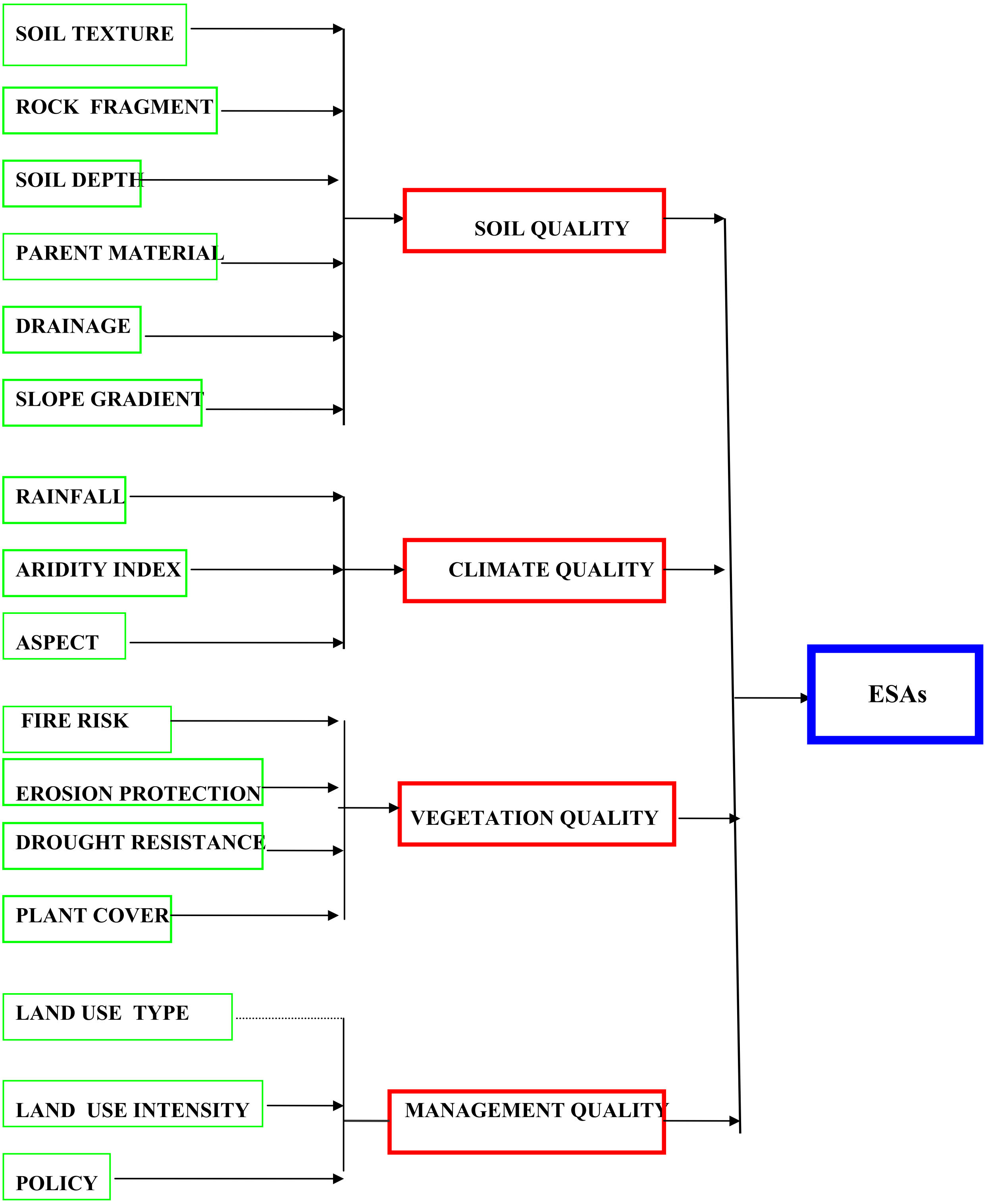

Fig. 14. Parameters used for the definition and mapping of the ESAs to desertification.

2.1 Soil

The following minimum data basis for soils at the appropriate scale (e.g. 1:20 000 or 1:50 000) are required for definition of the ESAs to desertification at regional scale:

(a) soil texture
(b) parent material
(c) soil depth to limitating layers
(d) slope grade
(e) drainage conditions
(f) surface rock fragment cover

Soil textural classes of particles <2 mm of the non-consolidated parent material, or the parent material at 1.5 m if the soil is deep developed, are given using the USDA system of soil texture designation. Table 2 shows the different textural groups in a triangle system.

Table 2. Textural classes classified according to water holding capacity.

Symbol	Designation	Textural classes
Y	very clayey	More than 60% clay
C	Clayey	SC, SiC, C
L	loamy	L, SCL, CL, SiCL, SiL
S	sandy	LS, SL
X	extremely sandy	S

The parent material is defined using the geological map of the study area. The various types of parent materials are grouped into the following classes according to their petrology and mineralogical composition and their sensitivity to desertification (Table 3).

Table 3. Major classes of surficial consolidated or unconsolidated parent materials.

Major class	Group	Type
Igneous rock	acid igneous	Granite, grano-diorite, quartz-diorite, rhyolite
		Pyroclastics
	basic igneous	Gabbro, basalt, dolerite
	ultrabasic igneous	Peridotite, pyroxenite, ironstone, serpentine
Metamorphic rock	acid metamorphic	Quartzite, gneiss
		Slate, phyllite
	basic metamorphic	Schist, gneiss rich in ferro-magnesian,
		Marble
Sedimentary rock	clastic sediments	Conglomerate,
		Sandstone,
		Siltstone, mudstone, claystone, shale
		Limestone
		Marl
Unconsolidated		Fluvial
		Lacustrine
		Marine
		Colluvial

The average soil depth to the consolidated bedrock in meters is required. Soil depth to the limiting layers is defined in the following classes: very shallow (depth <15 cm), shallow (15-30 cm), moderately deep (30-75 cm), and deep (>75 cm).

Slope gradient is described using topographic maps of the appropriate scale. The following dominant slope classes are distinguished: <6%, 6-18%, 18-35%, and >35%.

Drainage conditions are defined on the basis of the depth of hydromorphic features such as iron or magannese mottles or grey colors, and depth of the groundwater table. The following drainage classes are distinguished:

Very well to well drained soils

Soils with any Fe or Mn mottles or grey colours in some depth greater than 100 cm from the soil surface. The soil is not wet enough near the soil surface or the soil does not remain wet during the growing period of the plants. Water is removed from the soil rapidly.

Moderately well to somewhat poorly drained soils

Fe, Mn or grey mottles are present in the soil, in some depth between 30 and 100 cm from the soil surface. The soil is wet enough near the soil surface or the soil remain wet during the early growing period of the plants. Water is removed from the soil slowly.

Poorly to very poorly drained soils

Mottles of Fe and Mn are present in the upper 30 cm of the soil, or reducing (grey) colors. A permanent water table usually exist in depth greater than 75 cm. In some of these soils the ground water reach to the surface during the wet period of the year. Water is removed from the soil so slowly that the soils are wet at shallow depth for long periods.

Rock fragments (>6 mm) in the soil surface are defined on the percentage cover in three classes: >60%, 20-60%, and <20%.

2.2 Vegetation

Vegetation is defined in terms of type of vegetation and percentage cover of each type of vegetation. The type of vegetation is defined on the basis of the dominant species such as *macchia,* evergreen forest, deciduous forest, etc. (Table 4).

Table 4. Classification of natural vegetation and agricultural crops

Class	Vegetation
1	Mixed Mediterranean macchia/evergreen forest
2	Mediterranean macchia
3	Permanent grassland
4	Annual grassland
5	Deciduous forest
6	Pine forest
7	Evergreen forest except pine forest
8	Evergreen perennial agricultural crops
9	Deciduous perennial agricultural crops
10	Annual winter agricultural crops
11	Annual summer agricultural crops
12	Bare land

Vegetation cover is defined in classes according to its relation to soil erosion and land degradation as following: >40%, 10-40%, and <10%.

2.3 Climate

The following data on climate are required for the assessment of climate quality:

Temperature-mean monthly air temperature (^oC)
Precipitation-mean monthly precipitation amount (mm)
Frost-mean monthly number of days with minimum temperature < 0^oC
Potential evapotranspiration-mean monthly potential evapotranspiration (mm).

A regionalization of the climate data is required for deriving climate maps. The regionalization can be achieved by creating Thiessen polygons around each climate station. Corrections of Thiessen network can be made, where appropriate, in order to take into account topographic factors.

The concept of Bagnouls-Gaussen bioclimatic aridity index can be successfully used for determining the aridity index from easily available meteorological data. The Bagnouls-Gaussen aridity index (BGI) is defined as following:

$$BGI = \sum_{i=1}^{n} (2t_i - Pi) . k$$

where: t_i is the mean air temperature for month i in ^oC, P_i is the total precipitation for month i in mm; and k_i represents the proportion of the month during which $2t_i - P_i > 0$.

Slope aspect is considered here for climate quality assessment by distinguishing two classes one with NW and NE aspects and class two with SE and SW aspects.

2.4 Management characteristics

Land use can be classified according to several criteria leading to hierarchies of land use types. The number of criteria employed is dictated by the level of detail desired as well as by the availability of the proper data. The principal classification criterion is the main purpose for which land is used. Based on this criterion, the land use types can be distinguished as following:

Agricultural land (cropland, pasture or rangeland)
Natural areas (forests, shrubland, bare land)
Mining land (quarries, mines, etc.)
Recreation areas (parks, compact tourism development, tourist areas, etc.)
Infrastructure facilities (roads, dams, etc.)

a. land use intensity

For each of the above main land use types, the intensity of the use is assessed for each of the main land use types separately.

Agricultural land (cropland)
The intensity of land use for cropland is assessed by characterising the frequency of irrigation, degree of mechanisation, the existing of terraces, the use of agrochemicals and fertilisers, the crop varieties used, etc. Three levels of land use intensity are distinguished for the agricultural areas as following:

- *Low land use intensity(LLUI) (extensive agriculture).* Local plant varieties are used, fertilisers and pesticides are not applied, yields depends primarily on fertility of soils and environmental conditions. Mechanisation is limited. In case of seasonal crops, one crop is cultivated per year or the land remain under fallow.

- *Medium land use intensity (MLUI)*. Improved varieties are used, insufficient fertilisers are applied and inadequate disease control is undertaken. Mechanisation is restricted to the most important such as sowing, fertilisers application, etc.

- *High land use intensity (HLUI) (intensive agriculture).* Improved varieties are used. Application of fertilisers and control of diseases are adequate. Cultivation is highly mechanised.

<u>Pasture land</u>
The quality of management of pasture land can be assessed by estimating the carrying capacity of the area and comparing with the actual number of animals grazing the area. The sustainable stocking rate (SSR) expressed in animals per hectares can be calculated by the following equation:

$$\mathbf{SSR = X * P * F / R}$$

where: R is the required annual biomass intake per animal (sheep or goat 187.5 kg animal^{-1} year^{-1}, FAO 1991), X is the fraction including grazing efficiency and correction for biomass not produced during the latest growing season (grazed: 0.5, non-grazed 0.25 year^{-1}), P is the averaged palatable biomass after dry season (kg ha^{-1}), F is averaged fraction of the soil surface covered with annuals.

<u>Natural land (forests)</u>
A major distinction must be made between natural forests and managed forest. In the case of natural forests the quality of management is considered as high as there is absence of management, by definition. In the case of managed forests, the intensity of use is determined by the demand for forest products. Demand is difficult to measure and hence indirect procedures are employed. One approach involves assessment of the sustainable yield of a forest and its comparison to the actual yield by forming the ratio actual/sustainable.

<u>Mining land</u>
Mining activities have a highly degrading effect both during lifetime and after the end of the mining. Hence, a first distinction is made between active and inactive mining sites. For active sites, the enforcement of reclamation policies is an important determinant of degradation prospects of these sites. The intensity of land use can be assessed as following for the case of active mining: Surface or subsurface mining with fully erosion measurements undertaken will be considered as well managed. Surface or subsurface mining with moderate erosion measurements undertaken will be rated with medium land use intensity. Surface or subsurface mining activities without or slight erosion protection measurements will be rated with high land use intensity and high desertification risk.

<u>Recreation areas</u>
The diversity of types of recreation areas as well as the indirect effects of recreation activities on the environment requires the basic distinction between passive ad active recreation as it implies significantly different degree of stress on the land. Passive recreation, which is the least threatening the environment, includes walking, nature seeing, mountain

climbing, swimming and similar activities. Active recreation, which is the important for land degradation, includes skiing, cross country skiing games (e.g. sand rallies), etc. The quality of management is a function of both the size of demand as well as the management strategies and practices employed. The assessment procedure would involve: (a) assessment of the visitor carrying capacity of the recreation area (maximum number of visitors permitted per year), (b) assessment of the actual number of visitors per year, (c) calculation of the ratio of actual to permitted number of visitors per year,(d) rating the quality of management as high if the ratio is equal or less than unit, and with low if the ratio is greater than unit.

Tourism development

Like recreation areas, tourist areas can not easily assessed for the following reasons: (a) tourist areas may be parts of or intermingle with urban areas or existing settlements in general, (b) in some cases tourism is the principal activity in an area, (c) tourism may affect not only the particular geographic area but areas of other locations due to environmental linkage, (d) tourism and recreation activities are difficult to distinguish in practice and may occur simultaneous at the same place, (e) tourism may be important in certain areas only such as coasts and sensitive ecosystems. The intensity of tourism development can be assessed following the procedure described for recreation areas.

b. Policy

Particular attention is given for the definition of ESAs to desertification to the policies related to the land protection such as policies supporting terracing, policies favouring extensive agriculture, coastal protection policies, etc. Of course their effectiveness depends on the degree to which they are enforced. Therefore, rating of policies is based on the degree to which they are enforced. Hence, the information must be collected on the existing policies and their implementation /enforcement. The information needed depends on the policy under consideration. For example, in the case of terracing protection policy, a relevant piece of information might be the ratio of protected to existing terraces (Plate 10). In the case of extensive agriculture policy, a relevant piece of information might be the percentage of farms (or farmers) or the percentage of area under extensive agriculture.

Plate 10. A terraced olive grove in which the enforcement of the policy for repairing terraces is very low

3. The assessment procedure

As Fig. 14 shows, the assessment of the ESAs is based in the introduction of the physical characteristics of the land such as soils, climate and vegetation. Management characteristics such as land use type, intensity of land use and policies are included in order to stress the man induced desertification. The assessment involves two stages. In the first stage, the four indices for soil quality, climate quality, vegetation quality, and management quality are calculated providing a measure of the inherent quality of the physical environment and the man induced stress of desertification as in the following discussion.

3.1 Soil quality indicators

Soil is a dominant factor of the terrestrial ecosystems in the semi-arid and dry sub-humid zones, particularly through it's effect on biomass production. Soil quality indicators for mapping ESAs can be related to (a) water availability, and (b) erosion resistance. These qualities can be evaluated by using simple soil properties or characteristics given in regular soil survey reports such as texture, parent material, soil depth, slope angle, drainage, stoniness, etc. The use of these properties for defining and mapping ESAs requires the definition of distinct classes with respect to degree of land protection from desertification.

Table 5. Classes, and assigned weighing indices for the various parameters used for assessment of soil quality.

TEXTURE

Class	Description	Texture	Index
1	Good	L, SCL, SL, LS, CL	1
2	Moderate	SC, SiL SiCL	1.2
3	Poor	Si, C, SiC	1.6
4	Very poor	S	2

PARENT MATERIAL

class	Descriptio	Parent material	index
1	good	Shale, schist, basic, ultra basic. Conglomerates, unconsolidated	1.0
2	Moderate	Limestone, marble, granite, Rhyolite, Ignibrite, gneiss, siltstone, sandstone	1.7
3	Poor	Marl*, Pyroclastics	2.0

* For perennial vegetation, marl are removed to class 1.

ROCK FRAGMENTS

Class	Description	RF cover (%)	Index
1	Very stony	>60	1
2	Stony	20-60	1.3
3	Bare to slightly stony	<20	2

SLOPE

Class	Description	slope (%)	Index
1	Very gentle to flat	<6	1
2	Gentle	6-18	1.2
3	Steep	18-35	1.5
4	Very steep	>35	2

SOIL DEPTH

Class	Description	depth (cm)	index
1	Deep	>75	1
2	Moderate	75-30	2
3	Shallow	15-30	3
4	Very shallow	<15	4

DRAINAGE

Class	Description	index
1	well drained	1
2	Imperfectly drained	1.2
3	Poorly drained	2

SOIL QUALITY

class	Description	range
1	high quality	<1.13
2	Moderate quality	1.13 to 1.45
3	low quality	>1.46

Soil texture is related to erodibility, water retention capacity, crusting and aggregate stability. The amount of available water is related to both texture and structure. Soils high in silt (silt loam) tend to have the largest available water holding capacity. In the opposite, sands have the smallest available water-holding capacity. Sandy soils tend to be more prone to drought than clayey soils because they retain less water at field capacity and the water retained is consumed more rapidly by the growing plants. The soil textural classes are grouped according to their water-holding capacity (Table 5).

Parent materials are classified according to their sensitivity to desertifciation (Table 5). Rock fragments present in the soil surface are classified in three class according to their capacity to conserve soil water and protect the soils from erosion as (Table 5).

Soil depth is defined as the depth of the soil profile from the soil surface to the top of the regolith or unweathered parent material. Soil depth is classified in four classes (Table 5). Slope grade is classified in four classes according to the effect on soil erosion (Table 5). Soil drainage condition is mainly used for assessing desertification risk due to salinization of flat areas located mainly in alluvial plains along the coast line or in depressions inside valleys. Three drainage classes are defined with respect to effect on salinization (Table 5).

Soil quality index (SQI) is then calculated as the product of the above attributes, namely soil texture, parent material, rock fragment cover, soil depth, slope grade, and drainage conditions as the following algorithm. The soil quality is then defined using Table 1.

$$\mathbf{SQI = (texture * parent\ material * rock\ fragment * depth * slope * drainage)^{1/6}}$$

3.2 Climate quality

Climate quality is assessed by using parameters that influence water availability to the plants such as amount of rainfall, air temperature and aridity, as well as any climate hazards as frost which might inhibit or even prohibit plant growth. Annual precipitation is classified in three classes considering the annual precipitation of 280 mm as a crucial value for soil erosion and plant growth (Table 6).

Table 6. Classes and weighing indices for climate quality assessment.

RAINFALL

class	Rainfall (mm)	Index
1	>650	1
2	280-650	2
3	<280	4

ARIDITY

class	BGI range	Index
1	<50	1
2	50-75	1.1
3	75-100	1.2
4	100-125	1.4
5	125-150	1.8
6	>150	2

CLIMATE QUALITY

climate quality index	Description	Range
1	High quality	<1.15
2	Moderate quality	1.15 to 1.81
3	Low quality	>1.81

The most effective measure of soil water availability is the assessment of precipitation minus evapotranspiration and run-off. However, this calculation requires relatively many data such as soil moisture retention characteristics, vegetation growth characteristics etc., therefore, the simple Bagnouls-Gaussen aridity index is used here. This index is grouped into six classes (Table 6).

Slope aspect is divided here into two classes (a) NW and NE and (b) SW and SE assigning the indices 1 and 2, respectively. The above three attributes are then combined to assess the climate quality index (CQI) using the following algorithm. The climate quality is then defined using Table 6, classified into three classes.

$$\mathbf{CQI = (rainfall * aridity * aspect)^{1/3}}$$

3.3 Vegetation quality

Vegetation quality is assessed in terms of (a) fire risk and ability to recover, (b) erosion protection to the soils, (c) drought resistance, and (d) plant cover. The existing in the Mediterranean region dominant types of vegetation are grouped into four categories according to the fire risk (Table 7). Also four categories are used for classifying the vegetation according to the protection to the soil from erosion (Table 7). Five categories are used for classification of vegetation with respect to drought resistance. Finally, plant cover is distinguished into three classes.

Table 7. Classes and weighing indices of parameters used for vegetation quality assessment.

