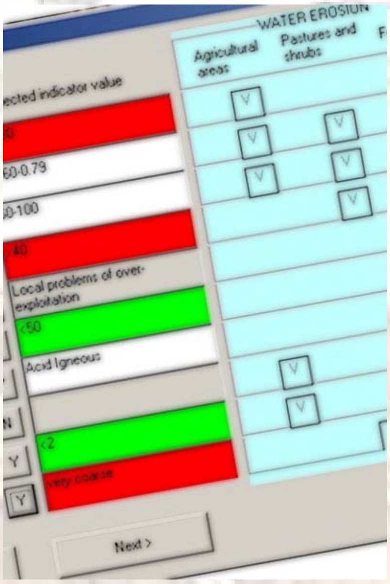
DESIRE REPORT series



Methodology for evaluation of applied land management practices and techniques in terms of land degradation and economic feasibility for combating desertification using indicators.

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Contents

1. Introduction

Desertification is one of the most serious environmental issues at global, national, regional and local scales (UNEP, 1992). Effective land desertification measures require both appropriate land management practices and macro policy approaches that promote sustainability of ecosystem services. It is advisable to focus on protection or prevention and anticipatory planning rather than on rehabilitation of desertified areas since areas affected by desertification are usually at high stage of land degradation and the expected results may be ambiguous. WOCAT project has also stressed the importance on prevention than on rehabilitation which is much more costly and might not be able to achieve full results. Land management practices and techniques are proposed in this project for protection of productive land from degradation and desertification. The functions of a rehabilitated land would remain below original functions before degradation since the resilience of the system is expected at lower level before degradation.

National Action Programmes, stipulated by the UNCCD, have identified the main processes of land degradation contributing to desertification and proposed the necessary measures to prevent and mitigate their impacts. Important identified processes or causes of land degradation and desertification are soil erosion, soil salinization, loss in organic matter content, soil sealing, forest fires, and overgrazing. Based on these processes, appropriate land management practices and techniques have been proposed for protecting land degradation and desertification. The proposed actions in National Action Plans for combating desertification have been defined separately for the various economical sectors such as agriculture, husbandry, forests, and water resources. The proposed actions included management practices for protecting soil and water resources such as: traditional water-harvesting techniques, water storage, diverse soil and water conservation measures, improving groundwater recharge through soil-water conservation, protection of vegetative cover of soils, minimum tillage, etc. Maintaining adequate vegetative cover to protect soil from wind and water erosion has been characterized is a key preventive measure against desertification.

The regional action plans formulated by the Northern Mediterranean countries (Annex IV) have highlighted the need for: (a) developing efficient communication with the scientific community, (b) sensitizing all stakeholders in affected areas through education and training, (c) discussing political, social and economic factors and their relation with desertification. The success of rehabilitation management practices have depended on the availability of human resources, capital for operation and maintenance, infrastructure development, degree of dependence on external sources of technology, and cultural perceptions. Using indicators for analysing complex processes of degradation has been characterized as a valuable tool assessing land capability to withstand further degradation and to select appropriate land management practices for combating desertification. The objective of this work package is to derive a methodology to simulate and evaluate the various land management practices and techniques in terms of land degradation and economic feasibility for combating desertification using the appropriate indicators.

2. Analysis of data

The data base of indicators created and presented in deliverable 2.1.3 (AUA, 2010) has been further analyzed in the deliverable 2.2.1 (AUA, 2010) for conducting a comparative analysis among the various study sites worldwide. The appropriate statistical methods have been applied and presented in deliverable 2.2.1 in order to identify the most appropriate and effective indicators for assessing the effectiveness of the various land management practices and techniques in land uses and landscapes prone to desertification. The obtained data from the various study sites were classified and analyzed according to the processes or causes identified in each study field site presented in deliverable 2.2.1. Based on this classification, algorithms were derived for each process or cause of land degradation assessing land degradation and desertification risk. It was the first time that this methodological procedure was applied worldwide using the DESIRE case study sites, while it was previously tested only in the Mediterranean area. The derived algorithms were included in a decision support system to be used as a tool for various stakeholders for assessing land degradation and desertification risk under the existing physical environmental, economic and social conditions and to select the appropriate land management practices and techniques for combating desertification.

3. The derived methodology on assessing land desertification risk

The proposed number of indicators, even though they were all directly or indirectly related to land degradation and desertification, was too large to be practically applicable. The list of indicators was substantially decreased after the statistical analysis to the most appropriate and effective indicators suited to the range of local physical and socio-economic conditions of the study field sites. As Table 1 shows, the number of indicators related to water erosion in cropland, pastures, and forest was reduced from 49 to 17, 15, and 11, respectively. The number of candidate indicators assigned were 16, which were reduced to 10. The impact of soil salinization on land degradation and desertification can be assessed by using 9 indicators. The greatest number of candidate indicators described was for water stress, reduced from 50 to 12 indicators (Table 1). Finally, the candidate indicators identified for the causes overgrazing and forest fires were substantially reduced from 44 and 29 to 16 and 8, respectively.

Table 1. Number of candidate indicators used for the analysis and number of effective indicators for each process or cause of land degradation and desertification

a/a	Degradation process	Major land use	Number of candidate indicators	Number of effective indicators
1	Soil erosion by water runoff	Agriculture	49	17
		Pastures and shrubland	49	15
		Forests	49	11
2	Tillage erosion	Agriculture	16	10
3	Soil salinization	Agriculture, natural vegetation	27	9
4	Water stress	Agriculture, natural vegetation	50	12
5	Overgrazing	Natural vegetation, agriculture	44	16
6	Forest fires	Natural vegetation	29	8

Table 2 gives the coefficients of linear regression for each indicator and process identified in the study sites for the linear model assessing land degradation and desertification risk. The correlation coefficients (adjusted R^2) range form 0.42 to 0.85 (Table 2). The lowest correlation was found for the indicators assessing desertification risk index in areas affected by forest fires. The highest correlations was found for indicators relating desertification risk in areas affected by overgrazing.

The algorithm for assessing desertification risk index (DRI) for each process or cause can be defined by combing the indicators presented in Table 2 with the corresponding linear coefficient values in the multiple regression equation. As an example, the following algorithm corresponds in the assessment of desertification risk index for areas in which the main cause of land degradation is water stress:

DRI = 0.316xRS + 0.194xGE + 0.194xSG - 0.110xDA - 0.107xIS - 0.139xFR = 0.194xSEC - 0.442xRLA + 0.028xWS + 0.313xTC + 0.108xPD + 1.096xPI.