FIRE RISK

Class	Description	Type of vegetation	index
1	Low	bare land, perennial agricultural crops, annual agricultural crops (maize, tobacco, sunflower)	1
2	Moderate	annual agricultural crops (cereals, grasslands), deciduous oak, (mixed), mixed Mediterranean, macchia/evergreen forests	1.3
3	High	Mediterranean macchia	1.6
4	very high	pine forests	2

EROSION PROTECTION

Class	Description	Vegetation types	Index
1	Very high	Mixed Mediterranean macchia/evergreen forests	1
2	High	Mediterranean macchia, pine forests, Permanent grasslands, evergreen perennial crops	1.3
3	Moderate	Deciduous forests	1.6
	Low	Deciduous perennial agricultural crops (almonds, orchards)	1.8
4	very low	Annual agricultural crops (cereals), annual grasslands, vines,	2

DROUGHT RESISTANCE

Class	Description	Types of vegetation	Index
1	very high	Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia	1
2	High	Conifers, deciduous, olives	1.2
3	Moderate	Perennial agricultural trees (vines, almonds, ochrand)	1.4
4	Low	Perennial grasslands	1.7
5	very low	Annual agricultural crops, annual grasslands	2

PLANT COVER

class	Description	plant cover (%)	index
1	High	>40	1
2	Low	10-40	1.8
3	very low	<10	2

VEGETATION QUALITY

vegetation quality index	Description	range
1	high quality	1 to 1.6
2	Moderate quality	1.7 to 3.7
3	low quality	3.8 to 16

The vegetation quality index (VQI) is assess as the product of the above vegetation characteristics related to sensitivity to desertification using the following algorithm. Then the vegetation quality index is classified into three classes defining the quality of vegetation with respect to desertification. (Table 7).

$$\mathbf{VQI = (fire\ risk * erosion\ protection * drought\ resistance * vegetation\ cover)^{1/4}}$$

3.4 Management quality or degree of human induced stress

As it was mentioned above, the land is classified in the following categories according to the major land use for assessing the management quality or the degree of human induced stress:

1. Agricultural land
 - cropland
 - pasture
2. Natural areas
 - forest
 - shrubland
 - bare land
3. Mining areas (quarries, mines, etc.)
4. Recreation areas (parks, compact tourism development, tourist areas, etc.)
5. Infrastructure facilities (roads, dams, etc.)

After defining the type of land use in a certain piece of land, then the intensity of land use and the enforcement of policy on environmental protection is assessed for the particular type of land use.

a. Land use intensity

<u>Agricultural land-cropland</u>
The intensity of land use of a cropland is classified into three classes (Table 8) based on the frequency of irrigation, degree of mechanisation of cultivation, application of fertilisers and agrochemicals, types of plant varieties used, etc, described previously.

<u>Pasture land</u>
The intensity of land use of a pasture land is defining by estimating the sustainable stocking rate (SSR) and the actual stocking rate (ASR) (described previously) for the various pieces of land under grazing. Then, the intensity of land use is assessed by using the ratio of ASR/SSR and classified into three classes (Table 8).

<u>Natural areas</u>
In natural areas such as forests, shrubland etc., the intensity of land use is defined by assessing the actual (A) and sustainable yield (A/S). Then, the intensity of land use is classified into three classes based on the ratio A/S (table 8).

<u>Mining areas</u>
The intensity of land use for areas with mining activities is defining by evaluating the measurements undertaken for soil erosion control such as terracing, vegetation cover, etc. Then , the intensity of land use is classified into three classes based on the evaluated degree of land protection from erosion (Table 8).

<u>Recreation areas</u>
In areas undergoing active reaction such as skiing, rallies etc., the intensity of land use is evaluated by defined the actual and the permitted number of visitors per year (A/P). Then the land use intensity is classified into three classes based on the ratio A/P (Table 8).

b. Policy

The policies related to environmental protection are classified according to their degree in which they are enforced for each case of land use. The information on the existing policies are collected and then the degree of implementation/enforcement is evaluated. Three classes related to the policy on environmental protection are defined (Table 8).

The management quality index (MQI) is assessed as the product of land use intensity and the enforcement of policy for environmental protection using the following algorithm. Then the management quality is defined using Table 8.

$$\textbf{MQI} = (\textbf{land use intensity} * \textbf{policy enforcement})^{1/2}$$

Table 8. Classes and weighing indices of parameters used for land management quality assessment.

CROPLAND

Class	Description	Index
1	low land use intensity (LLUI)	1
2	Medium land use intensity (MLUI)	1.5
3	high land use intensity (HLUI)	2

PASTURE

Class	Description	Stocking rate	Index
1	Low	ASR< SSR	1
2	Moderate	ASR=SSR to 1.5*SSR	1.5
3	High	ASR>1.5*SSR	2

NATURAL AREAS

Class	Description	management characteristics	Index
1	Low	A/S = 0	1
2	Moderate	A/S < 1	1.2
3	High	A/S = 1 or greater	2

MINING AREAS

Class	Description	erosion control measurements	index
1	Low	Adequate	1
2	Moderate	Moderate	1.5
3	High	Low	2

RECREATION AREAS

Class	Description	A/P visitors ratio	index
1	Low	>1	1
2	Moderate	1 to 2.5	1.5
3	High	>2.5	2

POLICY

Class	Description	Degree of enforcement	index
1	High	Complete: >75% of the area under protection	1
2	Moderate	Partial: 25-75% of the area under protection	1.5
3	Low	Incomplete: <25% of the area under protection	2

MANAGEMENT QUALITY

Class	Description	Range index
1	High	1 to 1.25
2	Moderate	1.26 to 1.50
3	Low	>1.51

4. Matching the results

The final step comprises the matching of the physical environment qualities (soil quality, climate quality, vegetation quality) and the management quality for the definition of the various types of ESAs to desertification. The four derived indices are multiplied for the assessment of the ESAs index (ESAI) as following:

$$\mathbf{ESAI = (SQI * CQI * VQI * MQI)^{1/4}}$$

The ranges of ESAI for each of type of the ESAs (as they were defined above), including three subclasses in each type appear in Table 9. Each type of ESAs is defined on a three-point scale, ranging from 3 (high sensitivity) to 1 (lower sensitivity), in order the boundaries of the successive classes of ESAs to be better integrated. It must be pointed out that the range for each type of ESAs has been adjusted in a such a way that it can include the various types of ESAs resulted from the various studies conducted in the target area of the island of Lesvos. Then this methodology has been validated in two areas (a) the Agri basin (Italy) and (b) Alentejo region (Portugal), which have been assigned as target areas for desertification studies in the frame of the EC research project MEDALUS.

Table 10. Types of ESAs and corresponding ranges of indices.

Type	Subtype	Range of ESAI
Critical	C3	>1.53
«	C2	1.42-1.53
«	C1	1.38-1.41
Fragile	F3	1.33-1.37
«	F2	1.27-1.32
«	F1	1.23-1.26
Potential	P	1.17-1.22
Non affected	N	<1.17

The mapping symbol of each type of ESAs includes the class and subclass, four suffixes corresponding to the used land qualities (‘s’ for soil, ‘c’ for climate, ‘v’ for vegetation and ‘m’ for management) and four numbers indicating the degree of limitation for each quality (Fig. 15).

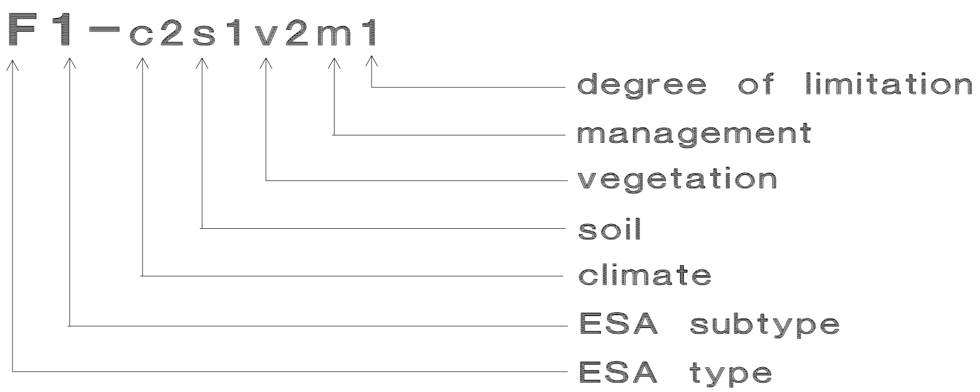

Fig. 15. Mapping symbol used for characterisation of the ESAs to desertification.

C. REGIONAL DESERTIFICATION INDICATORS (RDIs)

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The approach to RDI's is applied here primarily for soil erosion by water, for which the detailed methodology has been most fully developed. The underlying rationale is based on a one-dimensional hydrological model, which is used to estimate potential vegetation cover, if required and storm runoff based on climatic and vegetation data. The forecast runoff, accumulated across the frequency distribution of storms, is used to give a climatic erosion potential, which is then appropriately combined with measures of topography and soil erodibility to estimate the expected rate of soil erosion at a resolution of 1 km.

Desertification Indicators are identified with unacceptably high current rates of erosion, and with high sensitivity of erosion rates to potential changes in climate or land use. The methodology may be applied to a number of environmental processes. Here it is being applied to water erosion, salinisation, depth of the active (unfrozen) layer and peat mire accumulation. It is proposed to extend it to wind erosion in the near future.

C. INDICATORI DI DESERTIFICAZIONE REGIONALI (RDIS)

L'approccio ai RDIs è principalmente applicato qui per l'erosione idrica, per la quale la dettagliata metodologia è stata sviluppata in pieno. La base logica è basata su modello idraulico avendo una singola dimensione, che è usato per stimare la copertura vegetale potenziale, se necessario, e di stimare il deflusso da eventi basato sui dati climatici e vegetali. Il deflusso previsto, accumulato attraverso la frequenza di distribuzione degli eventi, è usato per dare la potenziale erosione dovuta al clima, la qual è combinata con le misure topografiche e d'erodibilità del suolo per stimare l'atteso tasso d'erosione del suolo ad una risoluzione di 1 km.

Gli Indicatori di Desertificazione sono individuati con inaspettati alti tassi d'erosione, e con un'alta sensibilità dei tassi d'erosione ai cambiamenti potenziali del clima e l'uso del suolo. Questa metodologia può essere applicata a vari processi ambientali. Qui è applicata all'erosione idrica, alla salinizzazione, alla profondità dello strato attivo (non congelato) e all'accumulazione di lettiera fangosa di torba. La proposta è di applicarla all'erosione eolica nel prossimo futuro.

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Η προσέγγιση στους ΠΔΑ εφαρμόζεται εδώ κυρίως για την υδατική διάβρωση, για την οποία η λεπτομερής μεθοδολογία έχει αναπτυχθεί πληρέστερα. Το υπόβαθρο είναι βασισμένο σε ένα μονοδιάστατο υδρολογικό μοντέλο που χρησιμοποιείται για να υπολογίσει τη δυνητική φυτοκάλυψη, εάν χρειάζεται, και την απορροή που δημιουργείται από καταιγίδες βασισμένο σε δεδομένα κλιματικά και βλάστησης. Η προβλεπόμενη απορροή, συσσωρευμένη κατά την κατανομή συχνότητας των καταιγίδων χρησιμοποιείται για να παράγει το δυναμικό της κλιματικής διάβρωσης το οποίο τότε συνδυασμένο κατάλληλα με μετρήσεις τοπογραφικές και διαβρωσιμότητας του εδάφους υπολογίζει τον προβλεπόμενο ρυθμό της διάβρωσης του εδάφους με ακρίβεια 1 km.

Οι δείκτες απερήμωσης ταυτίζονται με απαράδεκτα υψηλούς ρυθμούς διάβρωσης και με υψηλή ευαισθησία των ρυθμών διάβρωσης σε δυνητικές αλλαγές στο κλίμα ή στη χρήση γης. Η μεθοδολογία μπορεί να εφαρμοστεί σε μια σειρά από περιβαλλοντικές διαδικασίες. Εδώ εφαρμόζεται στην υδατική διάβρωση, αλάτωση, βάθος ενεργής (μη παγωμένης) στρώσης και συσσώρευση τύρφης. Προτείνεται να επεκταθεί στην αιολική διάβρωση στο κοντινό μέλλον.

C. INDICADORES REGIONAIS DE DESERTIFICAÇÃO (RDIs)

A abordagem dos Indicadores Regionais de Desertificação é aqui aplicada principalmente em relação à erosão hídrica do solo, fenómeno para o qual a metodologia detalhada foi o mais amplamente desenvolvida. A ideologia subjacente baseia-se num modelo hidrológico unidimensional, utilizado para estimar um coberto vegetal potencial, se necessário, e também escoamento torrencial com base em dados climáticos e de cobertura vegetal. O escoamento previsto, acumulado de acordo com a frequência de ocorrência dos episódios chuvosos, é utilizado para calcular um potencial erosivo em função do clima, o qual é depois devidamente combinado com medições topográficas e de erodibilidade dos solos, para estimar o grau de erosão hídrica do solo, com uma resolução espacial de 1 km^2*.*

Os Indicadores de Desertificação são identificados com taxas de erosão inaceitavelmente elevadas e com elevada sensibilidade dessas taxas de erosão a potenciais alterações climáticas ou de uso do solo. A metodologia apresentada pode ser aplicada a um determinado número de processos ambientais. Neste caso está a ser aplicada à erosão hídrica do solo, salinização, profundidade do horizonte vivo do solo e sedimentação aluvionar. Propõe-se a sua extensão ao processo de erosão eólica num futuro próximo.

C. INDICADORES REGIONALES DE DESERTIFICACION (IRD)

La aproximación a los IRD se aplica aquí básicamente a la erosión hídrica, para lo cual se ha desarrollado la metodología de una modo más completa. El razonamiento subyacente está basado en un modelo hidrológico unidimensional, que es usado para estimar la cobertura potencial de la vegetación, si es necesario, y la escorrentía por evento, basada en datos de vegetación y clima. La escorrentía predicha por el modelo, acumulada a través de la distribución de frecuencias de los eventos lluviosos, se utiliza para porporcionar la erosión climática potencial, que se combina entonces de manera apropiada con medidas de topografía y erosionabilidad del suelo para estimar la tasa esperada de erosión con una resolución de 1 km.

Los Indicadores de Desertificación son identificados con tasas de erosión actual inaceptablemente altas, y con alta sensibilidad de las tasas de erosion a cambios potenciales en el clima o el uso del suelo. La metodología se puede aplicar para diversos procesos ambientales. Aquí se aplica para erosión hídrica, salinización, profundidad de la capa activa (no congelada) y acumulación de turba. Se propone su extensión a la erosión eólica en el futuro inmediato.

1. Rationale for Estimating Total Potential Erosion Rate

The proposed approach consists of taking a very simple and conservative erosion model, and showing that it can be disaggregated into components which respectively depend on climate, vegetation, topography and soil factors. These factors can then be assessed separately, using available data sources, and used to make regional forecasts. Because the component are explicit, the impact of changes in land use or climate can also be clearly identified, so that sensitivity to changed conditions can be estimated.

The rate of sediment transport is estimated as a mean soil loss in Tons/Ha, obtained as a product of terms which are primarily dependent on soil, climate/vegetation and topography. This approach originates from early work by the USDA (Musgrave, 1947), leading to expressions of the general form:

$$S = kq^m \Lambda^n \qquad \text{(C1)}$$

where k is the soil erodibility,
q is the overland flow discharge per unit width
Λ is local slope gradient
and m, n are empirical exponents in the range 0 - 2.

The particular form proposed here for rill erosion is:

$$S = k\left(q\Lambda - \Theta\right)^2 \qquad \text{(C2)}$$

where Θ is a flow power threshold

The reasons for this particular choice are discussed at greater length below.

In this expression, the first term, k, is the soil erodibility. Soil properties also influence the threshold, Θ. The discharge per unit width, q, can be re-written as:

$$q = j\,x \qquad \text{(C3)}$$

where j is the runoff (per unit area)
and x is the distance downslope (from the divide)

The term $q\Lambda = j \; x\Lambda$ then explicitly breaks down into a climatically driven term, j, and a topographic term $x\Lambda$. If sediment transport is evaluated at the slope base, then this term is closely correlated with the total slope relief, $H = x\overline{\Lambda}$, where $\overline{\Lambda}$ is the mean slope gradient.

The climatic term needs to be appropriately summed over the frequency distribution of storm rainfalls, but it can be seen that this approach provides a rationale for combining the effects of topography, soils and climate into a single integrated erosion forecast.

2. Factors controlling water erosion

Water Erosion is known to be directly controlled by a number of factors (Fig. 16); climate, vegetation, soil properties and topography. Each factor is itself complex, and the various factors interact with one another. In creating synthetic indicators, it is important to use a clear scientific rationale to combine relevant measures of these factors into composite indicators. This analysis is targeted on such a synthesis, and so differs in approach from that in Section A2 above, although essentially making use of similar components.

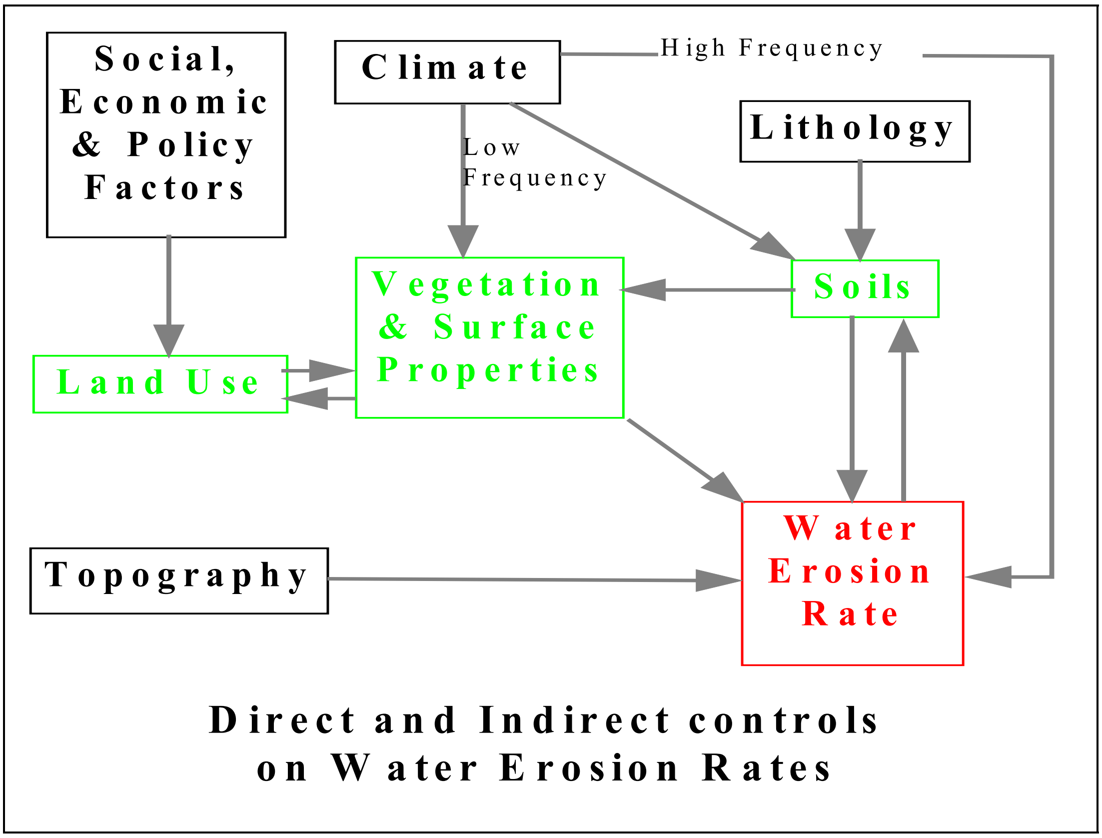

Fig. 16: Flow diagram showing the main controls on water erosion

2.1 Climate

Both low frequency and high frequency components of the climate are important for erosion. Low frequency events determine the seasonal cycle of the soil water balance which provides the environment for growth of crops or natural vegetation. It may be appropriate to run a vegetation growth model (natural or crop) which then contains the potential to give a dynamic response to changed land use or climate conditions. Alternatively land cover may be derived from ground-based survey or remote sensing, with potentially greater accuracy but without the potential for responding to prospective changes. Almost all Mediterranean environments are dominated by overland flow in the summer, but in wetter environments there is substantial sub-surface flow and groundwater recharge in winter (up to 75% of total rainfall), whereas drier environments are dominated by overland flow almost year round. Similar balances also influence the potential for salinisation in the drier areas where parent materials are rich in sodium.

High frequency rainfall events are clearly crucial for generating overland flow. The simplest effective tool for estimating runoff is the notion of a threshold storm size. Beneath the threshold there is little or no runoff; above it all or a high proportion of the additional rainfall generates overland flow. This approach is illustrated in figure 17(a) for data from a US experimental catchment. Thus the average annual overland flow runoff (per unit area) is estimated as:

$$J = \sum_{r>h} p(r-h)$$

where the summation is made over all storms, r which exceed the runoff threshold h and p is the proportion of runoff above the threshold (C4)

For a mathematically defined distribution function, the runoff may be estimated by integration. For example, if the distribution of storm (or daily) rainfalls is exponential:

If $N(r) = N_0 \exp(-r/r_0)$

then $J = pR\exp(-h/r_0)$

where N(r) is the number of days with rainfall $> r$ (C5)

N_0 is the number of rain days,

r_0 is the mean rain per rain day,

R is the total rainfall $= r_0 N_0$

In practice a sum of two exponential terms (Kirkby & Cox, 1995) is more appropriate in most cases, and the parameters should be calculated for each month separately.