Where: RS is rain seasonality, GE is ground water exploitation, SG is slope gradient (%), DA is rate of deforested area (% per year), IS is impervious surface area (ha per 10 km^2 of territorial surface per 10 years), FR is fire frequency (years), SEC is soil erosion control (area protected per total area, %), RLA is rate of land abandonment (ha per 10 years per 10 km^2) , WS is water scarcity (Water available supply per capita / water consumption per capita during the last 10 years), TC is tourism change (number of overnight stays in a specific destination over one year / average overnight stays in the last 10 years, %), PD is population density (people per km^2), PI is policy implementation of existing regulations for environmental protection. The DRI is estimated by multiplying coefficient of linear regression for each indicator by the weighing indices of the corresponding class of indicator given in Table 2 (deliverable 2.1.3).

Table 2. Coefficients of linear regression analysis for assessing land degradation and desertification risk in various land uses and degradation processes or causes

Indicators	**Water erosion**			**Tillage erosion**	**Soil salinization**	**Water stress**	**Overgrazing**	**Forest fires**
	Agricultural areas	**Pastures and shrubs**	**Forests**					
	β0=0.004 R^2=0.52	β0= 0 R^2=0.76	β0= 0 R^2=0.45	β0=0 R^2=0.45	β0=0 R^2=0.65	β0=0 R^2= 0.74	β0=0 R^2=0.85	β0=0 R^2=0.42
CLIMATE								
Rainfall	0.348							
Potential ETo					0.225			
Rainfall seasonality	-0.245	0.654	0.410			0.316	0.427	0.361
Rainfall erosivity							-0.306	
Aridity index			0.225				0.541	
WATER								
Water quality					0.346			
Groundwater exploitation					1.497	0.194		
SOIL								
Drainage					0.413		-0.308	
Parent material				-0.206				
Slope aspect	0.191							
Slope gradient	0.359			0.429		0.194		
Soil depth	0.082	0.167	0.225					
Soil texture		0.115						
Organic matter	0.170			0.314				
Exposure of rock outcrops							0.189	
VEGETATION								
Major Land use				0.159				-0.284
Vegetation cover type	0.089		0.369					

Plant cover	0.089	0.305	0.169				0.413	
Deforested area						-0.110		
WATER RUNOFF								
Flooding frequency					-0.295			
Impervious surface						-0.107		
FIRES								
Fire risk			-0.417					
Fire frequency						-0.139	0.401	
Burned area		-0.182	0.309				-0.496	
AGRICULTURE								
Farm size							0.587	
Farm ownership					0.152			
Land fragmentation							1.581	0.106
Parallel employment	-0.159							
CULTIVATION								
Tillage operations	0.158			0.320				
Tillage depth		-0.240		0.207				
Tillage direction		0.124						
Mechanization index				-0.164				
HUSBANDRY								
Grazing control		0.186					0.179	0.616
Grazing intensity			-0.392				0.256	
LAND MANAGEMENT								
Fire protection			0.247				0.941	0.167
Sustainable farming	0.196							
Soil erosion control						0.194	0.435	
Soil water conservation		0.134						
Terracing (presence)	0.176			0.107				
LAND USE								
Land abandonment	-0.364		0.133			-0.442	-0.971	
Land use intensity	0.205	0.175		0.368				0.120
Period of existing land use		0.112					-0.221	
Distance from seashore					0.297			
WATER USE								
Irrig. % of arable land					0.836			
Runoff water storage	-0.155	0.314						
Water scarcity						0.028		
TOURISM								
Tourism intensity		0.127						
Tourism change						0.313		
POPULATION								
Old age index								0.117
Population density			0.356		-0.573	0.108		
Population growth rate								-0.111
INSTITUTIONAL								
Farm subsidies	0.105	0.405						
Policy implementation	0.380	0.282		0.116		1.096		

4. Assessment and validation of the derived methodology

The derived methodology was assessed using independent indicators measured in other field sites. The assessment was based in the comparison of the desertification risk index with: (a) existing experimental soil erosion data, and (b) data of soil aggregate stability and soil organic matter content of the surface horizon. Soil erosion data were collected by the Agricultural University of Athens during the execution of the European Commission research projects: (a) Mediterranean Desertification and Land Use - MEDALUS I (Kosmas *et al*., 1993), (b) MEDALUS II (Kosmas *et al*., 1995; (Moustakas *et al*., 1995; Danalatos *et al*., 1995, Tsara *et al*., 2001), and (c) Tillage Erosion: Current State, Future Trends and Prevention – TERON (Kosmas *et al*., 2001; Gerontidis *et al*., 2001). Soil erosion data were used from nine experimental field sites under various soil, topographic, land use and climatic conditions. The measured soil sediment losses in the various rainfall events were expressed on annual average basis for comparison with land desertification risk index defined by the derived methodology in this study.

Concerning soil aggregate stability and soil organic matter content, a number of 39 soil sites were selected in the study field site of Crete. The selected sites were located in soils formed in various parent materials, under various climatic, topographic and land use characteristics. In each site, all the necessary indicators for defining desertification risk were measured. Undisturbed soil samples were taken only from the surface A-horizon for laboratory measurements. The selected soil samples were analyzed for particle-size distribution of the <2-mm fraction by the Bouyoucos hydrometer method (Gee and Bauder, 1986). The organic carbon content was measured using the modified Walkey-Black wet oxidation procedure (Nelson and Sommers, 1982). The wet sieving technique by Yoder (1936) was used for the determination of the mean weight diameter of the soil aggregates.

As Fig. 1 shows, annual soil erosion rates are related with desertification risk index estimated by the corresponding algorithms developed in this study. Desertification risk index increases rapidly in low rates of soil erosion (up to 5 t ha^{-1} yr^{-1}) and then desertification risk index is increasing slowly while erosion rates are very high. This relation of desertification risk index and annual soil erosion rate can be attributed to the resilience of a system to withstand degradation. For example a relatively deep soil under certain climatic, vegetative and topographic conditions characterized with moderate desertification risk will remain in this class until soil depth reaches to a threshold value (less than 30 cm) where desertification risk is high with low potential of ecosystem to provide services.

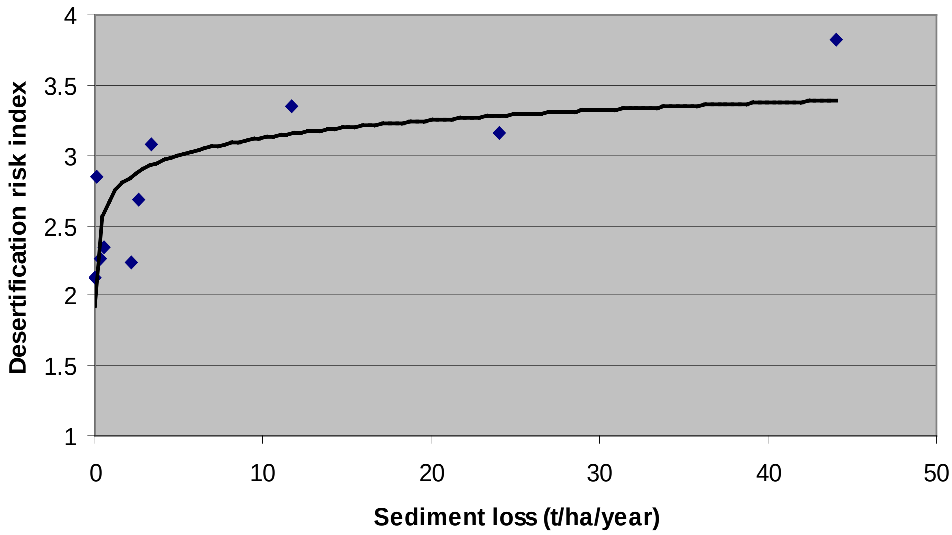


Fig. 1: Relation of desertification risk index estimated by the derived methodology using the equations of Table 2 and annual soil sediment loss measured for the same sites

Soil organic matter represents a key indicator for soil quality, both for agricultural and environmental functions. Soil organic matter is a major indicator influencing physical, chemical, and biological soil parameters. Aggregation and stability of soil structure increase with organic matter content. This in turn increases infiltration rate and available water capacity of the soil, as well as resistance against erosion by water and wind. Decrease of organic matter content is a key factor in accelerating soil erosion and thus for irreversible land degradation and desertification. As Fig. 2 shows, desertification risk index decreases as soil organic matter content in the surface horizon increases. A similar relation has been found for soil aggregate stability and desertification risk index (Fig. 3). Therefore, the development methodology on assessing desertification risk shows a relatively satisfactory relationship with independent physical indicators such as soil erosion, soil organic matter content and a lower relationship with aggregate stability for the Crete study field sites.

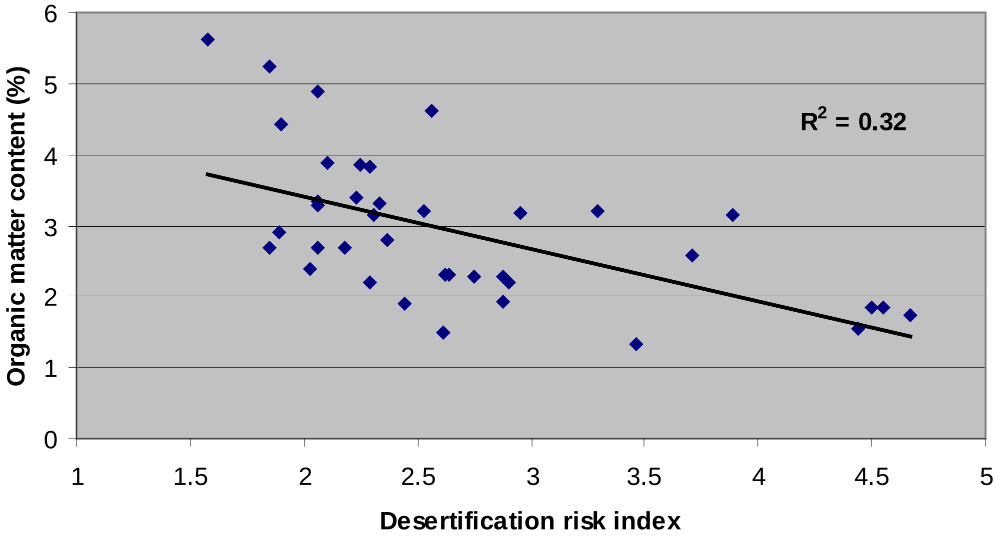


Fig. 2: Relation of desertification risk index estimated by the derived methodology and organic matter content of the surface horizon measured for the same sites

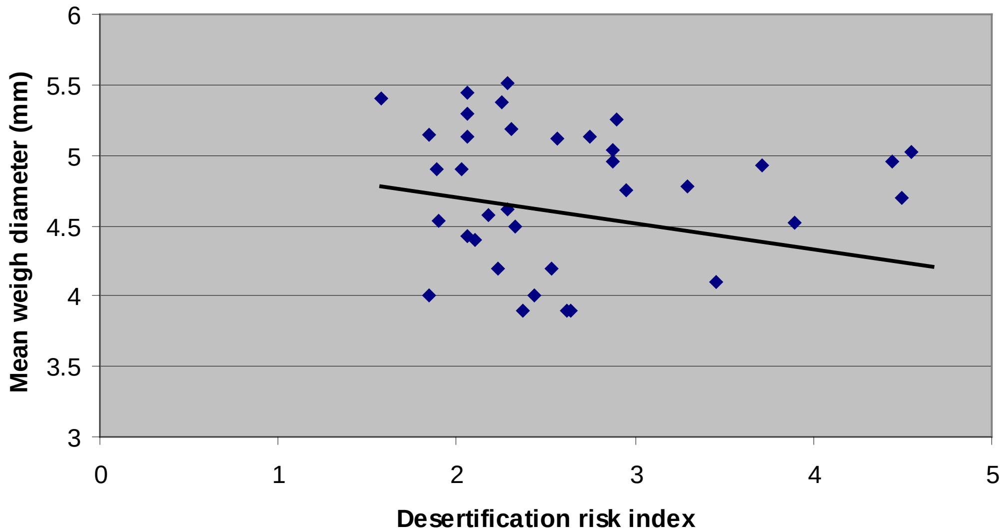


Fig. 3: Relation of desertification risk index estimated by the derived methodology and soil aggregate stability of the surface horizon measured for the same sites

5. Desertification Risk Assessment Tool

Desertification Risk Assessment Software and Tool is an expert system designed to provide an estimation of land desertification risk through the selection of appropriate degradation processes and corresponding indicators. Risk assessment was performed to identify the most appropriate and effective indicators suited to a wide range of local physical and socio-economic conditions for assessing the effectiveness of the various land management practices in land uses and landscapes prone to desertification. In this context, the advantages of computer technology and specifically of the expert systems are unambiguous. Such an incorporation may be of use in achieving:

- the analysis of a wide range of alternatives for land management practices;
- the evaluation and selection of the main indicators through which desertification risk may be assessed in a variety of locales worldwide;
- the development of a consensus among various groups (politicians, managers, experts, etc.) in assessing desertification risks and thus, the Expert System becomes the arena of focused disagreement.