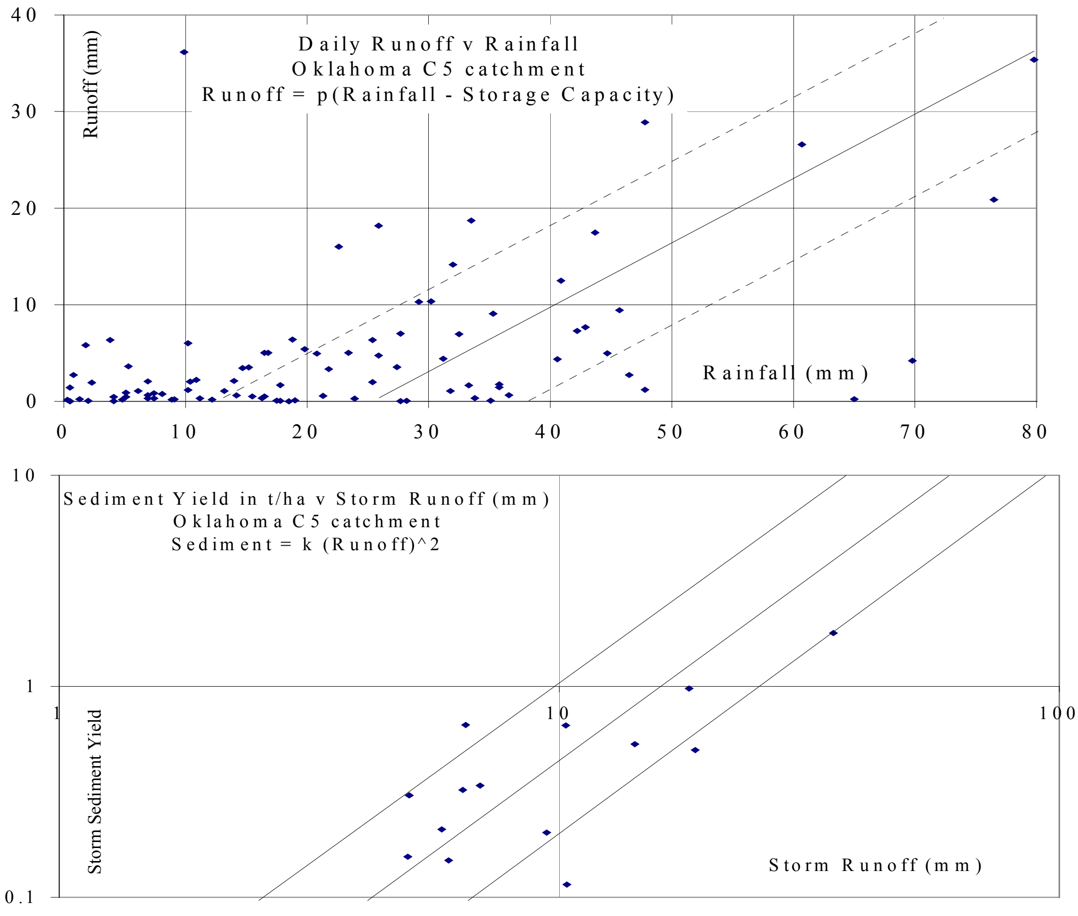

Fig. 17. Relationships between Storm rainfall, Runoff and Sediment Yield (total Storm Runoff .v. Storm Rainfall, above; and Storm Sediment Yield .v. Total Storm Runoff, below).

Summation over storms is achieved by fitting the distribution of daily rain amounts to the sum of two exponential distributions, using the monthly values for number of rain days, mean rain-day and its standard deviation. Thus the cumulative frequency of a daily rainfall in excess of r is:

$$N(r) = N_0\left[\frac{\mu}{r_1}\exp\left(-\frac{r}{r_1}\right) + \frac{1-\mu}{r_2}\exp\left(-\frac{r}{r_2}\right)\right]$$

where μ is a fraction, normally between 0 and 1, (C6)

and r_1, r_2 are rainfall intensity parameters.

The mean and variance of this distribution are:

$$\bar{r} = \mu r_1 + (1-\mu)r_2$$
$$\sigma^2 = r_1^2\mu(2-\mu) - 2r_1 r_2\mu(1-\mu) + r_2^2(1-\mu^2) \qquad \text{(C7)}$$

It has been found convenient in practice to solve these equations iteratively, assuming a fixed ratio r_1:r_2 =5.0.

In the expression for sediment transport used above (equation C2), sediment transport is related to (Discharge)^2. Integration over the frequency distribution should then be for terms:

$$\sum_{r>h} p^2(r-h)^2 = 2p^2 R r_0 \exp(-h/r_0) \text{ etc.}$$

The effect of the threshold term makes additional changes to the integrated sum, leading to terms of the form:

$$2p^2 R r_0 \exp(-h/r_0)\exp\left(-\frac{\Theta}{r_0 H}\right) \text{ for the single exponential distribution.} \qquad \text{(C8)}$$

Figure 17(b) illustrates the empirical form of the relationship between runoff and sediment yield for single storms, and figure 18 for annual totals.

2.2 Vegetation

Figure 18 shows data for sites which differ in their vegetation cover, but which all have very similar total rainfall. It is concluded that vegetation and associated soil properties, in particular soil organic matter content, have a major impact on the runoff threshold, *h*, which takes values of about 10 mm for bare soil up to 100 mm or more for forested areas. Vegetation acts on several ways, which may be dominant under different conditions, first by protecting the soil from rainsplash impact and crusting, second by intercepting rainfall which is lost to evaporation and third by building up organic matter in the soil which greatly enhances the short-term dynamic storage and release of soil moisture. The combined effect of these processes is to increase the runoff threshold, *h*. Vegetation also resists erosion by adding to surface roughness which reduces overland flow velocity, and binds the soil together with shallow root mats, particularly in grasses. This second group of processes tend to increase the erosion threshold, Θ and increase the soil erodibility, *k*.

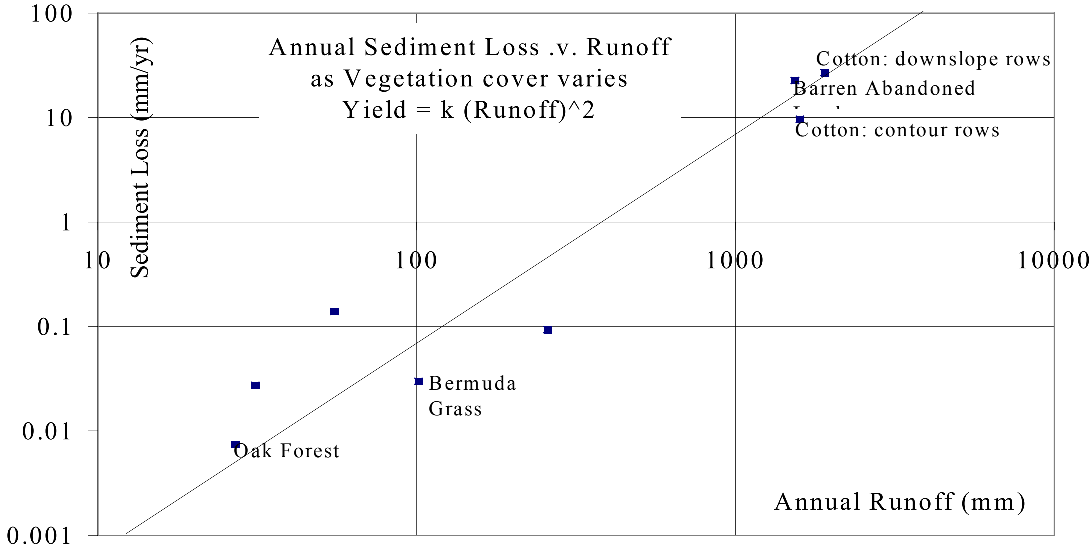

Fig. 18. Annual overland flow runoff and sediment yields for sites in Mississippi, with similar annual rainfall of 1 500-2 000 mm

The vegetation cover may be obtained as a potential cover, using a growth model based on evapotranspiration and water use efficiency, or from remotely sensed images. The former approach has the advantages of allowing Soil organic matter to be estimated at the same time as vegetation biomass, and of providing a means of forecasting the impact of climate and/or land use changes. However, it is recognised that vegetation is strongly influenced by agricultural activity, both in cropland and by grazing, fire management etc., so that the use of remotely sensed images may be more valid. A Combination of the two methods may be used to give some measure of expected global change impacts and sensitivity.

Figure 19 outlines the rationale of the growth model. Vegetation is grown generically rather than using distinct functional types as in DVGM's. Gross Primary Productivity (GPP) is estimated from actual evapotranspiration, which is in turn estimated from potential evapotranspiration and rainfall. A global water use efficiency is used to convert actual evapotranspiration to GPP. Respiration is estimated as a function of temperature to give Net Primary Productivity (NPP), with an increased rate of loss when NPP is negative, to simulate a deciduous response. Leaf (and root etc.) fall is estimated as a fraction of biomass which decreases with size, as more of the plant has a structural role and there is a smaller fraction of leaves and active roots. Leaf fall is added to the Soil Organic Matter (SOM) which decomposes at a proportional rate which increases with temperature. The model can be run to equilibrium using monthly averages, or run for a time-based past climate sequence or future scenario.

Agricultural Landuse may be simulated by harvesting fractions of the natural leaf fall or standing biomass, either to a timetable or according to availability. Differences between computed potential and remotely sensed actual land cover give a direct measure of total human disturbance.

Alternatively, vegetation may be derived from remotely sensed land cover data, taken from AVHRR or similar coverage at 1 km resolution. Atmospherically corrected mosaics can be used to give monthly values of NDVI (Normalised Differential Vegetation Index) and surface temperature, and these can be interpreted to estimate land cover and/or biomass. In this method, however, there is no estimate of soil organic matter, which must be estimated from soil data bases or other sources.

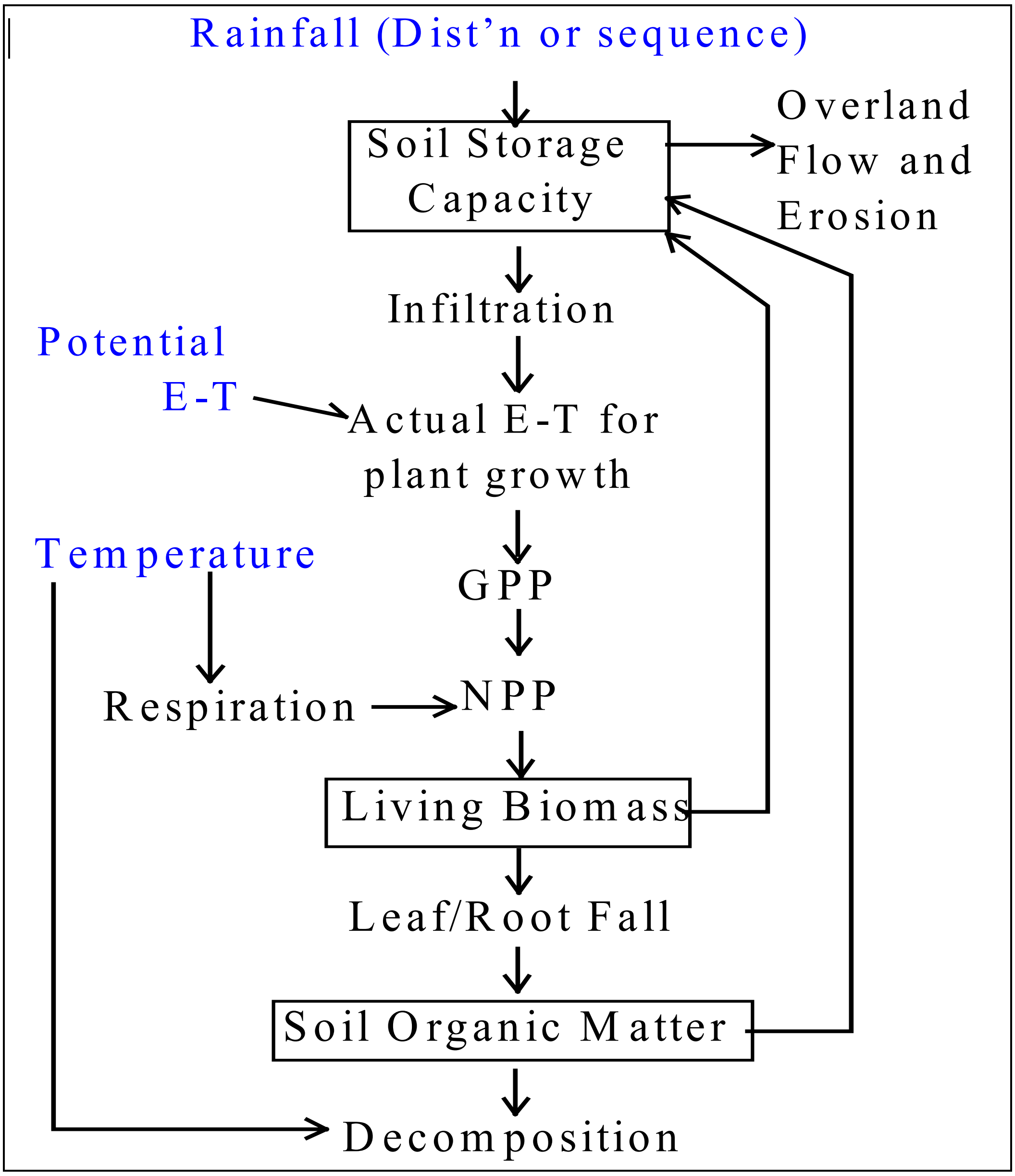

Fig. 19. Schematic flow diagram for natural vegetation growth model.

When vegetation biomass and cover has been derived from either method, the effective storage capacity or runoff threshold h is estimated as:

$$h=b.h_m+VI+\lambda H \qquad \text{(C9)}$$

where b is the proportion bare (unvegetated) surface,
h_m is the mineral soil storage,
V is the plant biomass,
I is the interception storage per unit biomass,
λ is the storage per unit of organic soil
and H is the soil organic matter biomass.

In this relationship V, b and H are all varying seasonally, and h_m, I may also vary dynamically with the course of crusting over a series of storms, and with rainfall intensity during a storm.

The runoff threshold and proportion of subsequent runoff are simplifications of cumulative infiltration and runoff curves. Runoff Threshold is estimated from the crown cover, soil organic matter and soil texture/ structure characteristics. The threshold represents the effects of surface storage in random roughness and plough furrows, the dynamic evolution of soil crusting and moisture storage within the upper soil layers. Surface Storage changes rapidly over the year on cultivated land, as raindrop impact forms a crust on newly ploughed land, and reduces furrow roughness.

Thus vegetation exerts an extremely strong effect on runoff and erosion. Under natural conditions, vegetation responds strongly to climate. For a non-seasonal climate there is therefore a strong peak of erosion for semi-arid conditions, following the pattern observed by Langbein and Schumm (1958). At low rainfalls, increased precipitation produces an increase in runoff over very sparse vegetation, but, at higher rainfalls the increase in vegetation reduces runoff by increasing the runoff threshold very strongly. Only when vegetation density has reached a maximum (in temperate or tropical forests) can increases in runoff begin to take place again. However, there is some evidence that, under semi arid climates, the annual occurrence of high rainfalls on sparsely vegetated surfaces at the end of the dry season can reduce the strength of this vegetation protection effect. Under annual crops there is generally a period of high risk when there is little ground cover, particularly if rains immediately after germination create a crusted surface from which runoff may be very high (b high and h_m low in equation C9 above). Mediterranean tree crops, such as olive, almond and vine, are generally tilled frequently to conserve rainwater and discourage weeds, so that effective storage is very high, although it may be accompanied by substantial tillage erosion, which is not considered in this analysis.

2.3 Soil Properties

The most important soil property is the erodibility, the parameter k in equation C2 above. A second important parameter is the erosion threshold Θ, which determines the minimum flow power for erosion to occur. These two parameters are distinguished from the hydraulic properties of the soil, which are subsumed within the runoff threshold, h.

Erodibility is seen as primarily a property of the soil texture, with highest values for fine sand and silt soils with low clay content, but it also responds significantly to both vegetation and SOM. Vegetation stems provide roughness elements in the flow, reducing flow velocity and therefore flow power acting on the soil. Both SOM and clay content (except in sodic soils) generally increase the size of stable soil aggregates, and hence reduce erodibility. However, the single most important component of erodibility is to distinguish light and heavy soils, for which the erodibility differs by at least 100x.

The erosion threshold, Θ depends partly on soil texture, but is low even for very stony soils. It is much more important to recognise the importance of a strong root mat, particularly of grasses, which is able to provide an estimated threshold of 1-20 $m^2\ hr^{-1}$, in comparison with a grain threshold of 0.1 $m^2\ hr^{-1}$ for 10 mm stones. From the form of the final term in equation (C8) above, it is clear that a high erosion threshold greatly increases the differences in erosion rate between low and high relief areas.

2.4 Topography

Erosion studies suffer from a shortage of long records including extreme events, and from an imbalance in experimental data, with many more measurements for cultivated than for uncultivated conditions. To partially remedy this, data have been used from three other sources (figure 20); first from the form of hillslope profiles, which are formed in the long term from the action of erosional processes, second from the topography of stream heads, which also respond to the interplay of these forces. And third by comparison with the results of more detailed models, such as the MEDRUSH model developed within the MEDALUS project.

Much erosion plot data is concentrated on a set of standard conditions, particularly of plot length. Furthermore the analysis of many of these data takes no account of sediment routing, including possible deposition, within the plot. In consequence, few data can be used directly to discriminate between topographic alternative expressions, although equations of form (C1) have generally been fitted to existing data sets.

Hillslope profiles may be back analysed, if some assumptions are made about equilibrium with rates of downcutting and uplift, of if the form is assumed to be declining in a Davisian sense towards a base level. The results of these analyses support the general power law forms of equations (C1) and (C2), but do not discriminate well between them.

Stream head locations may be studied either for permanent stream head locations (Dietrich and Dunne, 1993) or for ephemeral gullies appearing immediately after storms (Poesen *et al*, 1997). The methods described in Kirkby (1994) may be used to compare these forms with those observed. It is argued (Kirkby & Bull, in press) that equation (C2), with a correction for an upper limit of sliding stability under wet conditions, gives the best fit to all observed data, and this appears to be the best means of discriminating among power law functions similar to equation (C1).

Finally detailed erosion models have also been used, and give a good measure of agreement, but of course the comparisons rely strongly on the formulation of the sediment transport functions, so that there is a strong danger of circularity in the derivation.

At present it seems as though stream head locations provide the best means of defining a topographic function. They have the added advantage that they span a range of time scales, from the impact of individual storms to the integrated landscape impact of a historical sequence or distribution of major events.

3. The Integrated Soil Erosion Indicator

Combining the terms described above, an estimate is obtained for the average rate of soil erosion, averaged over an area. The expression is grouped into three sets of terms, which are termed the soil factor, the bio-climatic factor and the topographic factor.

$$Y = k \quad H^2 \exp\left(-\frac{\Theta}{r_0 H}\right) / L \quad \sum_{months} \left[2p\, r_0\, R \exp(-h / r_0)\right].$$

$$= k \quad \Psi \quad \Omega$$

where k is the Soil Erodibility (C10)

Ψ is the topographic erosion indicator

and Ω is the bio - climatic erosion indicator

and where these are broken down into:

Y = Sediment loss (mean per unit area)
k is soil erodibility
R = total monthly rainfall
r_0 is mean rain per rain-day
h = runoff threshold from equation (C9) above.
p is proportion of runoff above the runoff threshold
Θ is the flow power erosion threshold
H is mean slope relief
L is mean slope length.