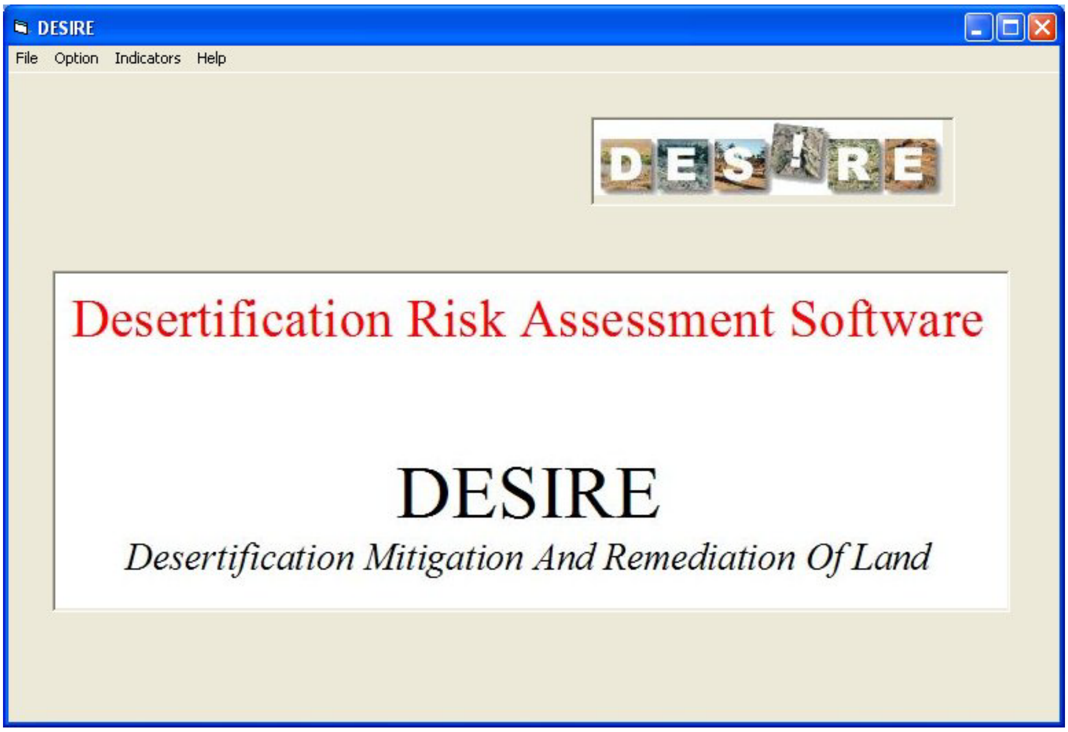
In this regard, the Expert System may allow the decision-makers to generate appropriate and timely desertification measures. It may also provide a standard for assessing the effectiveness of the various land management practices. The architecture and the description of the knowledge based system are presented in the following discussion. The program is designed to run in a Windows environment. An effort was made that the program would be user friendly and self-explanatory, guiding the user step by step.

Installation and use

The DESIRE.exe application with the corresponding files should be copied in a folder on a user's hard disk. Application activates by clicking/double-clicking on the DESIRE.exe file.

Main screen

Initiating the DESIRE application produces the Main Screen:



The main screen contains the following menus:

1. **File –** for saving and opening of the sessions
2. **Option –** for selecting a type of Erosion degradation processes
3. **Indicators –** for defining Indicator values and viewing results
4. **Help –** for information related to DESIRE application and instructions for use

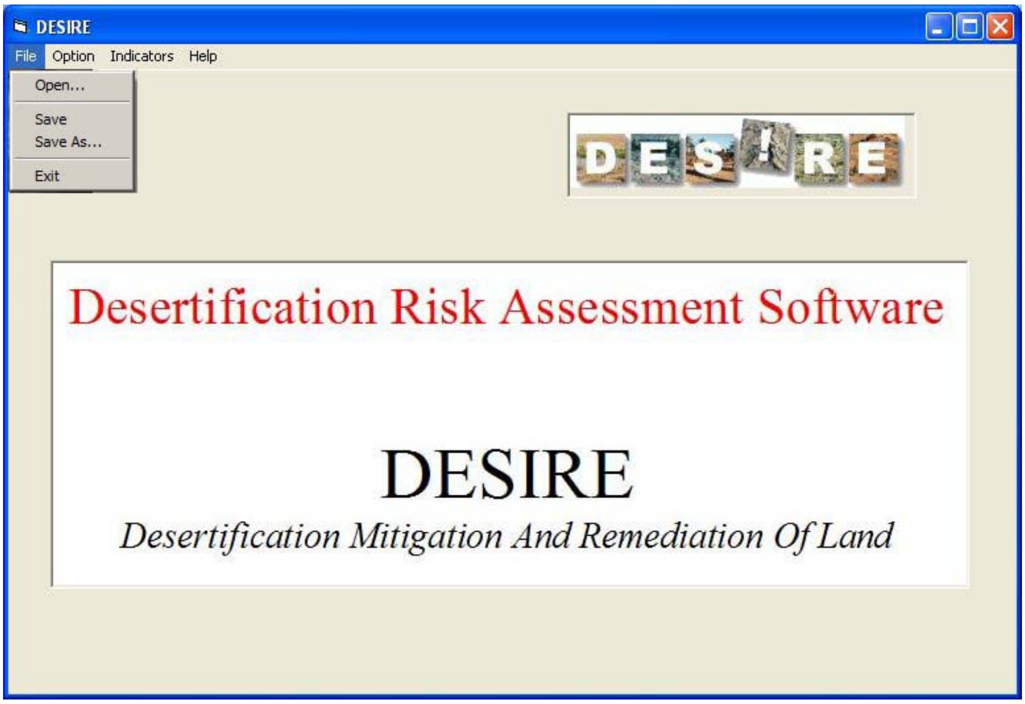
Each menu consists of the corresponding actions, explained in detail in the Help file.

Creating a new session

A new session is automatically created when the DESIRE application is initiated. Up to two more saved sessions can be simultaneously opened for comparison.

Open/Save session – File menu

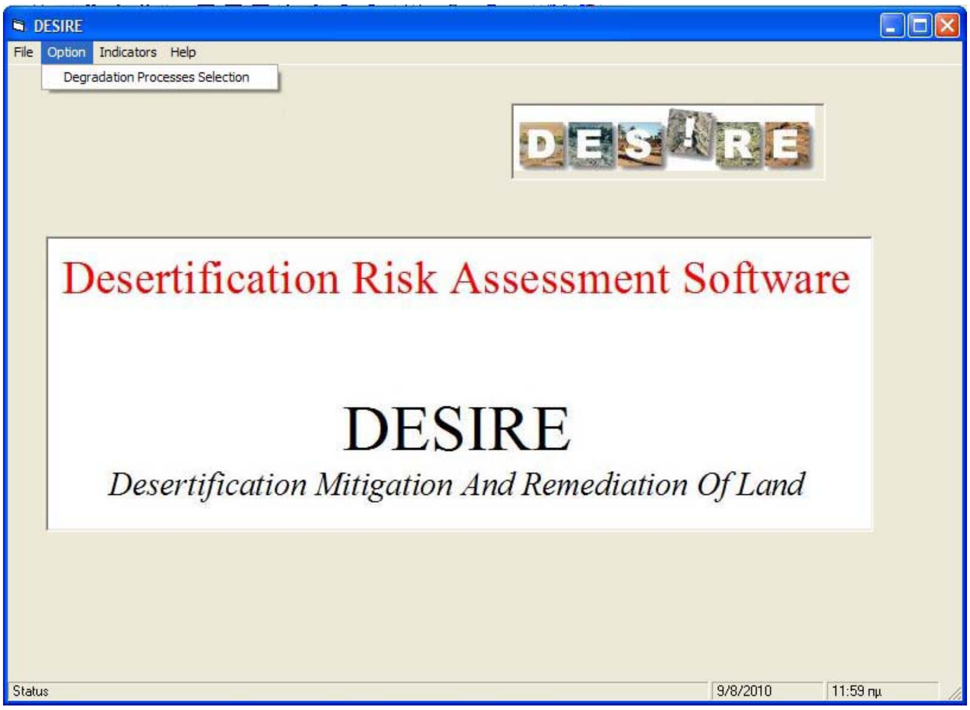
The file menu consists of the following commands:



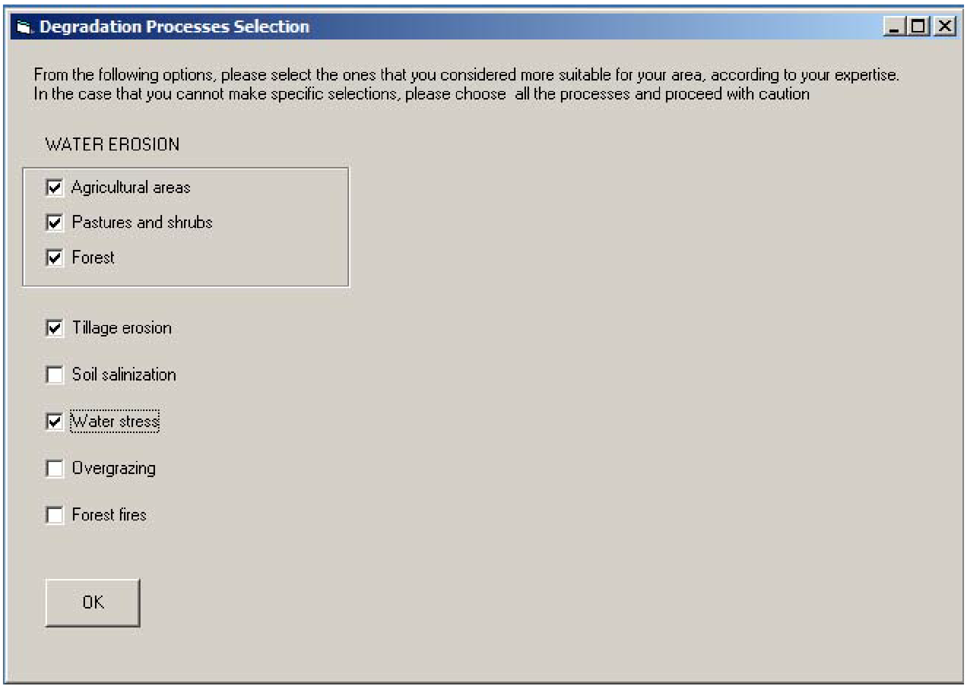
The use of the these commands is as follows:

Open – opens a saved session from a file for comparison/editing (up to two more besides the current session).
Save – saves a current session in a file.
Save As – saves an altered session under a different name as a new file.
Exit – exits the DESIRE application.

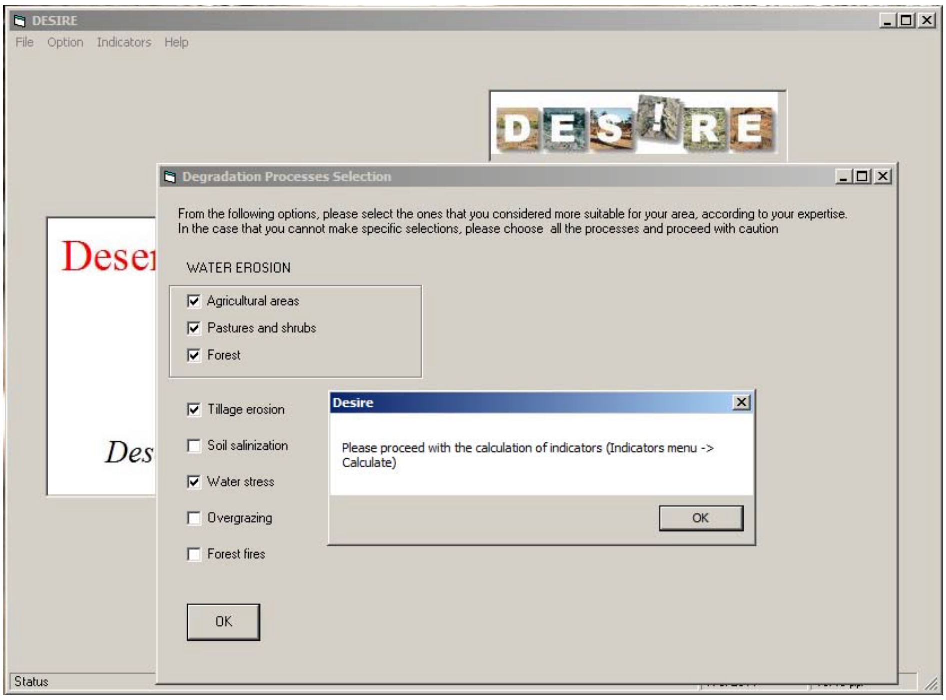
<u>Selection of degradation processes and vegetation cover type – Option menu</u>
The option menu contains the Degradation Processes Selection command.