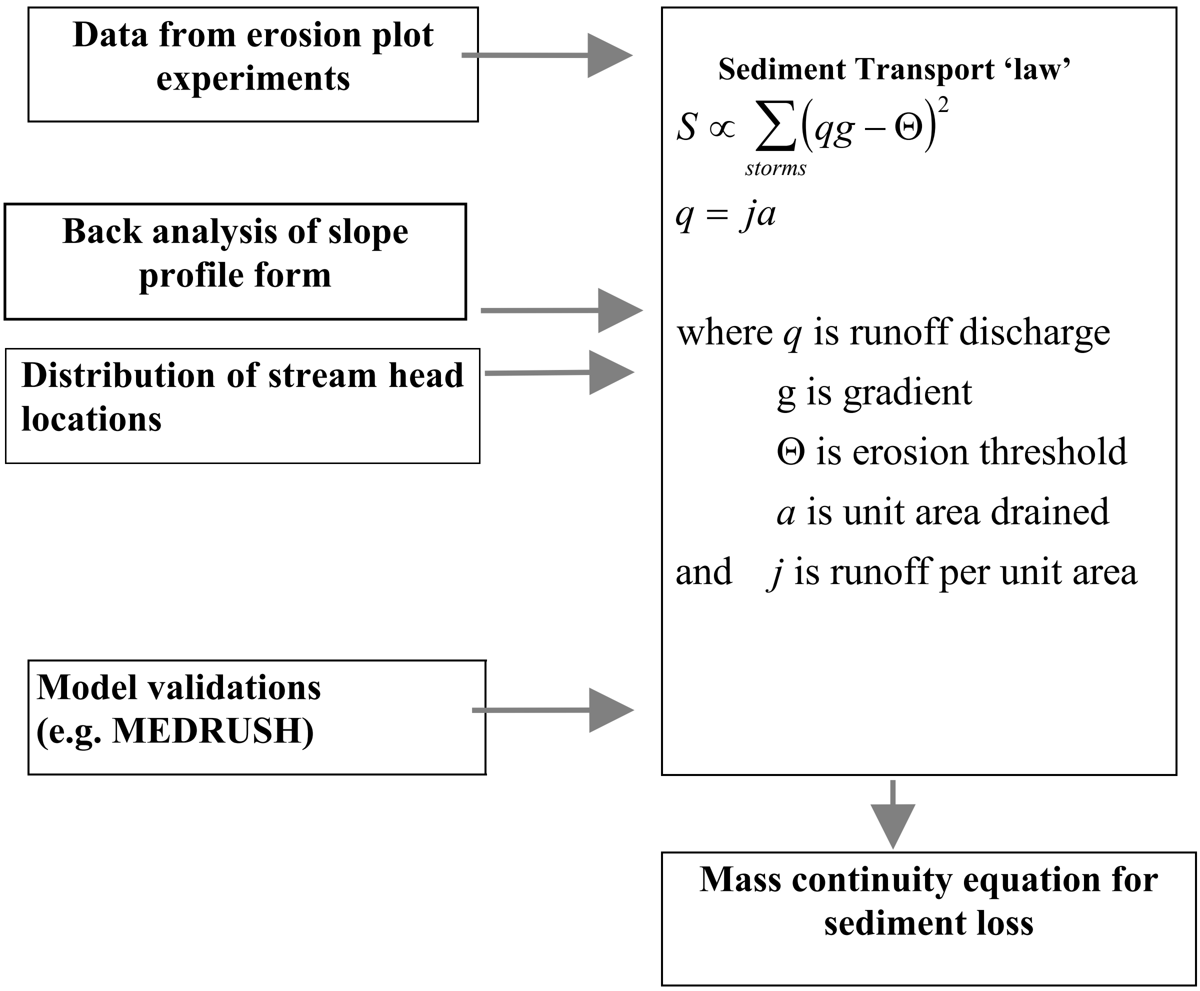

Fig. 20. Sources of data for relationship between topography and erosion

The influence of the bio-climatic factor may be seen very approximately for a non-seasonal climate by assuming an equilibrium soil organic matter and vegetation, for which the storage capacity is approximately proportional to actual evapotranspiration. For a semi-arid climate this is in turn almost equal to rainfall. If the mean rain per rain-day (r_0) remains constant, the bioclimatic index then takes the approximate form:

$$\sim R \exp(-R/R_0) \qquad \text{(C11a)}$$

for a suitable value of the constant R_0.

This expression rises linearly for small rainfall, and levels to a maximum at R_0 before falling again, demonstrating in a simple form the Langbein and Schumm vegetation effect. This approximation breaks down severely at large rainfalls, when the storage, *h* takes a more or less constant value related to the potential evapotranspiration, E_P, so that the expression behaves as:

$$\sim R \exp(-E_P/R_0). \qquad \text{(C11b)}$$

As temperature is changed, the potential evapotranspiration rises and R_0 rises even more. The resulting curves are sketched in figure 21. It is clear from the forecast curves (for non-seasonal climate regimes) that higher temperature tends not only to increase erosion rates everywhere, but also to shift the peak erosion towards higher rainfall areas.

The topographic indicator shows a very strong dependence on hillslope relief; proportional to H^2 if the slope length (or drainage density) is assumed constant and proportional to *H* if slope gradient is assumed constant (=*H/L*). Figure 22 shows the way in which a high erosion threshold substantially accentuates the influence of elevation, essentially depressing the erosion of low-relief areas under high threshold conditions, such as a strong turf root mat.

It is important to correctly allocate topographic and soil classes, since there is a strong correlation between high relief areas and strong rocks/soils. After a period of adjustment through erosion, erodible areas are reduced to lowlands while less erodible areas form highlands. High erosion is partly associated with the anomalies from such equilibrium landscape which are associated with recent tectonics or sea level change. More generally, the erosion of an uplifted highland area produces marginal piedmont areas where dis-equilibrium conditions of high erosion rates tend to persist longest in the landscape.

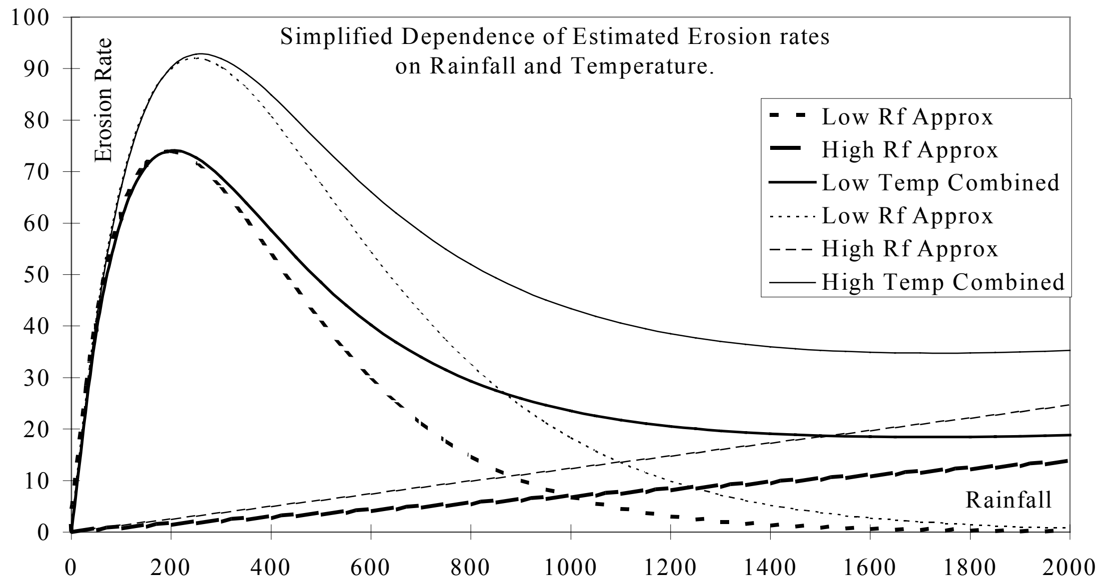

Fig. 21. Simplified dependence of bio-climatic erosion indicator on rainfall and temperature for a non-seasonal climate, following equation (C11).

4. Implementation

Fig. 23 outlines the possible data sources to compute the regional erosion estimate. Monthly averaged climate data is available from the KLIMAT data set (Kramer and Leemans, 199x) and monthly historic data has been interpolated for Europe in the MARS data set (EMAP, JRC, Ispra) for a 20 year period of daily data. This provides adequate data both to run the vegetation model and to estimate the frequency distribution of rainstorms. The model runs best if there are either daily data, or some additional data on the rainfall distribution. If only monthly totals are available, then mean rain per rain-day is estimated as 1.3 x (mean rain per day). If Number of rain-days is available, then its coefficient of variation is taken as the averaged value of 1.27, but fuller information gives better results. In all cases tested, it has been satisfactory to assume that the mix of exponential distributions is based on two intensities which are in the ratio 5:1, but if data sets are adequate, it may also be possible to fit this ratio.

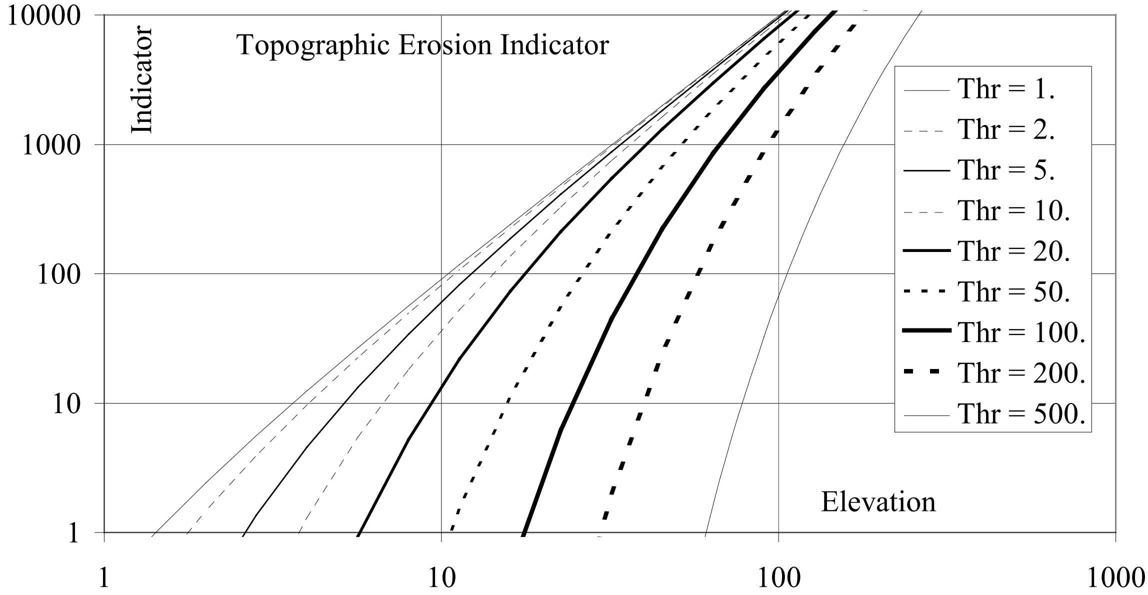

Fig. 22. The topographic erosion indicator showing the influence of the flow power erosion threshold, Θ.

These data are available for ½° x ½° latitude x longitude grids (approximately 50 km), and this scale sets some limitations on the resolution of the final product. For some areas better data are available, and it may be possible to apply an intelligent interpolation procedure in combination with the DEM to offset temperature and rainfall with elevation and with respect to prevailing weather circulation types. Where vegetation is generated from the climate, it has the same limitations of resolution, but, if AVHRR data is used, the land cover is improved to 1 km resolution.

Topographic data is most readily taken from existing DEM's. At present the most widely available DEM for the whole of Europe (and the world) is at a 1 km resolution, but improved resolutions are likely to become available in the near future. After some experimentation, the proposed measure of local relief is the standard deviation of elevations within a fixed radius of each point. For a resolution of 1 km, the least acceptable radius is 1.5 km, giving a sample of 9 points for each calculation. Figure 24 shows the results of using a circle of 1km radius to the original (50 m) and progressively degraded resolutions for a part of the Guadalentin catchment. The left hand diagram shows the topography at 50 m resolution. The centre diagram shows the relief calculated for a circle of 1 km radius based on 100 m resolution (approximately 300 points in each calculation), and the third diagram compares this estimate of relief from that obtained for the same 1 km radius from the DEM of 400 m resolution (13 points in each calculation). It may be seen that the estimate is independent of the resolution, and degrades only slightly. Clearly there is a smallest circle which can be used for any resolution. Tests also show that the size of the circle has much more effect on the result than changes in the DEM resolution used, keeping circle size constant. This method can therefore be used with the best resolution DEM available for each area studied.

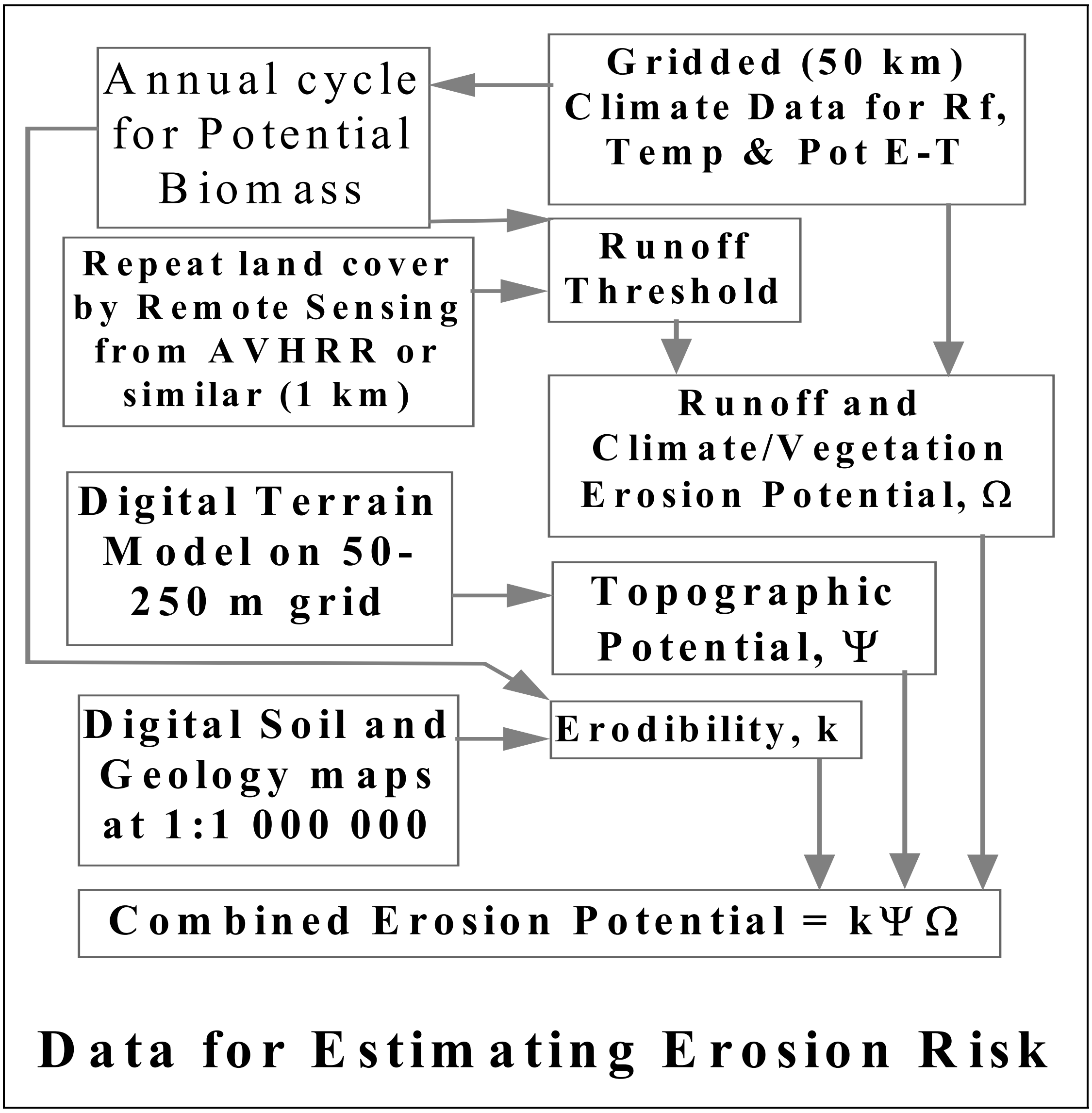

Fig. 23. Data sets available for estimating regional erosion risk

The resolution of the final product is partially limited by the resolution of the available climate data, but the impact of vegetation, soil and topography can generally add significant detail which largely justifies production at a 1 km resolution.

Complete tests of the model are not yet available. Fig. 25a shows the bio-climatic indicator estimated for uncultivated vegetation in the Mediterranean, showing greatest erosion potential in Greece, Portugal and Italy. Fig. 25b shows the changes expected for a uniform 2°C temperature rise, indicating increased erosional risk in most of southern Europe, but with a smaller impact or a negative impact in the drier areas of north Africa, following the inference drawn from Fig. 21. The relationship with climate is also explored for a transect of points between 30° and 35°N in North America, which corresponds approximately to the area from which Langbein and Schumm's original data was drawn.

Although there is a great deal of scatter in the forecasts, as there was in the original data, Fig. 26 shows that the bio-climatic index is able to reflect the interaction between rainfall, vegetation and sediment yield in a realistic way.

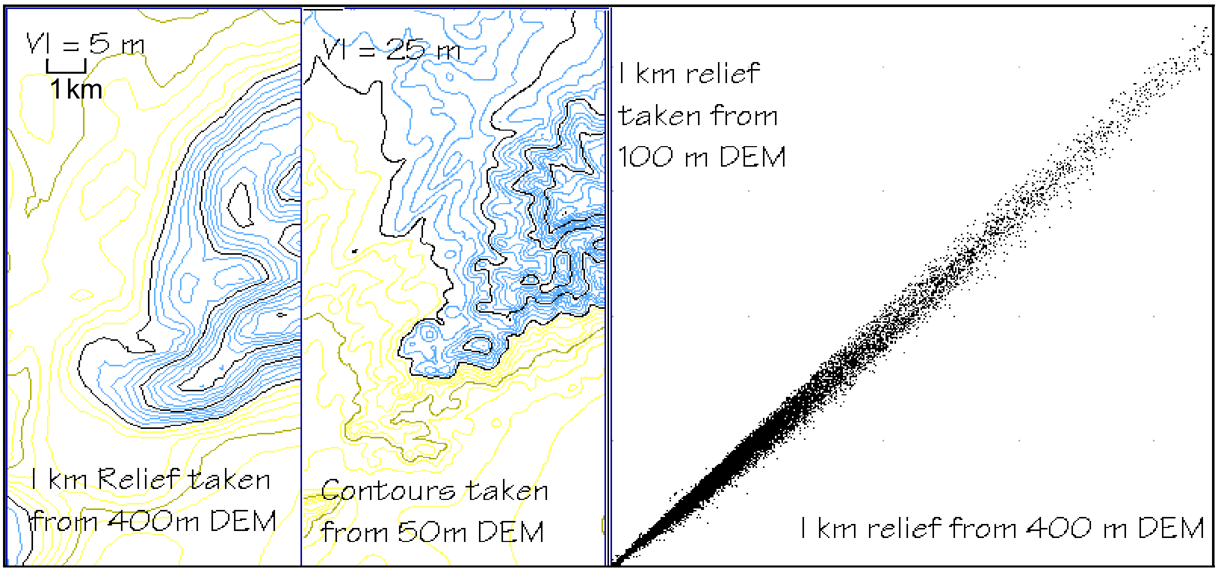

Fig. 24. 1 km Relief measured from a 400 m DEM is compared here with the topography from the 50 m DEM, and Relief measured from 100m and 400m resolutions is compared.

5. Salinisation Indices

The volume and quality of water is a critical resource issue in semi-arid countries. The excess of irrigation demand over natural recharge is increasing through population growth, demand for horticultural crops and climate change. Soil salinisation occurs where harmful salts, notably sodium salts, are concentrated by evapotranspiration, and accumulate to levels which limit crop growth and create undesirable soil properties which hinder infiltration and increase dispersion of clay minerals.

Exploitation for agriculture, notably through irrigation and groundwater pumping, exacerbate this problem. Within southern Europe, salinisation has been identified as a significant component of some Environmentally Sensitive Areas, particularly in Spain, Italy and Hungary.

The simple one-dimensional hydrological model which has been used for Soil Erosion Risk is also being developed currently to provide regional indicators of salinisation potential within a GIS, currently with a grid resolutions of 50 km set by the climatic data base. This provides a comparable methodology to that being used for erosion, in order to compare areas where salinisation is already a significant process of land degradation, and to estimate the sensitivity of areas to further development.

The model currently estimates salinisation potential as a function of climate, topography, water balance, depth to water table and initial salinities of rainfall, irrigation water and soil. Salinisation risk may be assessed in this way from remotely sensed land cover, with interpolated climatic and DEM data, and linked to thematic soil maps. The data required are available globally, and the methodology is being applied not only to Southern Europe but also to areas in Africa, the Middle East and Central Asia.

In constructing the model, it is assumed that water containing ions from rainfall, irrigation and groundwater comes into equilibrium with the solid chemical constituents of the soil, ignoring interactions amongst them. The soil solution is then concentrated by evapotranspiration. Where the resulting strength exceeds saturation solubility, there is re-deposition within the soil, creating salinity problems where this occurs for harmful constituents. The flow diagram in figure 27 shows how concentration for each ion is calculated. 'Proportions' in water are fractions of saturated concentration for the ion.

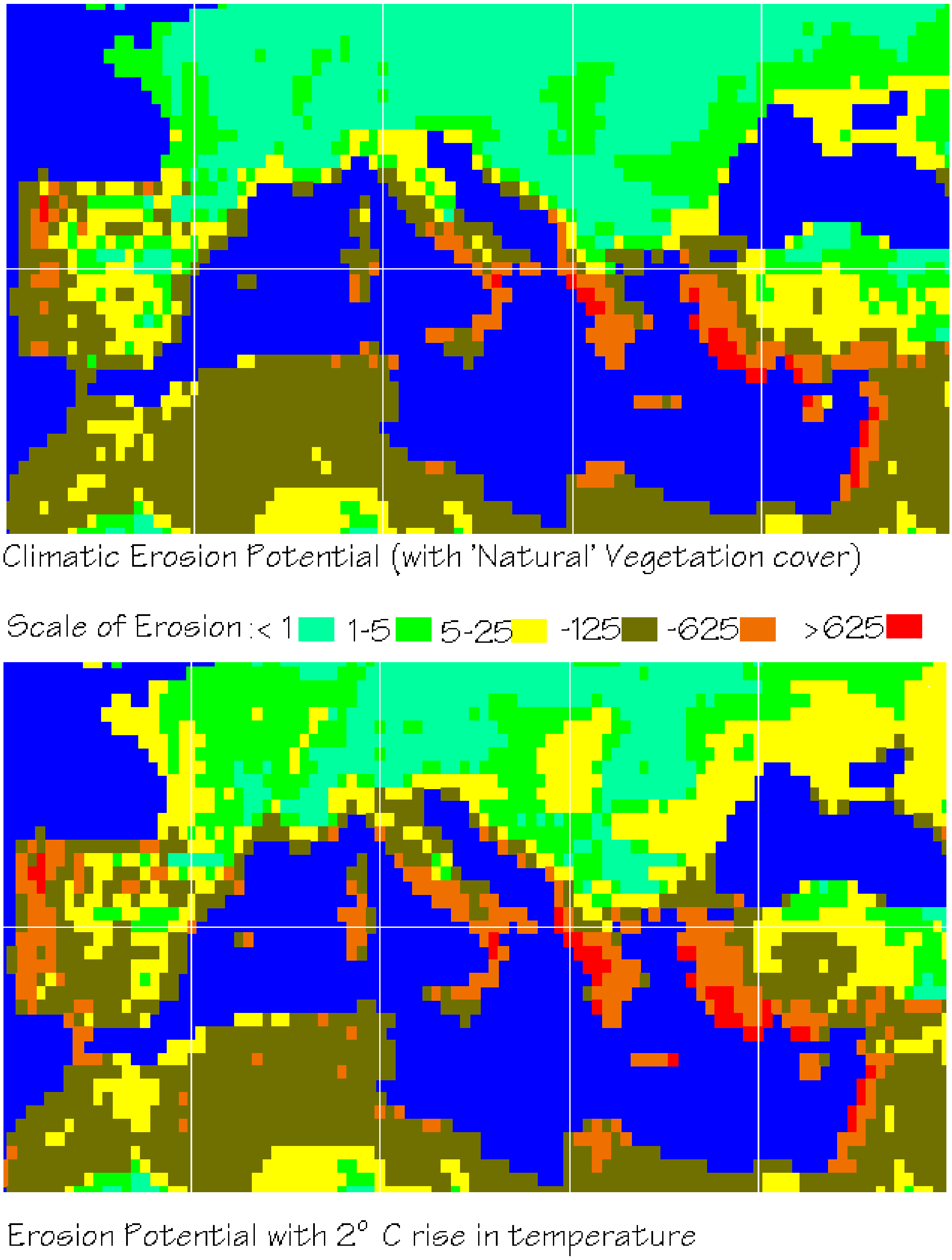

Fig. 25 (a): Forecast climatic erosion potential for the Mediterranean,
(b) Forecast climatic erosion potential with temperatures raised by 2°C

The rate of groundwater rise may be related to the ratio of water table depth, h, to height of capillary rise h_0, and to the unsatisfied water demand, $(E_P\text{-}R\text{-}I)$ where E_P is the potential evapotranspiration (E-T). Actual E-T is estimated from rainfall and potential E-T. The model shows how the risk of severe salinisation increases with the proportion of Sodium in the soil, and decreases with the ratio of Rainfall to Potential E-T and with water table depth. As expected, potential problems are greatest for high Sodium soils and where water tables are within 2 m of the surface.

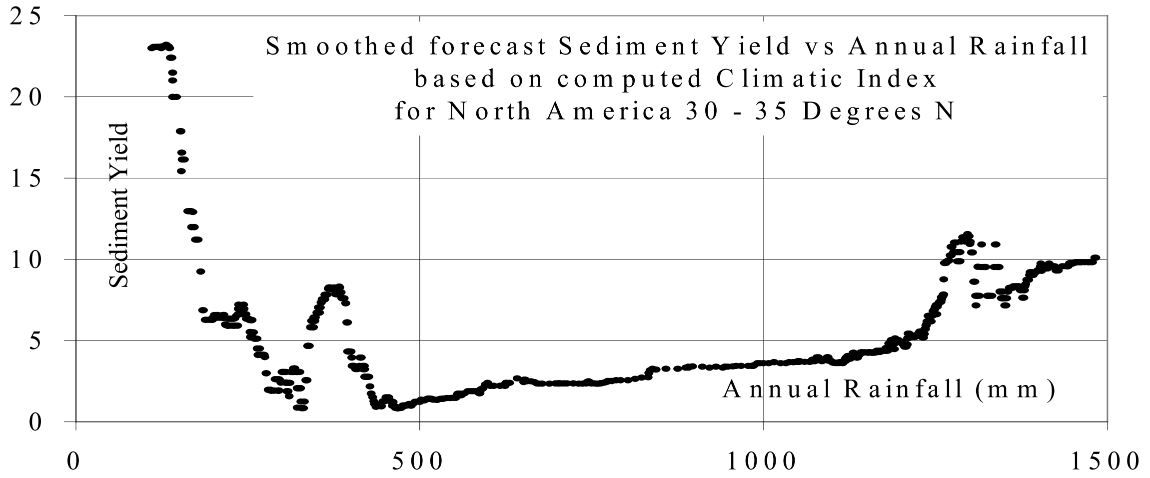

Fig. 26. Smoothed forecast relationship between annual rainfall and sediment yield for southern USA.

A Variant of the model is being used to simulate the equilibrium or time-dependent profile of salinity with depth in the soil, allowing direct links to be made with field observations and the regional model.

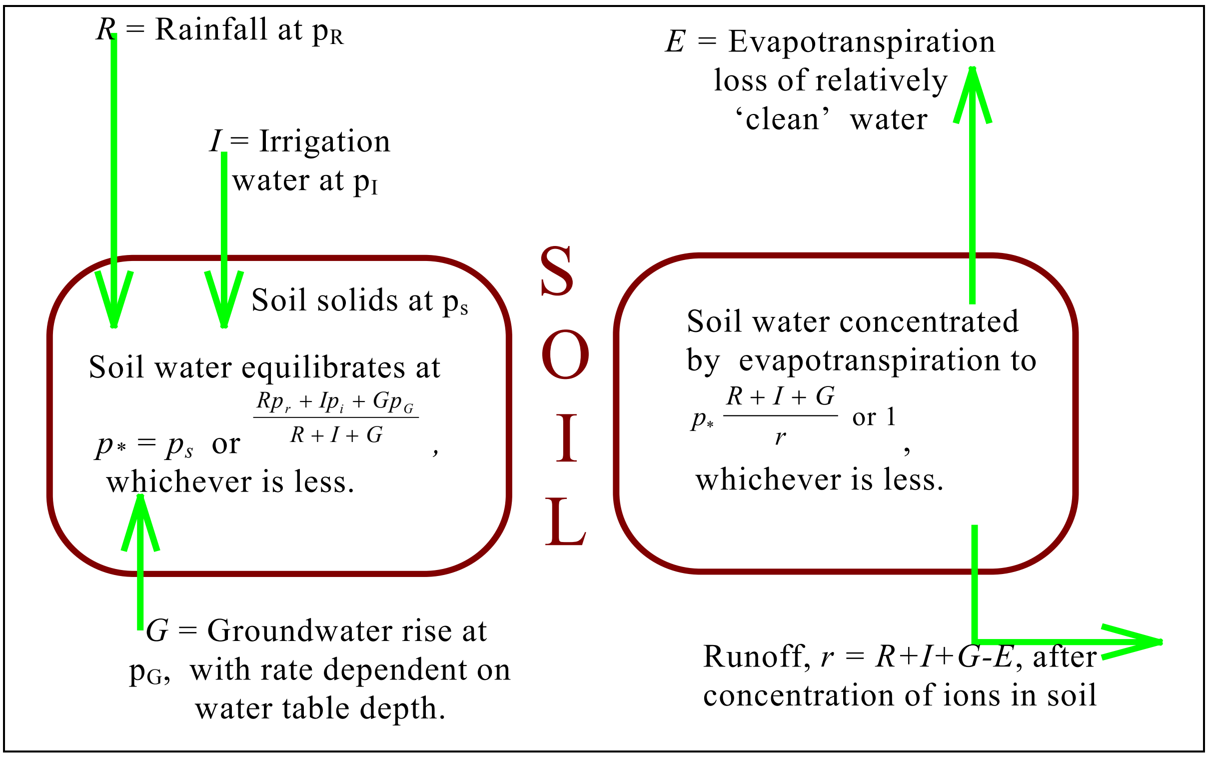

Fig. 27. Modelled Water and solute equilibrium in soils

6. Conclusions

This work outlines a scientifically consistent and objective approach to Regional Indicators for Desertification. Regional Indicators provide a planning framework which allows international and national agencies to assess the overall extent of erosion or other risk factors, and to allocate resources for more detailed investigation.

The nature of Regional Indicators is that they provide only a general overview. Coarse scale indicators should be used to define areas where more detailed studies are needed. They are therefore seen as the outermost shell for an explicitly nested approach to determining and mitigating risks. As the scale changes, the dominant controlling factors also change, from climatic and macro-economic at continental scales, to considerations of local topography, aspect and individual farming practice at the scale of a community at which remediation strategies must be applied.

The scientific rationales at these widely different scales should remain compatible. In this way parameters of regional indicator model may be derived from and related to more detailed catchment or plot models, in accordance with the nested approach advocated in this work.

D. APPLICATION OF THE PROPOSED METHODOLOGY FOR DEFINING ESAs

1. The island of Lesvos (Greece)

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Agricultural University of Athens, laboratory of Soils and Agricultural Chemistry

1.1 Application of the derived methodology

The various types of environmentally sensitive areas to desertification occurring in the island of Lesvos were defined after conducting a detailed survey of all the required land parameters and management characteristics mentioned in the proposed methodology. The following maps have been compiled at the scale of 1:50,000:

- Soil texture
- Parent material
- Drainage conditions
- Surface rock fragment cover
- Slope gradient
- Soil depth
- Degree of soil erosion
- Rainfall distribution
- Slope aspect
- Aridity
- Vegetation fire risk
- Soil erosion protection by vegetation
- Vegetation drought resistance
- Plant cover
- Intensity of land use
- Policy on land protection

Based on the above methodology maps have been produced for the island of Lesvos representing the four qualities used for the definition of the ESAs. As Fig. 28 shows, the majority of the island of Lesvos has moderate quality soils (61.5% of the area) with respect to desertification risk followed by low quality soils (30.7%). Soils of high quality are greatly restricted (7.8%). The high percentage of moderate and low quality of soils is mainly attributed to the steep slopes, and to the shallow depths favoring high rates of overland flow and erosion and restricting soil water storage capacity.

The physiographic configuration of ragged terrain of high elevation differences with steep slopes and landscapes dissected by channels and rivers favours high erosion rates and occurrence of landslides in some cases. Extensive parts of the island are covered with rock fragments favouring water conservation, restricting soil erosion and protecting the areas from desertification. In the majority of the land (63% of the area) the proportion of the soil surface covered by rock fragments is high, ranging from 20-60%. The greatest part of the soils are moderately deep (soil depth 30-75 cm) covering 67.2% of the area. Relatively extensive areas are highly degraded with soils having depth less than 30 cm (15.3% of the area) pointing to a higher sensitivity to desertification. Lowland alluvial plains are limited. The presence of relatively shallow ground water table in plains favors salinization and therefore desertification.

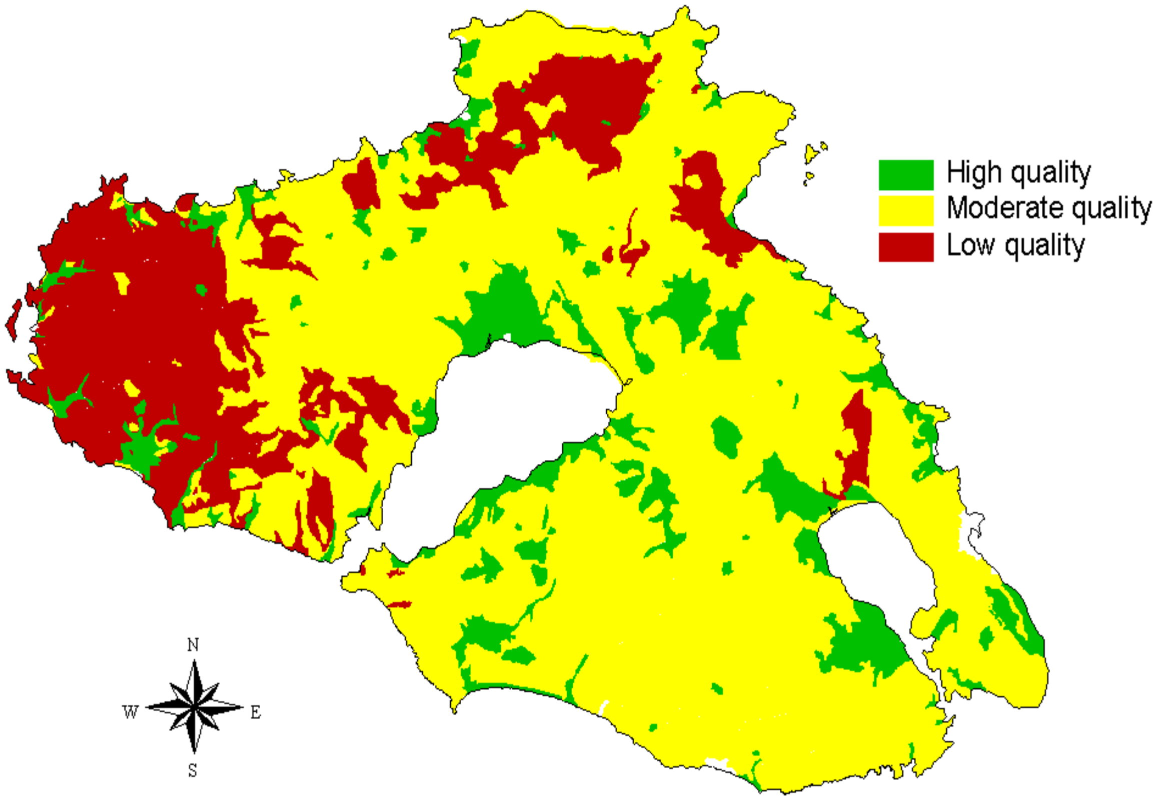

Fig. 28. Soil quality map of the island of Lesvos related to desertification risk.

As Fig. 29 shows, the majority of the island is characterized by moderate climate quality (88% of the area). This is mainly attributed to the relatively low amount of precipitation occurring in the area and the high bioclimatic aridity index. The island of Lesvos is characterised by a dry sub-humid climate in the eastern and central part with 670 mm of annual precipitation. However, there is a strong gradient of rainfall from east to west along which the amount of rain decreases by more than 45%. The lower amount of rainfall, occurring in the western part of the island, combined with the drier conditions prevailing particularly in the south-facing slopes creates high water deficit for the growing plants for a long period. The greatest part of the island (74%) is characterised as very dry with an aridity index greater than 150. Taking into consideration the general aridity index of the climate, a high moisture deficit occurs in the island of Lesvos reducing vegetation cover and increasing the possibility of fire occurrence especially in the areas covered by pines or macchia vegetation.

The majority of the various types of vegetation existing in the island is characterized as high (40.7%) and moderate quality (37.7%) (Fig. 29). This is mainly attributed to the presence of vegetation of high resistance to drought with high percentage cover. The greatest part of Lesvos (81%) is relatively well vegetated with perennial vegetation protecting sufficiently the soils from raindrop impact. Considering that vegetation cover presents possibly the most crucial element of soil erosion control in slopping areas, the natural forests or the well managed olive groves which cover the majority of the island (62%) offer high to moderate erosion protection to the soils. Areas with soils exposed to high erosion risk due to low vegetation cover represent about 22% of the island area.

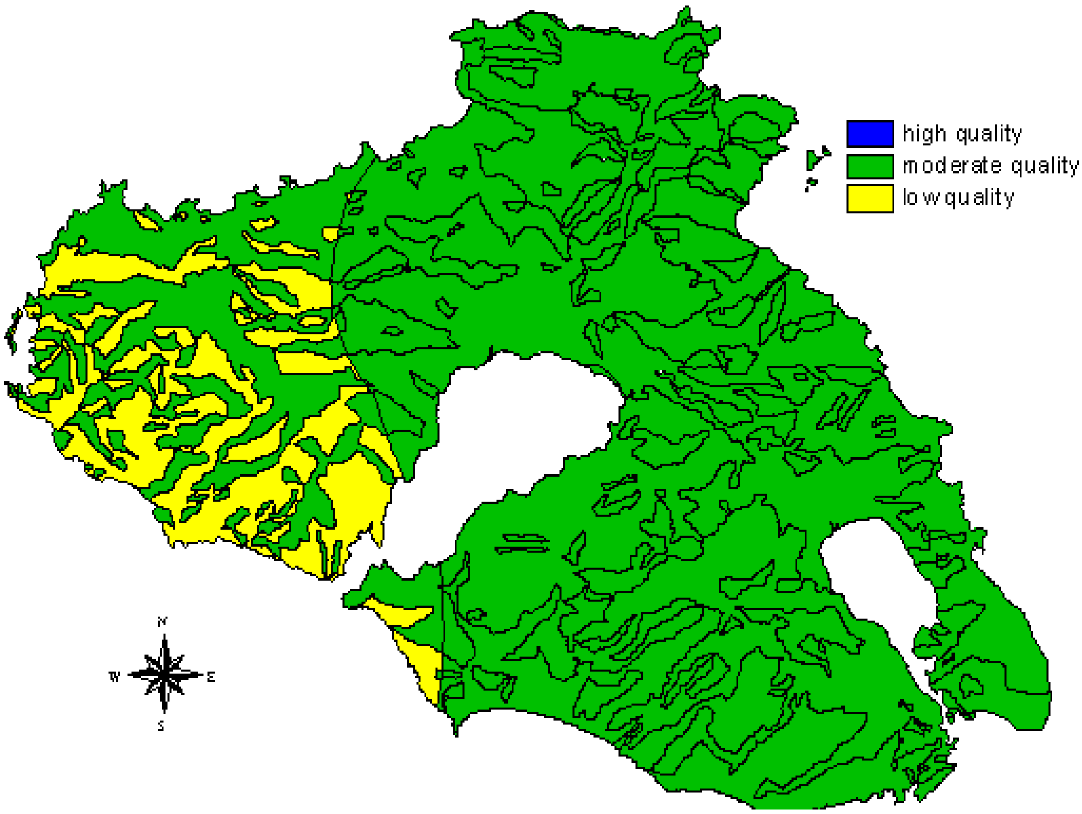

Fig. 29. Climate quality map of the island of Lesvos related to desertification risk.

The high aridity index of the climate resulted in the development of vegetation of high resistance to drought. This is due to the more extensive pine (*Pinus halepensis*) forests, olive plantations and macchia vegetation. Of course the presence of high proportion of vegetation with high fire risk increases the erosion potential of soils in hilly areas. The extensive pine forests (high fire risk) combined with prolonged dry climatic conditions increase the possibility of transmitting a fire in nearby areas with vegetation cover of low fire risk.

Fig. 31 shows that the management quality of the land is low especially in grazing areas. The intensity of grazing has increased dramatically in the last decades due to (a) rapid decline of wheat production and (b) significant increase of subsidies for grazing animals. Shepherds damaged the natural vegetation by deliberately setting fires to eradicate the vegetation and encourage the growth of grass, which was then overgrazed. An obvious consequence of overgrazing is the increase in soil erosion. Areas under pine or oak forests are well managed and environmentally protected and they are classified as having high management quality.

Areas with moderate quality of management correspond mainly to terraced olive groves. The rapid increase of labour cost while the price of olive oil remained constant or declined in the last decade has resulted in only partially repairing the collapsed terraces in hilly areas. These terraces have been constructed with stones some hundreds or even thousands of years ago. The soil was removed from other places to fill these terraces. This conservation management requires high labour cost for the maintainance of the terraces. In the last decades, the value of such terraces has decline markedly because they are difficult to access and because they cannot easily be cultivated with tractors.