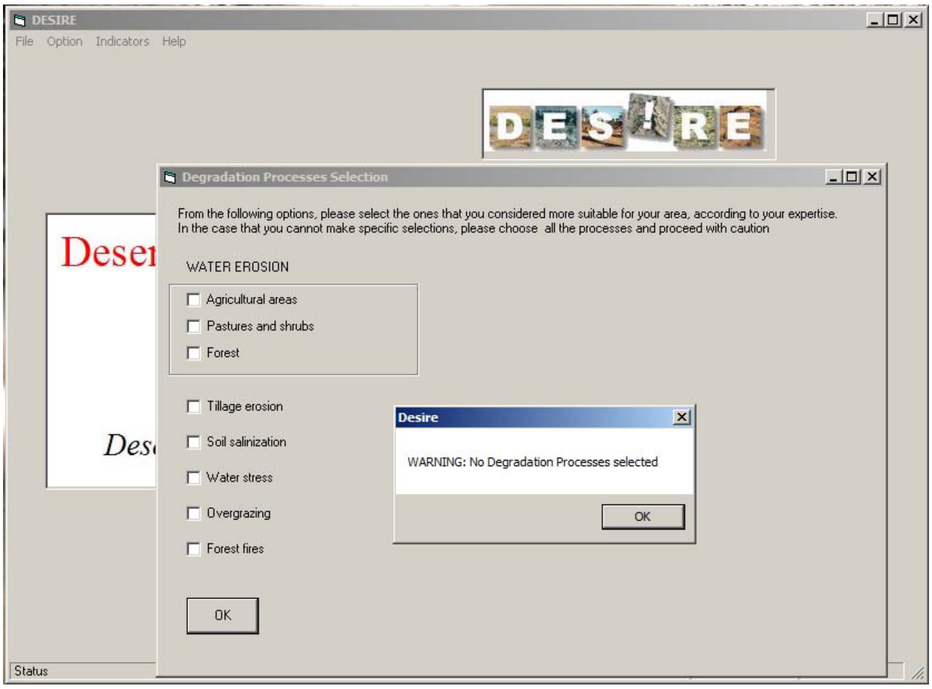
The degradation Processes Selection opens the dialog box, where all the pertinent degradation processes for the specific case should be selected by clicking on the appropriate boxes. An example with selected Water erosion (all three processes), Tillage erosion and Water stress is presented in the following:



The selection of the required Degradation Processes is saved by clicking on the OK button. A message box appears which indicates the next step.



In case that the OK button is clicked with no Degradation Process selected, a warning message box appears:

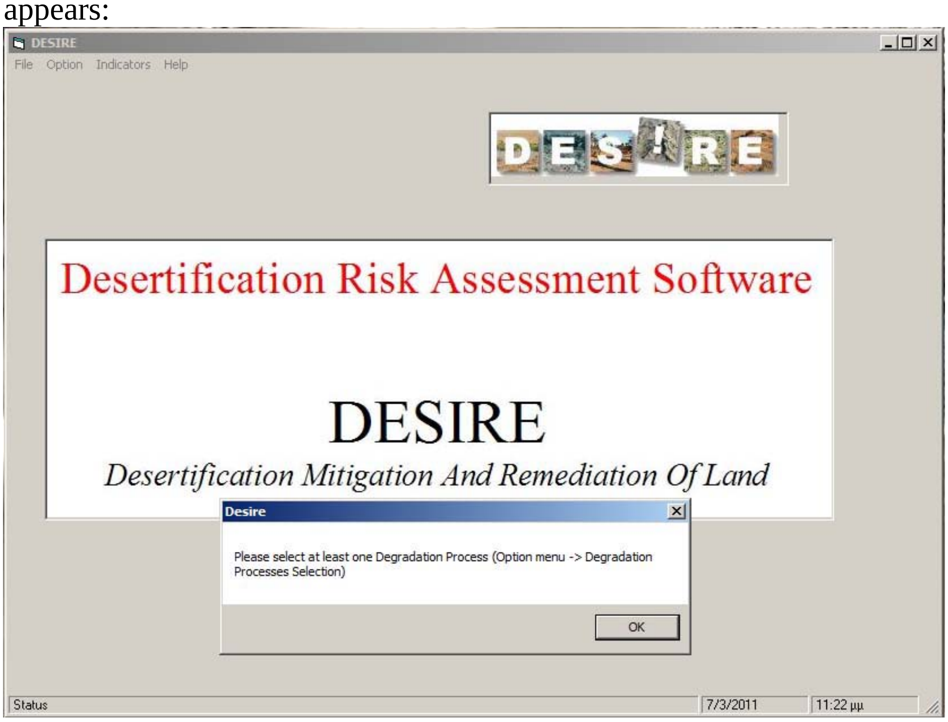


Indicators menu

Main menu for the Desertification Risk Assessment. It consists of the following commands:

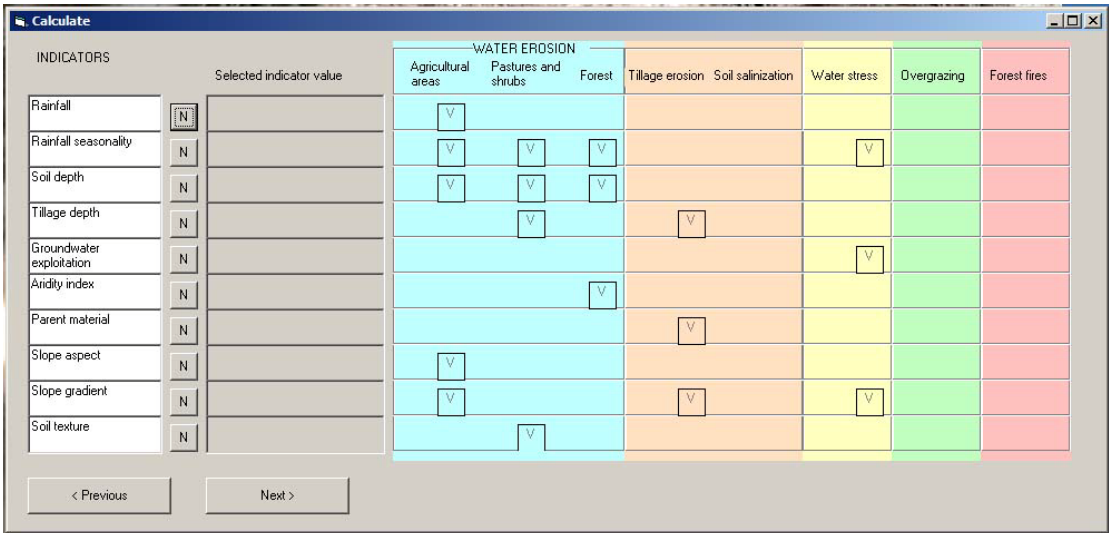
Calculate – Dialog box for Indicators input.
View – Dialog box for viewing and printing of the results.