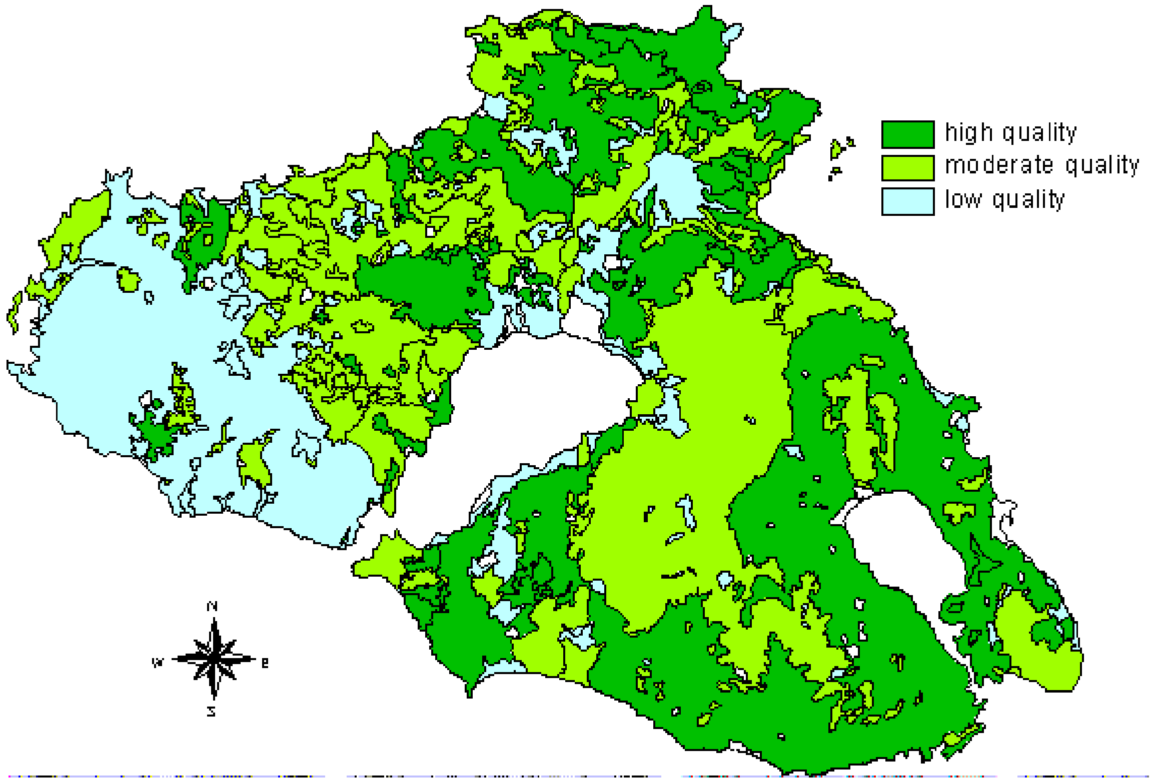

Fig. 30. Vegetation quality map of the island of Lesvos related to desertification risk.

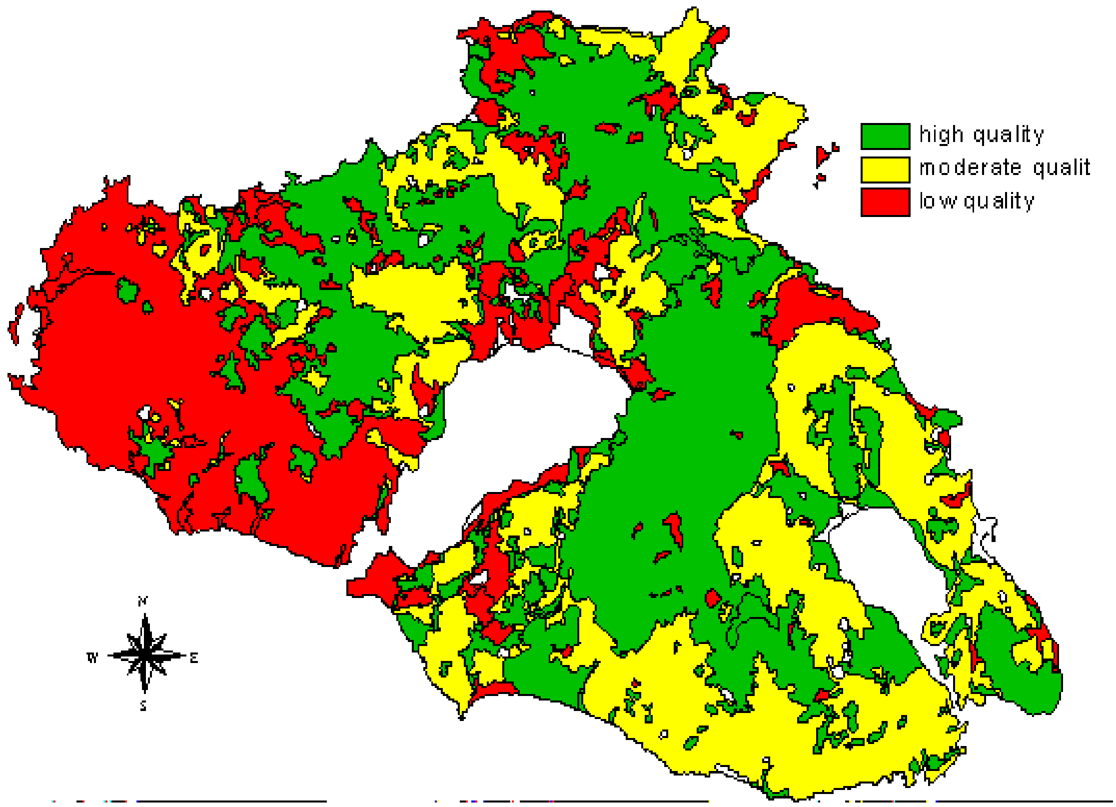

Fig. 31. Management quality map of the island of Lesvos related to desertification.

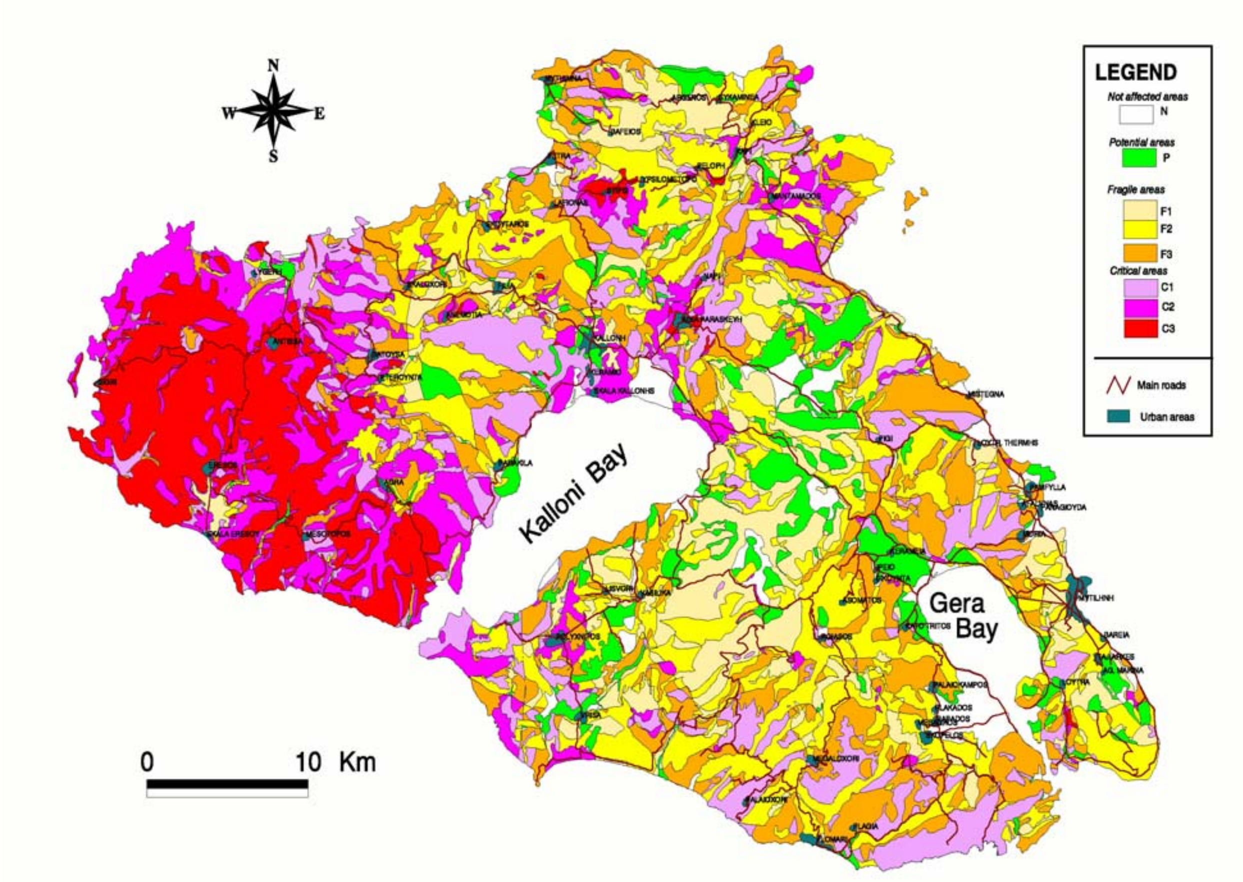

Fig. 32. Map of environmentally sensitive areas to desertification for the island of Lesvos.

The map of ESAs to desertification indicates that the majority of the island is classified as critical or fragile to desertification (Fig. 32). A 37% of the island is classified as critical, 52.4% as fragile, 7% as potential and only 3.6% of the area is not threatened by desertification.

The critical areas (S1, S2, and S3 in the map), located mainly in the western part of the island, have badly degraded very shallow (depth 0-15 cm) to shallow (15-30 cm) soils severely to very severely eroded, and poorly vegetated. Burning and overgrazing of this climatically and

topographically marginal areas constitutes a degradation-promoting land use, further deteriorating the existing land resources. This area is very sensitive to low rainfall and extreme events.

The fragile areas (F1, F2 and F3) are very sensitive to degradation under any change to the delicate balance of climate, and land use. Any change is likely to enhance reduction in biological potential with the result that this area will loose the remaining vegetative cover and be subjected to greater erosion rates. This area is threatened by higher rates of degradation under (a) slight climate change and (b) if the existing type of land use such as the well adapted olives are replaced or the pine forests are burned. Due to the relative good vegetative cover, the soils of this zone are moderately shallow (depth 30-50 cm) to moderately deep (50-100 cm), well vegetated with olive trees, pine or oak forests, slightly to moderately eroded.

The potential environmentally sensitive areas are mainly restricted to relatively deep soils of nearly flat to gently sloping under good vegetation cover and management practice. These areas are sensitive to degradation under significant changes of the climate and of human activity. Non threatened areas by desertification are confined to parts of the island with very deep soils, nearly flat with very deep ground water table.

1.2 Description of ESAs to desertification

Based on the data obtained from the applied methodology for defining ESAs to desertification in the island of Lesvos, the various types and subtypes of ESAs can be described as following in terms of land characteristics and management quality.

Critical ESAs

Subtype C3: Areas with very steep (dominant slope >35%), mainly coarse-textured, stony, shallow, well drained soils formed mainly on pyroclastics parent materials. The climate is mainly characterised as semi-arid, in few cases as dry-sub-humid, with rainfall ranging mainly from 300-650 mm, and dry bioclimatic index (Bagnouls-Gaussen aridity index-BAI ranging from 120-150). Areas of this subtype are usually found in south-facing slopes. The existing dominant vegetation is mainly phrygana or maquis characterised by high fire risk, moderate erosion protection, very high drought resistance, and plant cover usually ranging from 25-50%. These areas are mainly under moderate land use intensity (due to low income, highly degraded areas) and incomplete enforcement of the existing policy on environmental protection.

Subtype C2**:** Areas with very steep (dominant slope >35%), usually coarse-textured, stony, shallow, well drained soils formed mainly on marble and ignibrite parent materials. The climate is mainly characterised as semiarid, in some cases as dry sub-humid, with rainfall ranging mainly from 300-650 mm, and dry bioclimatic index-BAI (ranging from 120-150). Areas of this subtype are mainly found in south-facing slopes. The dominant vegetation is mainly phrygana or grasses characterised by high fire risk, moderate erosion protection, very high or high resistance to drought, and plant cover usually greater than 75% or in some cases 25-75%. These areas are mainly under moderate land use intensity and incomplete enforcement of the policy for environmental protection.

Subtype C1: Areas with mainly very steep, (dominant slope >35%), moderately fine-textured, stony, shallow to moderately deep, mainly well drained soils formed on marble, limestone, and ingnibrite parent materials. The climate is characterised mainly as dry sub-humid, in some cases as semiarid, with rainfall mainly >650 mm, and mainly very dry bioclimatic index (BAI >150). Areas of this subtype are mostly found in south-facing slopes. The dominant vegetation is olives, phrygana, cereals characterised mainly by low fire risk, moderate erosion protection, high resistance to drought, and plant cover usually greater than 75%. These areas are mainly under moderate land use intensity and partial enforcement of the policy on environmental protection.

Fragile ESAs

Subtype F3: Areas with very steep to steep, moderately fine-textured, stony to slightly stony, moderately deep to deep, well drained soils formed mainly on marble, schist, ultrabasic parent materials. The climate is mainly characterised as dry sub-humid, in some cases as semi-arid, with rainfall mainly >650 mm, and mainly very dry bioclimatic index (BAI >150). Areas of these subtype are found in north-facing slopes (mainly) or south-facing slopes. The dominant vegetation is olives following by pines, oaks and phrygana characterised mainly by low fire risk followed by moderate and very high fire risk, moderate erosion protection, high resistance to drought, and plant cover usually greater than 75%. These areas are mainly under moderate land use intensity and partial enforcement of the policy on environmental protection.

Subtype F2: Areas with mainly steep to gentle sloping, moderately fine-textured, stony, moderately deep to deep, well drained soils formed mainly on marble, schist, shale, ignibrite and ultrabasic parent materials. The climate is mainly characterised as dry sub-humid with rainfall greater than 650 mm, and very dry bioclimatic index (BAI >150). These areas are mainly found in north-facing slopes, in some cases in south-facing slopes. The dominant vegetation is olives and pines and in some cases oaks or phrygana, characterised mainly by low fire risk or in some cases by high fire risk, moderate to high erosion protection, high resistance to drought, and plant cover usually greater than 75%. These areas are under moderate land use intensity and complete enforcement of the policy for environmental protection.

Subtype F1: Areas with steep to gently sloping, moderately fine-textured, mainly stony or free of rock fragments, deep to moderately deep, well to imperfectly drained soils formed mainly on shale, schist and ultrabasic or in some cases on limestone, ignibrite and marble parent materials. The climate in most areas is characterised as dry sub-humid with rainfall >650 mm, and very dry bioclimatic index (BAI >150). These areas are mainly found in north facing-slopes or in some cases in south-facing slopes. The dominant vegetation is pines and in some cases olives and evergreen oaks characterised mainly by very high (pines) or in some cases by low fire risk (olives), usually moderate to low erosion protection, high resistance to drought, and plant cover usually greater than 75%. These areas are mainly under moderate land use intensity and complete enforcement of the policy for environmental protection.

Potential ESAs
Areas with nearly flat to gently sloping (slope <12%), moderately fine-textured, free of rock fragments to stony, very deep, mainly well drained or in some cases imperfectly to poorly drained soils formed mainly on shale, schist, ultrabasic, and unconsolidated deposits. The climate is mainly characterised as dry sub-humid with rainfall greater than 650 mm, and very dry bioclimatic index (BAI >150). These areas are usually found in north facing-slopes or they are flat. The dominant vegetation is mainly olives and pines and in some cases evergreen oaks or annuals, with usually low fire risk (olives) or high fire risk (pines), high to moderate erosion protection, mainly high resistance to drought, and plant cover usually greater than 90%. These areas are mainly under moderate land use intensity and complete enforcement of the policy on environmental protection.

Non threatened areas
Areas with nearly flat, moderately fine-textured, mainly free of rock fragments, very deep, usually well drained or in some cases imperfectly drained soils formed mainly on shales, ultrabasic rocks, unconsolidated deposits and alluvial deposits. The climate is mainly characterised as dry sub-humid with rainfall >650 mm, and very dry bioclimatic index (BAI >150). These areas are mainly found on north facing-slopes or they are flat. The dominant vegetation is olives or pines characterised mainly with low fire risk (olives) or in some cases with high fire risk (pines), moderate erosion protection, high resistance to drought, and plant cover usually greater than 90%. These areas are mainly under moderate land use intensity and complete enforcement of the policy on environmental protection.

1.3 ESAs and soil erosion

As Table 10 shows, the various types of ESAs to desertification are clearly related to the degree of soil erosion. The maps of ESAs and the degree of erosion were independently compiled. The ESAs map was derived by using the methodology for defining and mapping ESAs developed in this project, while the erosion map was compiled during the field survey of land parameters in the island of Lesvos. The defined as critical and fragile ESAs are clearly related to the degree of erosion. Critical-C3 areas are mainly characterized with very severely eroded soils (56.7% of this area), followed by severely eroded soils (30.9%). The areas belonging to critical-C2 ESAs are better protected from erosion with degree of erosion ranging mainly from moderate (37.2%) to severe (41.2%).

As figure 33 shows, the sensitivity of the various sub-types of ESAs to erosion decreases in the following order:

Critical-C3>critical-C2>critical-C1>fragile-F3>fragile-F2>fragile-F1>potenial>no-treatened

Therefore, the actions reguired for mitigation of desertification in environmentally sensitive areas to desertification are mainly related to protection of soils from erosion. Potential ESAs to desertification may require either protection from erosion or from salinization due to the presence of shallow ground water table.

Fig. 33. Change in area of the various degrees of soil erosion corresponding in the various types of environmentally sensitive areas of Lesvos

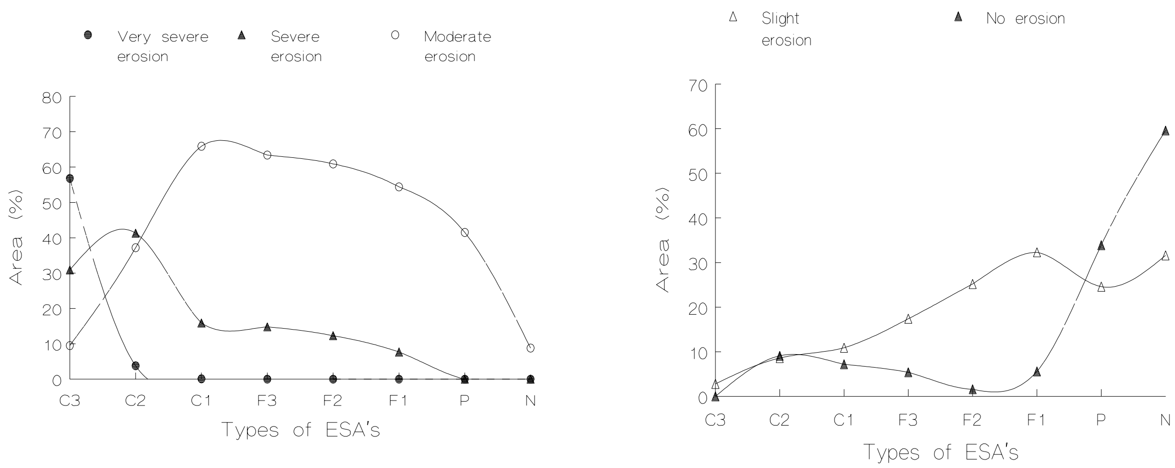

Table 10. Degree of erosion (area %) measured in the various types of ESAs on the island of Lesvos

ESAs	No erosion (NE)	Slight erosion (WE)	Moderate erosion (ME)	Severe erosion (SE)	Very severe erosion(VSE)	TOTAL
Critical-C3	0	2.8	9.5	30.9	56.8	100.0
Critical-C2	9.1	8.6	37.2	41.3	3.8	100.0
Critical-C1	7.2	10.9	65.9	15.9	0.1	100.0
Fragile-F3	5.4	16.4	63.4	14.8	0	100.0
Fragile-F2	1.6	25.2	60.9	12.3	0	100.0
Fragile-F1	5.6	32.3	54.4	7.7	0	100.0
Potential	33.9	24.6	41.5	0	0	100.0
Non affected	59.6	31.6	8.8	0	0	100.0

2. The Agri basin (Italy) ([1])

F. Basso, A. Bellotti, S. Faretta, A. Ferrara, G. Mancino, M. Pisante, G. Quaranta
Università degli Studi della Basilicata, Dipartimento di Produzione Vegetale

2.1 Application of the derived methodology

Based on the above methodology, four quality maps were produced for the Agri basin, as well as the final evaluation of the Environmental Sensitivity at basin level. All maps produced by the system have the final scale of 1:50 000; all values in the data base are continuous and the maps that follow are reduced in classes and colours for publishing reasons.

Fig. 34 shows the resulting soil quality layer; as we can see, the majority of the basin (65% of the area) has a low quality of soils (values > 9.6) even if a certain part of these soils have scores very close to the threshold value. A lower part of the basin has moderate quality (33%) and only a very little part can be assigned to the better quality (2%). This is resulting by the presence of large parts of areas with slopes greater than 18% (that cover about 62% of the area in Agri basin), an high presence of soils, having depth less than 30 cm (30% of the area) and an important presence of clays soils highly degraded, all factors that favour high erosion rates and occurrence of landslides in some cases. Better soils are mainly situated in the flat areas of the upper valley and along the main rivers.

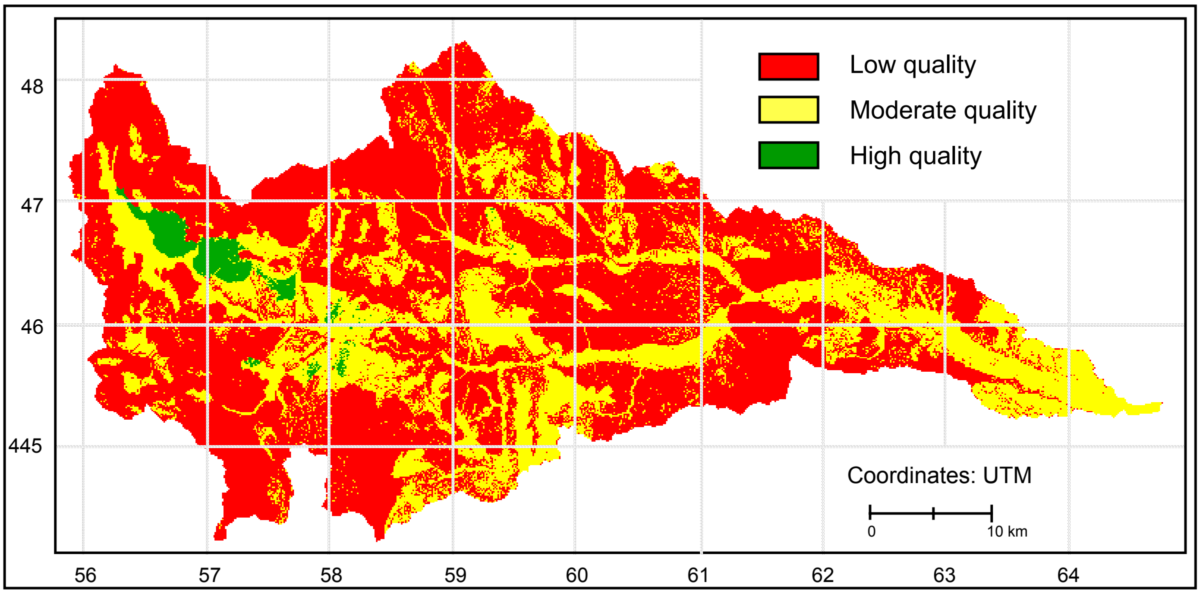

Fig. 34. Soil quality map of the Agri basin related to desertification risk.

[1] Research conducted with the aid of European Union funds "MEDALUS III Project. Basso and Pisante had mainly developed the agronomic aspects, Quaranta those socio-economic, Bellotti, Faretta, Ferrara, Mancino and Taberner the other aspects as well as the development and the application of the model.

Fig. 35 shows that a very great part of the basin is characterised by high (47%) and moderate climate quality (52%). Only a very little part (1%), near the Ionian sea, falls into low quality class. This can be mainly attributed to high rates of rain that occur in large parts of the basin. Rainfall is in fact about 2000 mm per year on Monte Sirino (west part of the basin) and 500 mm per year along the Ionian coast showing a consistent increase with increasing elevation. In addition, the average annual temperate is strictly related to elevation, ranging from 8 ^{o}C on the mountains to 16 ^{o}C in the middle and lower valley. Taking into consideration the Bagnouls-Gaussen aridity index, 48% of the Agri basin is characterised as moist with an aridity index less than 50. The rest of the basin is characterised as dry with an aridity index ranging from 50 to 125, and only 2% of the area has a very dry climate (aridity index 125-150). As for slope aspect, south-facing slopes are widely diffused creating favourable climatic conditions for land degradation and desertification. In the whole, the Agri Valley can be characterised as having a cool temperate mediterranean climate with a strong gradient from the coastline to the mountainsof the interior.

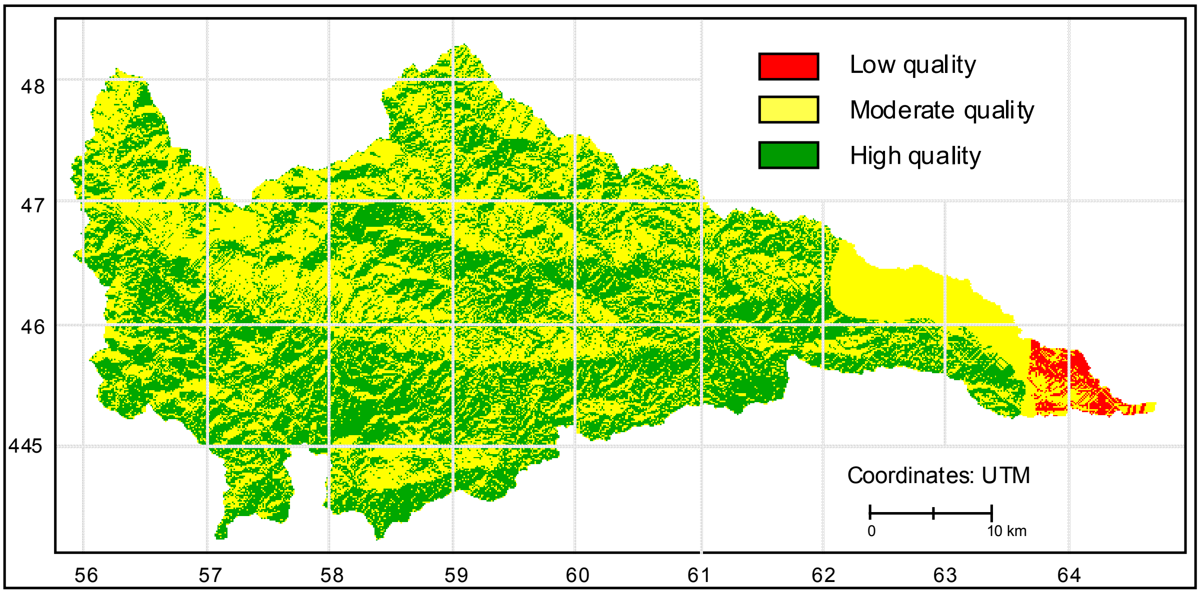

Fig. 35. Climate quality map of the Agri basin related to desertification risk.

Vegetation cover and vegetation physical structure are important factors concerning erosion. As Fig. 36 shows, a large part of the basin has a low quality vegetation (45%), another important part has a good quality (30%) and a minor part has moderate quality (25%). This is resulting by the fact that a significant part of the Agri basin has vegetation with very low ability in protecting the soil from erosion. This part corresponds mainly to areas cultivated with cereals or with a very low vegetation cover, in which we have more favourable conditions for overland flow and erosion and also an high sensitivity to drought. Fire risk seems to be a critical factor mainly in the lower part of the Agri basin, in areas prevailing covered by mediterranean macchia and pine forests. Considering also that vegetation cover is a crucial element in soil erosion control on slopping areas, a considerable part of the Agri basin (42%) has a vegetation cover less than 40% and it is subjected to very high erosion risk. Areas with vegetation cover less than 10% represent an important part 18% and are highly threatened for desertification, creating also serious flooding problems in the surrounding areas.

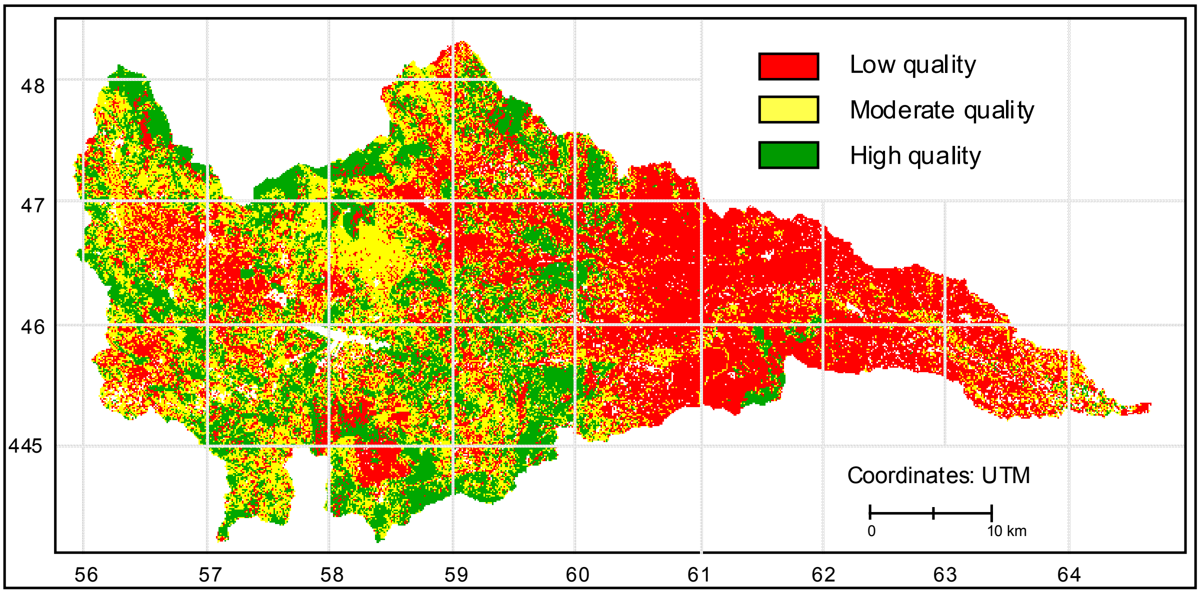

Fig. 36. Vegetation quality map of the Agri basin related to desertification risk.

Figure 37 shows the management quality of the basin. It must be noted that the basin, in the whole, is divided in two separate parts, one mainly corresponding to the upper valley and covering about the 48% of the surface, in which we have a moderate quality of the management indicators. The second part, that covers the remaining areas of the basin, and that presents a low quality of the management. This situation is mainly derived by the scarce enforcement of the management and the policies in relation to the environmental protection.

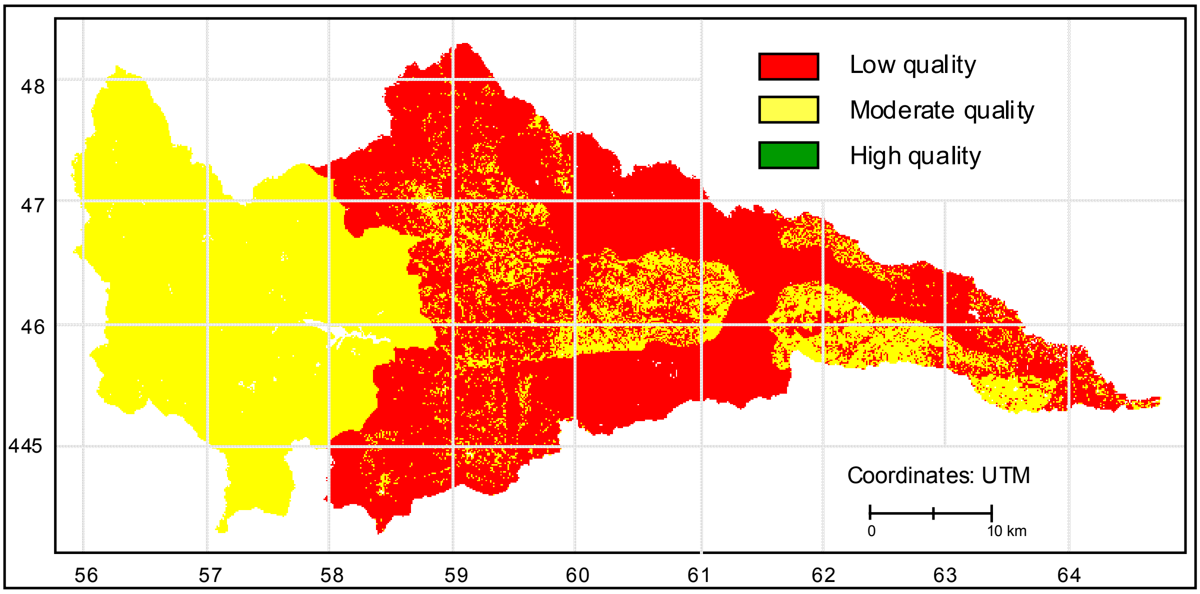

Fig. 37. Management quality map of the Agri basin related to desertification risk.

The map of Environmentally Sensitive Areas to desertification for the Agri basin is presented in Fig. 38. It clearly shows that a large part of the basin falls into the critical and fragile classes with a certain presence of potential or not threatened ones. 45 % of the basin is classified as Critical (with a mayor presence of C2 class), 34 % as Fragile (with large parts of the basin falling into F3) and only 4 % as Potential or Not Threatened.

The Critical areas (C1, C2 and C3) are mainly located in the middle and lower part of the basin and are mainly represented by Calanchi areas, and other areas in which the presence of clays, very low vegetation cover, high slopes, forest fires, overgrazing and low management quality produce a very high risk of soil degradation and a very high sensitivity to desertification.

The Fragile areas (F1, F2 and F3) are more widespread along the basin and are represented by zones in which management factors, quality of soils and climate are, in the whole, not very critical but in which little decrease of the quality of one of these factors can produce very critical situations.

The Potential and Not Threatened areas are mainly localised in the upper part of the valley and in any other parts where favourable climate and soil conditions (flat and deep soils with high annual rainfalls), good vegetation cover and efficient management are found.

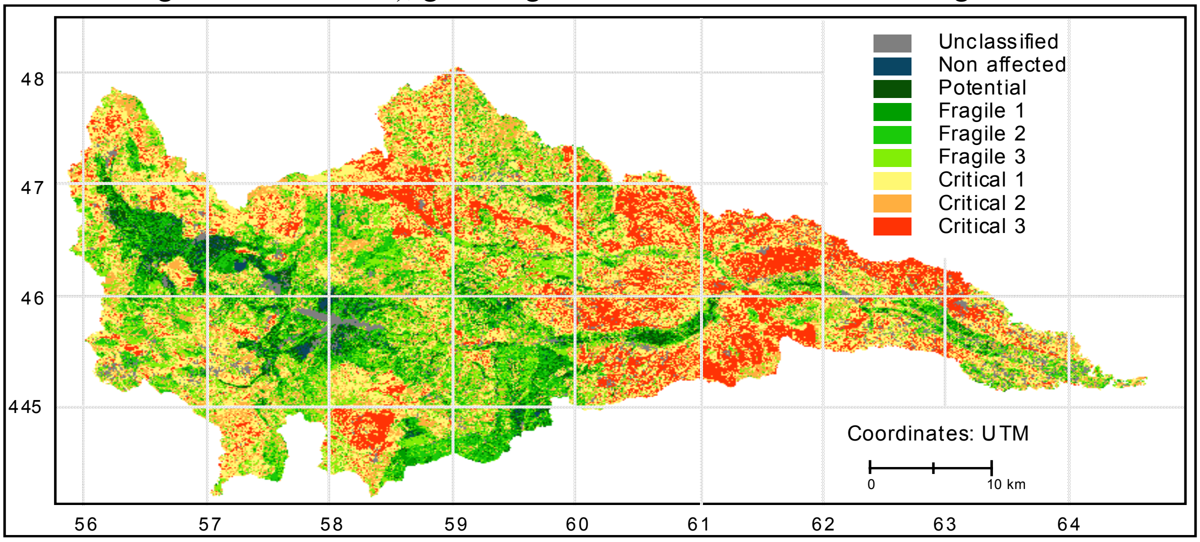

Fig. 38. Map of Environmentally Sensitive Areas to desertification for the Agri basin

3.2. An example of application of the ESAs estimate for land use management

Using the defined ESAs, a sensitivity analysis was conducted at municipality level. The following is an example of an analysis performed in the Agri basin on the different degrees of Environmental Sensitivity at Municipality level. The frequency of the different classes of all the used layers was considered for each municipality. A cluster analysis was applied on the obtained matrix of data, utilising the complete linkage and Euclidean distance methods. Figure 39 illustrates the resulting dendrogram.

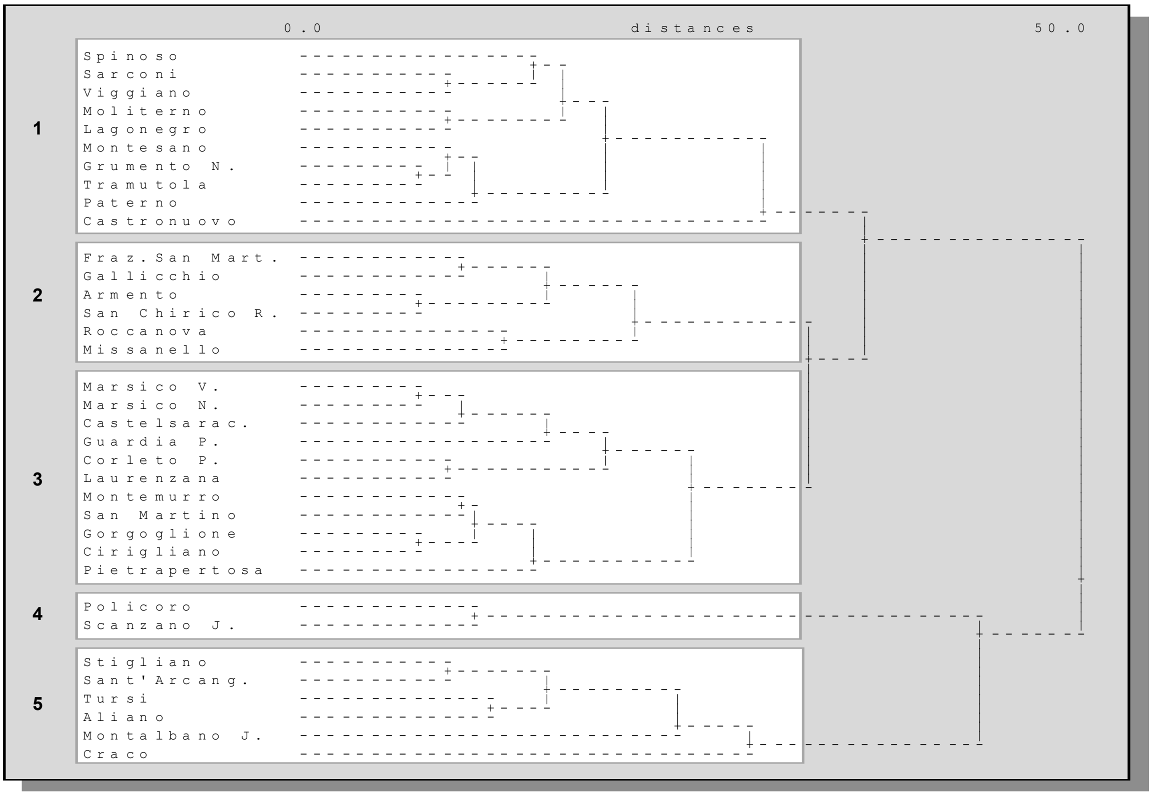

Fig. 39. Cluster analysis (Municipalities of the Agri Basin); complete linkage method; Euclidean distance.

By the analysis of the data reported in Fig. 39, it is possible to distinguish five sensitivity groups, or typologies, that correspond to five zones along the basin and represent five well defined environmental and socio-economic realities. Starting from these five groups it is possible to characterise the content of the different sensitivity grades through the analysis of the contribution that each layer gives (or groups of layers) to the definition of the sensitivity level. In this case the "quality level" has been chosen as an example to illustrate the kind of approach more simply.

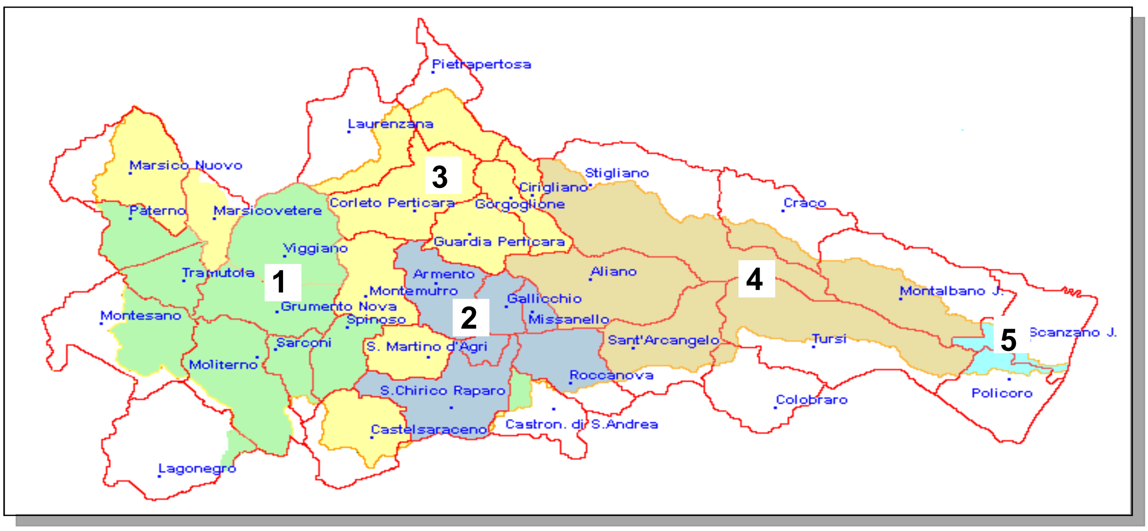

Fig. 40. Location, along the basin, of the groups of Municipalities obtained by cluster analysis.