NOTE: The number of Indicators depends on the selection of Degradation Processes and it may vary from 8 to 17 for individual processes (see Table 1). If several processes are assessed simultaneously, the number can be considerably higher. For example, 40 indicators are needed to assess water erosion (all three processes), tillage erosion and water stress. Available dialog boxes for Indicators input correspond to the total number of Indicators. In case that the Calculate command is started with no Degradation Process selected, a warning message box appears:



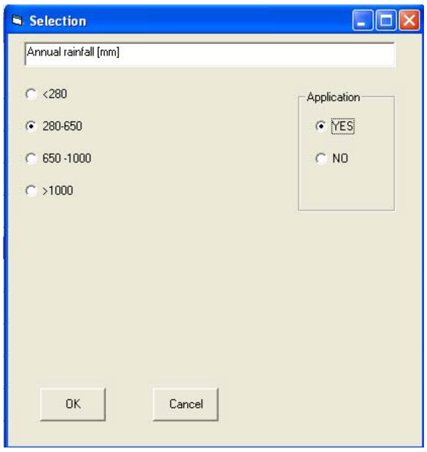
Defining Indicator values

The selection of indicators for Desertification Risk Assessment is performed through the Calculate dialog box. The selected Degradation Processes activate the corresponding indicators, which are automatically included in the calculation of significant indicators per process. The standard form of Calculate dialog box, for the selected Water erosion, Tillage erosion and Water stress degradation processes is presented in the following:



The calculate dialog box displays indicators in pages, with groups of up to 10 indicators per page. The buttons Previous and Next are used to move back and forth through pages, until all desired selections are performed.

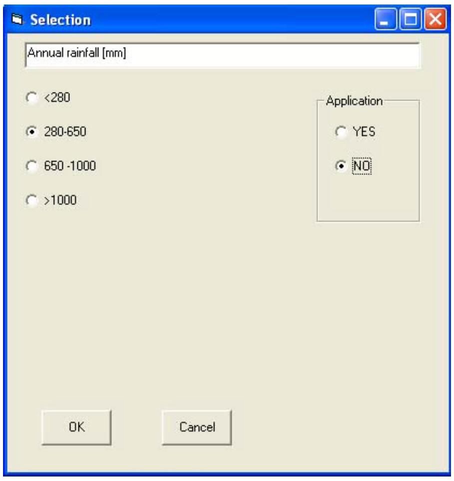
Available indicators for specific degradation processes have the button with Y or N in the appropriate row, with N as the default value showing that the indicator is not is use. The window on the right of the Y/N button is empty, showing that no value has been selected for that indicator. By clicking on the corresponding Y/N button, a case sensitive dialog box starts, giving the appropriate options for selection. For example – pressing the Y/N button in the row Rainfall opens the Annual rainfall Selection dialog box:



By selecting the indicator category on the left side, selecting Yes for the application options on the right and pressing OK, the selection of that indicator is completed and the the Y/N button changes its value. More information on the indicators that are used (including their classification) can be found in the description of indicators (Deliverable 2.1.1.).

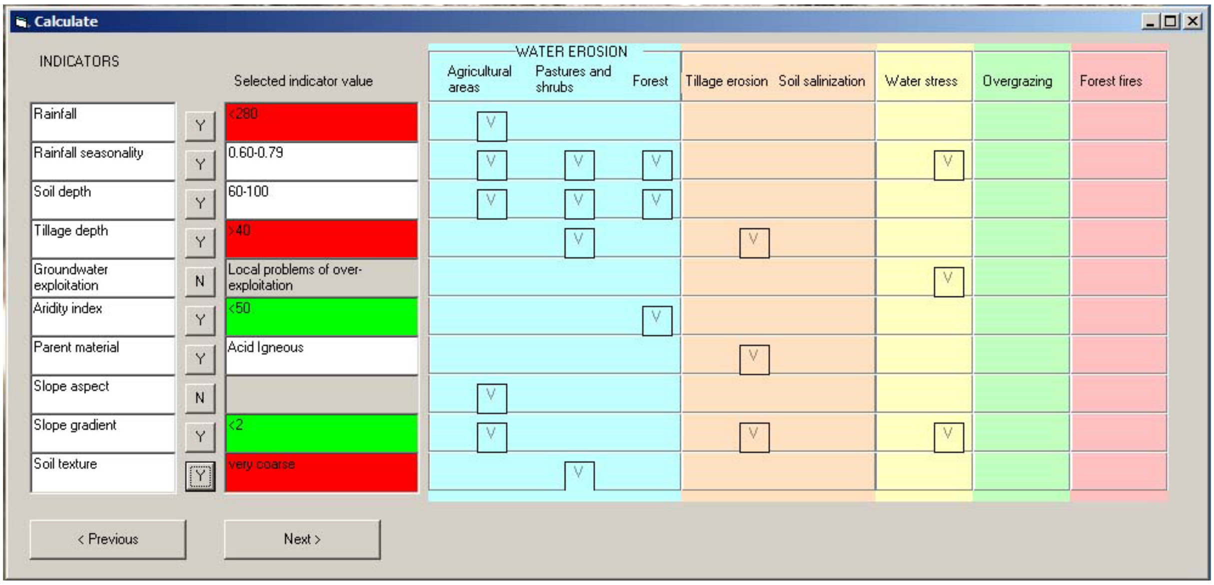
The button now has the value Y, showing that the indicator is in use. The window on the right of the Y/N button shows the specific value that has been selected for that indicator. When selected, standard indicators values are presented with the white background, maximum values are with red and minimum values with green background.

In the case that a Desertification Risk Assessment session has to be performed without the use of some indicators, but to preserve the selected value, the Y/N button should be pressed to open i.e. the Annual rainfall Selection dialog box and select No for the application options on the right side:



In such a case the Y/N button changes to N, showing that the indicator is not in use. The window on the right of the Y/N button still shows the specific value that has been selected for that indicator, but the field has been greyed, also indicating that the indicator is not in use for calculation.