Fig. 41 illustrates the graphs relative to the percentage of different Environmental Sensitivity grades of the four qualities and the municipality groups obtained by the cluster analysis. As we can see, it is possible to derive more and detailed information that can be used for management purposes by different levels of decision-makers. If we examine the graph on Fig. 41 we can see how the municipality groups 1, 2 and 3 have quite the same climate (all three are located in the Upper Val d'Agri). Group 1 differs for its criticality of socio-economic factors and a worse overall quality of soil factors, which need to be closely considered in this ambit; instead group 2, has better vegetation qualities associated to very critical socio-economic factors. Groups 4 e 5 differ, even though are similar from a geographical point of view: group 5 is characterised by a better level of socio-economic factors and by the worst climatic ones found in the basin, instead group 4 has worse vegetation conditions. In this ambit, supposing that sensitivity critical factor of an area is the 'vegetation' it is possible, in a very simple way, to define the characteristic, the priorities and the amount of interventions to mitigate the ongoing phenomena.

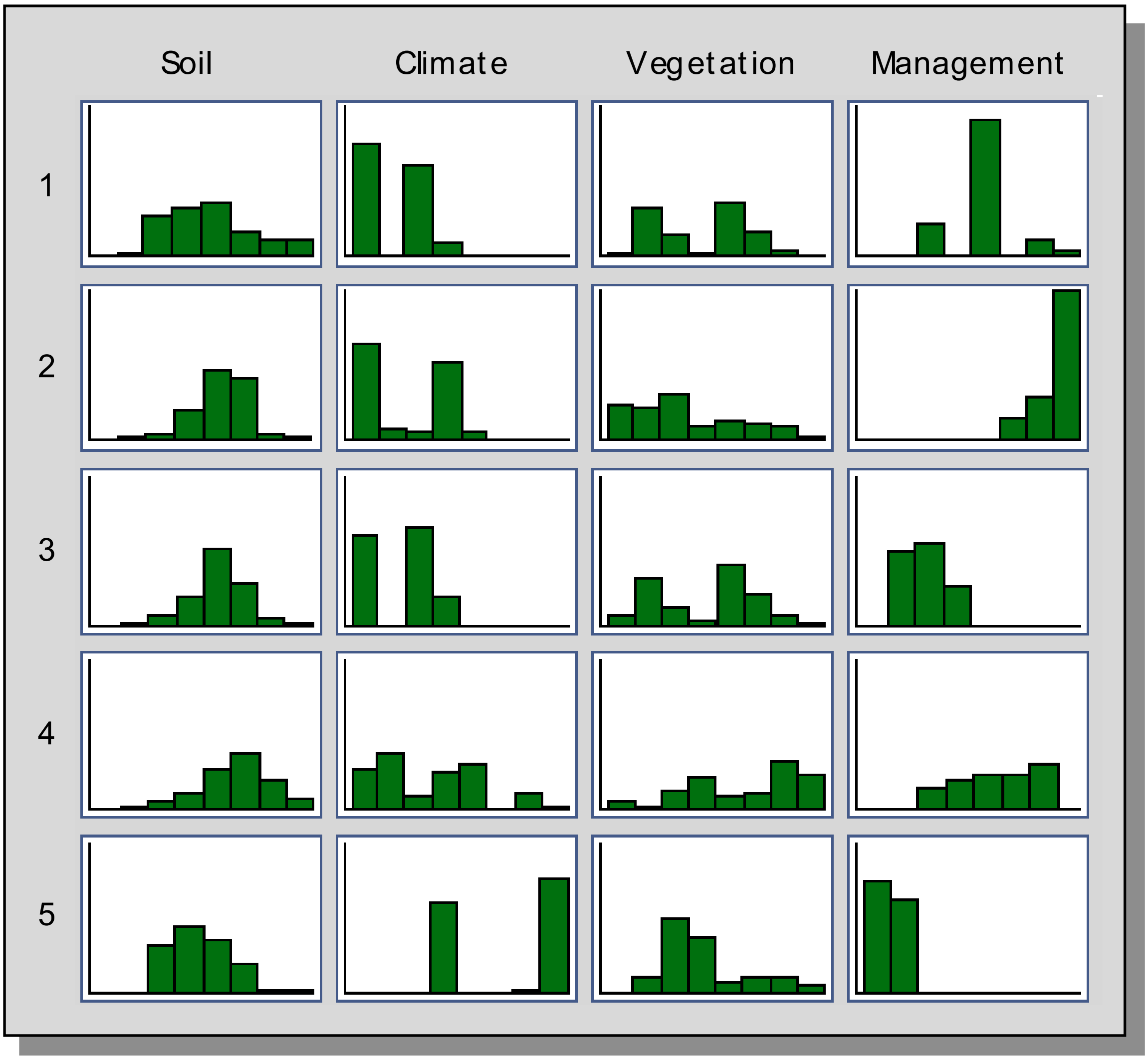

Fig. 41. Sensitivity profiles of the municipality groups in the Agri basin. The profiles are expressed in ES level frequency percentages in function to the single qualities. (X-axis from 1.1 - 1.8; Y-axis from 0 to 75 %).

These examples illustrate the applicability of this flexible method, diversified and efficient that gives broader investigation possibilities and the capacity to precisely evaluate the situations in progress as well as defining the more opportune strategies to reduce the overall environmental sensitivity of a given area. The use of cross analysis techniques in the proposed system, applied to pre-existing information, with other *ad hoc* collected data, can also be used to easily and efficiently point out specific degradation or environmental sensitivity phenomena. Furthermore, this approach not only allows the identification of different degrees of environmental sensitivity, at the same time allows the analysis of the factors that cause the evolution in progress.

3. The Alentejo region (Metrola municipality, Portugal)

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3.1. General characteristics of the area

Geographical Features

Desertification processes affect a great portion of the Portuguese territory especially the hilly and agricultural areas located inland. The Alentejo region is the southeastern part of the country, the main agro-silvo-pastoral region with a Mediterranean climate type and the most affected by desertification and drought.

Within the Alentejo region, Mértola municipality is a marginal rural area (1295 sq.), and certainly one of the most severely affected areas in Portugal. The geographical features of this MEDALUS Target Area can be resumed as follows:

- A vast peneplain formed on very old rocks – red and yellow schist and grauvaques – dated from Devonic and Carbonic periods. This is the main morphological unit with altitude ranging between 50 and 200 meters, intensively used in the past to grow cereals and breed cattle. The morphology can be characterised by a "rolling" topography with multiple summits with an isoaltitude of about 200 meters and deep valleys with steep slopes, resulting from quaternary river incision on the ancient plain surface.
- Some aligned elevations – quartzite crests (NW-SE) – reaching up to 370m (Alcaria Ruiva); 310m (Alvares) and 306m (S. Barão). This are prominent land forms, made of very hard parent material easily revealed on the surrounding plain landscape, presenting long shape configuration, and very steep slopes with complex profiles.
- An extremely dense hierarchical drainage network, presenting a highly complex dendritic pattern, where the Guadiana river (N-S) is the main channel, deeply incised on the peneplain. Its valley is large with a rocky flat bottom. The most important streams are tributaries of Guadiana and they all have torrential flow regime.
- Generally poor, eroded shallow soils, with a great percentage of rock fragments (schist and quartz), high clay content, low infiltration and water retention capacity, high runoff percentage, very low organic matter content and depths of only 5 to 10 cm. In some less degraded soil patches, organic matter and moisture content is higher and soil depth can be of 50-70 cm on lower areas of sedimentation.
- Dry to sub-humid climate type – Attenuated Meso-Mediterranean (Gaussen xerotermic index), with most of the rainfall concentrated between October and January. Sixty years average is of about 560 mm, and extreme annual total range from 236mm to 1079mm. Long droughts (1-3 years) and extremely violent storms (e.g. 130mm/24h) is also a common feature.

Human Impact – Land Use

The destruction of the vegetation in the Alentejo region, and particularly in Mértola, started at least three centuries ago, during the XVII Th Century when the first main human settlements were established. Consequently, as a result of successive incentives and policies to divide common land and increase cereal production, more and more vegetation and soil degradation occurred. Farming activities became more intensive, productive and technologically advanced during this century, as the "Wheat Campaigns" contributed to dramatically increase the amount of land devoted to degrading agricultural practices. *Quercus* forest was also severely affected during this period either by direct cutting to clear the land for farming purposes or to be sold as fuel for mining activities and domestic uses. Both contributed for a drastic decline in the traditional Mediterranean forest of this area.

Present land use in Mértola combines different agro-silvo-pastoral systems where vegetation cover assumes many different forms. It consists mainly of:

- Wide open shrub land, abandoned and hardly used as pastures for livestock production (cow, sheep); some sparse *Quercus* oak forest (*Quercus rotundifolia and Quercus suber)* accounting together for 38.5% of the municipality. This open *Quercus* forest – *Montado* – is actually a traditional multiple land use that combines the trees and its nuts, cereal cropping underneath and cattle breeding too, where the animals feed on stubble and on cultivated pastures.
- Dense Mediterranean Macchia on elevation tops and deep valleys with rocky slopes (Mato – well developed trees and shrubs) and an increasing mixed forest land, mainly exotic pines (*Pinus pinea* and *Eucalyptus globulus*, with high density cover, accounting for 31.3%. On land abandoned for a long time (more than 10 years), semi-natural shrub vegetation is used as natural pastureland for goats and bees. Recently, due to the subsidies being given to afforestation under the CAP accompanying measures, there is a very significant increase in forest land and a great number of new *Pinus pinea* plantations on abandoned land, with obvious negative consequences in terms of soil protection and biodiversity.
- There is still some cereal cropping and frequently ploughed land (27.4%). It can also be found in combination with cereals a sparse *Quercus ilex* and *Quercus suber* oak forest.

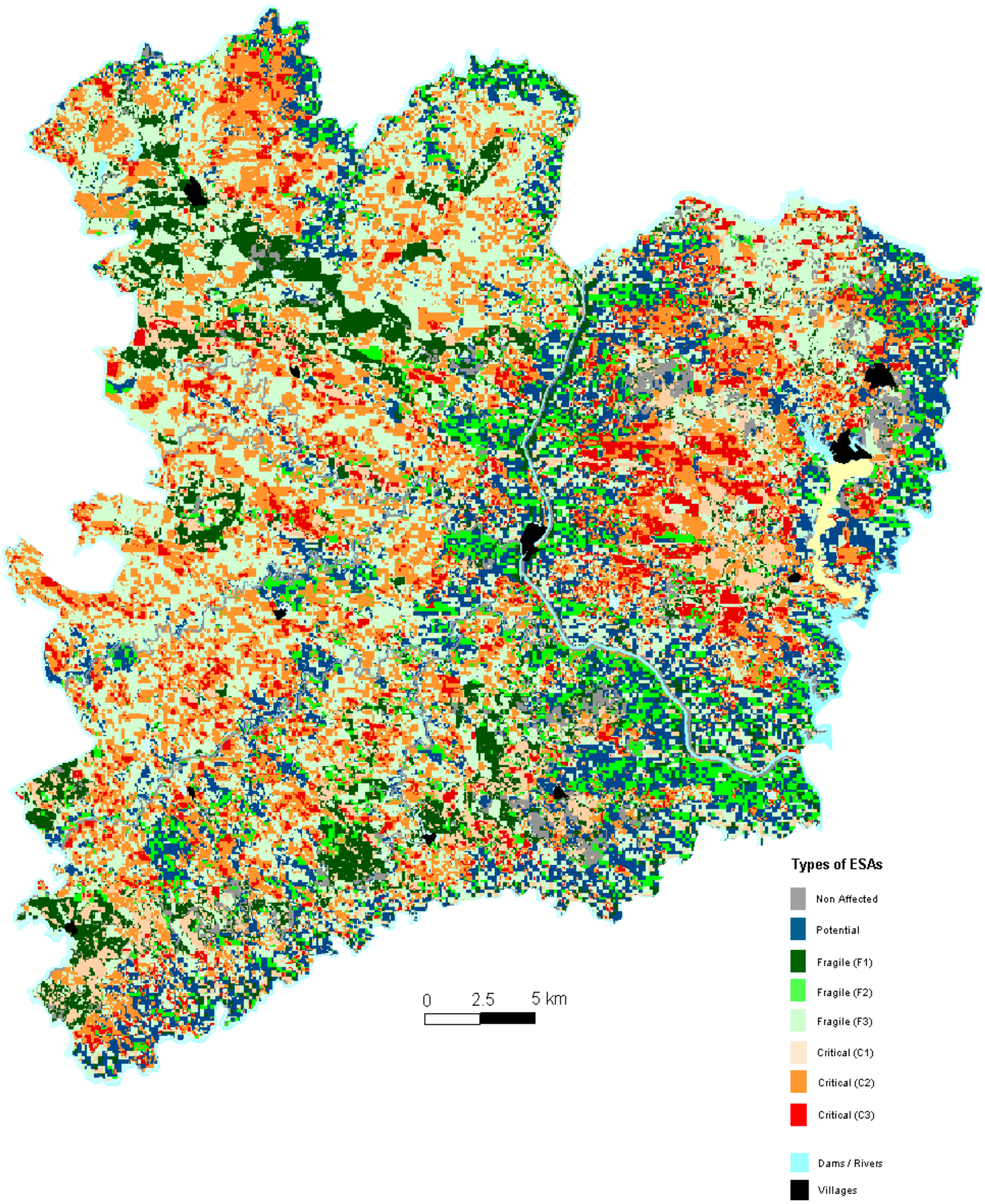
3.2. Mapping ESAs in Mértola

The full testing and application of the ESAs methodology resulted on a final map of Environmentally Sensitive Areas (Fig. 42) in the context of Desertification, that gives a rather satisfactory and clear picture of the critical land degradation levels in Mértola and also provides an identification of the less affected and fragile areas that need carefully defined management strategies in terms of land use and human intervention.

Critical ESAs

<u>Subtype C3</u> – These are severely degraded areas where there is no soil at all, corresponding to areas of steep to very steep slopes, predominantly with a southern aspect and entirely eroded soils; or to vast hilly areas where weathered rock appears on the surface, forming a coarse scree evolved on fine clay particles. These are also areas that present a great number of rock outcrops of a very poor parent material. The vegetation cover is here very badly developed, composed of ephemeral shrubs and annual plants that dry out during the dry season. Mértola has about 7.2% of its territory under this most critical situation as it concerns desertification an land resources degradation and present management of these areas is still very poor, since they are either abandoned, grazed or afforested. This situation is the result of widespread winter cereal cultivation (mainly wheat), using an intensive rotation for more that one hundred years, on medium to small properties that were inherited from common land division schemes early this century. The destruction of natural vegetation cover and the continuos and intensive use of soil resource has ended in physical and chemical soil degradation, that is the core of the desertification problem in this MEDALUS target area.

Fig. 42. Map of Environmentally Sensitive Areas to desertification for the Mertola municipality (Alentejo region)



Subtype C2 – Critical 2 areas (23.3%) are mainly the actual cereal cropping areas, where soils are also poor, stony and very shallow, based on red and yellow schist and quartz, with great percentage of rock fragments and depths of less than 10 cm. They also correspond to areas of steep slopes (18-35%) though ploughed and intensively used to cultivate wheat, utilising a huge amount of fertilisers. Since it is agricultural land, the vegetation cover is rather variable along the year, either composed of a fable cover of green wheat spikes that dry out before summer; a very short stubble cover after the harvest, or ploughed bare soil with no vegetation cover at all by late autumn. Yearly mobilisation of soil on a up and down slope direction followed by seeding during the wet period of autumn and winter, when precipitation events are more frequent and intense, maximises soil loss (4-6 ton/ha) and includes these areas in one of the most poorly managed in Mértola.

Subtype C1 – Within the cereal cropping areas, Critical 1 are the ones that present a lower degree of degradation due to factors such as aspect, slope or soil depth. Although included in agricultural land, they correspond to areas with more gentle slopes (6-18%), a Northern aspect or moderate to shallow soils (15-50cm), and account for 5.6% of the municipality.

Fragile ESAs

Subtype F3 – These are clearly areas of abandoned land. Fragile 3 type represents 31% of Mértola municipality and corresponds to former agricultural land, intensively used in the past for cereal cropping and as pastureland, but nowadays abandoned for more than 5 to 10 years. They are not associated with any specific slopes or soil types though some areas show some correlation with steeper slopes. Also included here are the areas that are still being used for grazing purposes with a vegetation cover composed of either annual herbacea or poorly developed spontaneous shrub vegetation. Fallow land that is put aside for several years is also included here. This type of ESAs present great sensitivity to desertification as they are highly vulnerable to climate change or to human impact through land use change and grazing pressure. Great care must be taken in the management of these areas in favour of conservation of land resources and landscape regeneration.

Subtype F2 – Fragile 2 areas account for 7.1 % of Mértola and can be described as areas of steep slopes in the proximity of the main river channels that flow to the *Guadiana*, with moderate to low quality soils and having a permanent shrub vegetation cover (mainly *cistus* and *lavandulas*), where human intervention has ceased many decades ago and only grazing by goats occurs today. Although F2 areas are already in a process of regeneration as it concerns soil and vegetation resources, its sensitivity is still rather high due to soil degradation levels attained in the past and to climatic constraints. Some recent high density *Pinus* plantations, with 2-5 years, on steeper slopes and shallow to very shallow soils are also included in this type.

Subtype F1 – This type of ESAs is clearly associated with *Quercus* evergreen forest (*Q. rotundifolia; Q. ilex; Q. suber*) on patches of moderate to deep soils (30-80 cm depth), less stony, of a moderate texture, well drained and with gentle to very gentle slopes. A tree vegetation cover with medium to high density and often a sub-cover of spontaneous shrubs offers a moderate to high erosion protection index and a high drought resistance. Proper management of these areas implies protection rules and conservation measures related to forestry and other activities, such as hunting. Fragile 1 represents nearly 9% of the municipality.

Potential ESAs

This is the type of ESAs that correspond to the most untamed and conserved areas as it concern vegetation cover. Morphologically they are correlated either to areas of very steep and rocky slopes, of difficult access, along the valleys of the main rivers and channels - *Guadiana, Cobres, Chança, Oeiras* and *Vascão*, or to elevation tops with the same type of vegetation cover – mixed Mediterranean Macchia with *Quercus* trees and a high density cover. These are areas of high biodiversity, with great genetic potential for regeneration of a flora that is well adapted to the physical environment. Some old *Pinus* and *Eucalyptus* forest with shrub vegetation underneath also fall on this category. On the other hand, Potential ESAs reflect also a different topographic and land use situation: areas of flat valley bottoms, where soil was “trapped” in specific topographic positions, with soil depth over 75 cm and fine texture due to sedimentation. Land use here is composed generally of olive trees, different kinds of orchards (citrus, almond-trees, carob-trees) and several types of vegetables. This type of ESAs accounts for 14.3% of Mértola and its management must take into account the extremely high degree of sensitivity to human impact, considering the ecological balance of the ecosystems.

Non threatened areas

The non threatened areas are great limited in 2.6% of the Mértola municipality.

3.3. Evaluation of the results

By analysing the ESAs map produced for Mértola municipality (Fig. 42), it can be concluded that although the majority of this territory is classified as fragile (47.1%) there is still a great part (36.1%) that is in a critical situation as it concerns desertification and land degradation processes.

These critical areas exist somehow all over the municipality and coincide with areas of greater agricultural activity or with severely eroded soils. The climatic characteristics of this region, associated with topographic and land use factors, have favoured desertification for a long time in the past, with very negative consequences for natural resources such as soil, water and vegetation and ecosystems present. These critical areas need management initiatives that can effectively promote a slow regeneration of the landscape as a means to combat desertification.

Fragile ESAs present a higher degree of conservation of soil and vegetation resources, since soils are deeper, and of better quality. Vegetation cover is an essential factor in assessing the degree of sensitivity and in fragile areas there is a great vulnerability to changes either in climatic conditions or in land use by Man.

The ESAs methodology developed in MEDALUS III, has proved to be a very useful one, of extreme importance both at local, national and European level, since it has provided not only the scientific community, but also national, regional and local governmental and non-governmental organisations with a kind of tool (GIS map) that reflects not only the negative situation, meaning the critically affected areas and their high degree of land degradation, but also the positive situation, which are the less degraded areas, the fragile and sensitive areas where better management is needed to put the resources and the regeneration potential forward, in the light of a Global Change scenario.

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The Medalus project – Mediterranean desertification and land use

Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification

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This publication, prepared within the framework of the EC funded MEDALUS project, presents a methodological approach to identify and map environmentally sensitive areas to desertification, based on a choice of appropriate indicators at relevant scales. Targeted areas in Greece (Lesvos Island), Italy (Agri basin) and Portugal (Alentejo region) have been used to test and improve the methodology. This publication may be used as a manual for the identification of environmentally sensitive areas to desertification in other Mediterranean areas.