Repeating the procedure on the Selection dialog box and selecting Yes or No for the application options on the right side activates/deactivates indicators. Activated indicators are automatically included in the calculation of significant indicators per process. Here is the example of the above mentioned procedure: Calculate dialog box with a possible combination of the first 10 indicators:



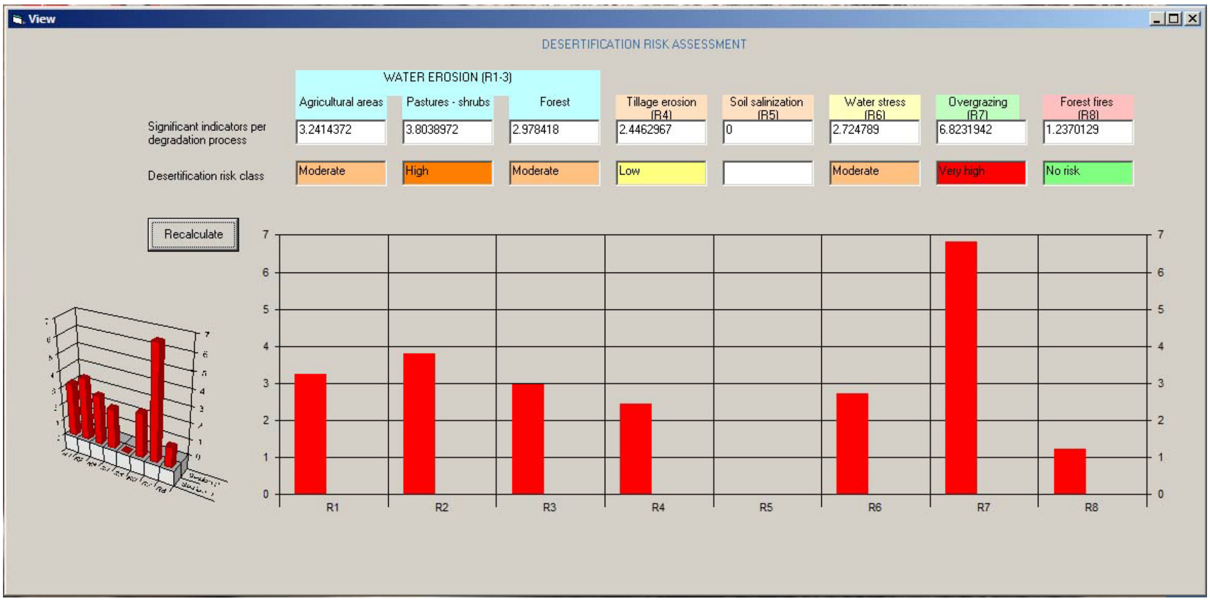
The pertinent example presents the following types of selected indicator values:

- Rainfall, slope gradient and soil texture have the worst values selected.
- Tillage depth and Aridity index have minimum values selected.
- Rainfall seasonality, Soil depth and Parent material have standard values selected.
- Groundwater exploitation has a selected value, but is not in use (deactivated).
- Slope aspect has no selected value.

View of results

The view of results interface presents in a numerical and graphical way the results of the calculation of the significant indicators per process for Desertification Risk Assessment. Water Erosion has three fields for corresponding processes: Agricultural areas, Pastures and shrubs and Forest.

In order to see updated results in an open View window, after some changes in the selection of indicators, please use the Recalculate button. That operation is automatically performed when the View window is opened for the first time. The following figure presents an example of one calculation where all the degradation processes are selected except Soil salinization:



Such an example presents also a scale for estimating desertification risk, ranging from Low to Very high with the corresponding colours ranging from green to yellow to orange and finally to red. As mentioned previously, Soil salinization process in this example is 0 since it is not selected and the Desertification class risk field is empty and without colour.

Troubleshooting

Instructions for the application of the installation parch for DESIRE software for Windows 7, Vista and XP (in case an error has appeared during the initiation of the program or selection of some commands) are as follows:

1. Unzip Library1.zip file in the folder of your choice.
2. Copy all unzipped files from the above folder to folder C:\Windows\System32 (comdlg32.ocx, MSCHRT20.OCX, MSCOMCTL.OCX and lib1.bat) . IMPORTANT: DO NOT replace existing files, if there are any (select Skip in the dialog box).
3. Open START->Accessories -> Command Prompt using right click on the mouse and selecting the option Run As … Administrator (provide password in required).
4. In the Command Prompt change the active directory using the command: C…> CD \Windows\System32 <ENTER> and run the BAT file C:\ Windows\System32>lib1.bat <ENTER>
5. Three dialog boxes should appear in sequence stating that each of OCX libraries installation has succeeded.

6. DESIRE software should now run normally.

6. Conclusions

The obtained data have shown that indicators can be used in assessing land degradation and desertification risk for a wide range of physical environmental, social and economical conditions in the study sites. Based on the correlation coefficient values of indicators selected for each process, a small selection of indicators can been characterized as significantly related to human actions. Land degradation and desertification due to soil erosion in agricultural areas is predominately related to land use intensity, rate of land abandonment, and policy implementation. The indicators plant cover, tillage depth, allocated subsidies, and policy implementation are predominately related to land degradation in pastures. In forested areas in which soil erosion is the main process of land degradation and desertification risk is mainly related to the indicators: grazing intensity, rate of burned area, fire protection, and population density. Important indicators affecting tillage erosion in cropland and pastures are tillage operations, tillage depth, and land use intensity. The main indicators affecting land desertification in field sites where soil salinization is the main process of land degradation are water quality, groundwater exploitation, irrigation percentage of arable land, and population density. Land degradation and desertification due to water stress is predominately related to the indicators rate of burned area, tourism change, and policy implementation. Land degradation and desertification due to overgrazing is mainly related to the indicators fire frequency, fire protection, rate of burned area, rate of land abandonment, grazing intensity, farm size, and land fragmentation. The indicator grazing control and major land use been mainly related to desertification risk in areas where forest fires have been defined as the main cause of land degradation.

Finally, the comparative analysis has shown that indicators may be used worldwide for assessing desertification risk. The derived methodology may be used to assess the efficiency and efficacy of different land management practices and degradation monitoring techniques for combating desertification at farm level and given the pertinent information at even regional level, in a variety of locales. The derived system of indicators may enable land users to test different scenarios for ecosystem vulnerability in order to assess critical stress factors and their impacts on desertification. In this regard, the developed ES may allow the decision-makers worldwide to generate appropriate and timely desertification measures by estimating the risk of certain applied responses. It may also provide a standard for assessing the effectiveness of the various land management practices. For such an assessment, the developed expert system has the following advantages:

- presentation and evaluation of a variety of desertification indicators simultaneously;
- delineation of the desertification risk (results) in a concise and holistic fashion;
- direct association of data input to the sensitivity of the results;
- interdisciplinary criteria and evaluation process; and
- integration among experts, administrators and decision-makers, since input from each group is needed for a successful run of the algorithm.

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