Symposium no. 44 Paper no. 650 Presentation: oral

SOTER as a tool for land use planning: experiences in West Africa and future applications

HERRMANN L. (1), **GRAEF F.** (1), **IGUE M.** (1), **WELLER U.** (2), **GAISER T.** (1), **HAMMEL K.** (1) **and STAHR K.** (1)

(1) Institute of Soils Science and Land Evaluation 310, University of Hohenheim, 70593 Stuttgart, Germany
(2) GSF, National Research Centre for Environment and Health, Biomathematics and Biometry, 85764 Neuherberg, Germany

Abstract

This paper deals with applications of the SOTER approach in different tropical and subtropical areas. It discusses advantages and constraints, possible sampling procedures, reasonable applications, and presents our view for modifications.

The SOTER approach was developed in order to provide a sound global database at a scale of 1:1,000,000 for land evaluation purposes and soil degradation studies. The chosen scale is a compromise having global resolution and regional/national applicability in mind. However, coastal West Africa with its small countries and a variety of applications for land use planning require higher resolution mapping (e.g. 1:200,000).

One advantage of SOTER is the open approach allowing different ways for map unit derivation, depending on the availability of data. Studies in West Africa show that satellite data are very useful in arid to semi-arid areas, whereas geology, topography and soil maps are necessary in areas with higher rainfall and denser vegetation. Mapping can be executed on the basis of randomised sampling points or transects. Randomised sampling allows a better statistical evaluation but is time and cost intensive.

Some modifications of the SOTER data structure would lead to better applicability. Experience in different countries has revealed that above the Terrain Unit a fourth unit would be desirable which could be called Geo-structural Unit. For a sound global legend these Geo-structural Units should be defined by an international commission in order to avoid mapping discontinuities at state frontiers.

Furthermore, we propose to describe Soil Components by a Profile Set rather than one representative profile in order to provide information for sound land use planning. In addition, our experience gives reason for a limitation of the number of map unit separation criteria.

Our applications were performed on the SOTER Terrain Component level because it has a resolution where single parameters (i.e. slope, texture) are sufficiently homogeneous to decide about implementation of single measures (i.e. mechanisation of agriculture). Results will be presented from Niger, Benin and Brazil.

In the latest project SOTER maps were used in southern Benin to describe the regional availability of soil water resources. Future projects aim at the incorporation of SOTER maps into regional expert systems concerning eolian erosion and propagation of parasitic weeds (Mediterranean).

Keywords: land evaluation, remote sensing, GIS, RDBMS, Niger, Benin

Introduction

Land evaluation and land use planning are urgent needs in most of the developing countries. In order to respond to this need the International Soil Reference and Information Centre in Wageningen (ISRIC) developed in close co-operation with other international institutions (FAO, IUSS, etc.) a concept for inventorying the physical environment: SOTER - Global and national soils and terrain digital databases (van Engelen, 1993).

This concept was meanwhile applied in a number of different environments. However, the advantages and restrictions of the concept were never systematically evaluated. Our aim was to test the concept with respect to mapping reality in the field and applicability for land evaluation purposes. Therefore, we applied SOTER in West Africa (SW-Niger, South and Central Benin) and South America (Brazil) in tropical environments. Based on these experiences, this paper discusses advantages and constraints, possible sampling procedures, reasonable applications, and presents our view for modifications.

The original SOTER approach

The SOTER approach is rather a flexible approach than a recipe describing a distinct workplan. Physical prerequisite using the approach is a Geographical Information System (GIS) and a Data Base Management System (DBMS).

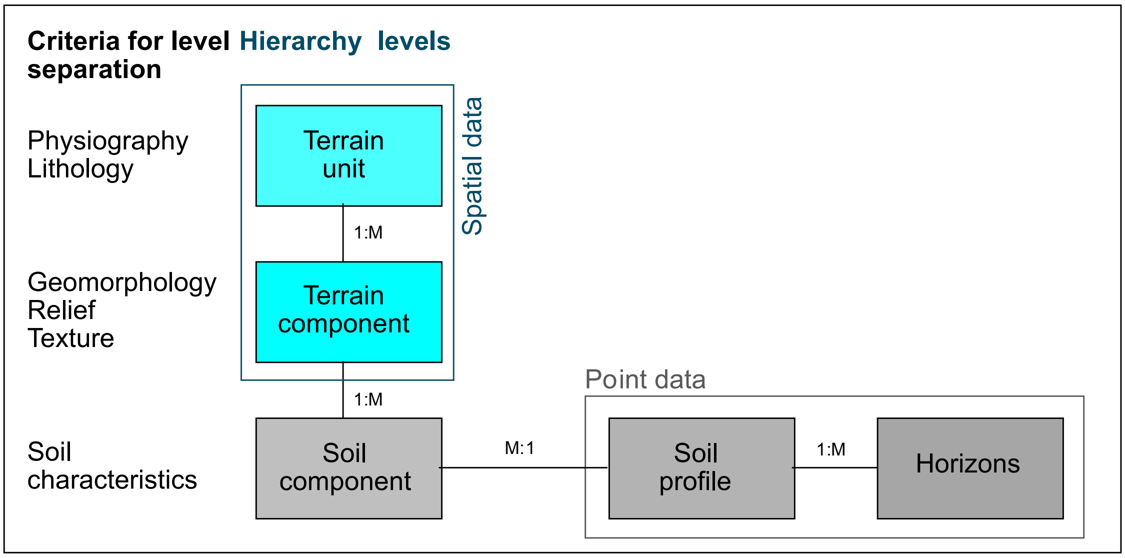


Figure 1 Original SOTER structure (van Engelen, 1993).

The data structure in the original procedures manual (van Engelen, 1993) aims at a resolution of 1: 1,000,000. It distinguishes three hierarchical levels: i. Terrain Unit, ii. Terrain Component and iii. Soil Component (Figure 1). Criteria for the level separation are i. physiography, lithology, ii. geomorphology, relief, texture and iii. soil characteristics. Only the two first levels should be mapped. So we deal with a downward separation which does not finally end up with a soil map. The Soil Component actually describes a group of spatially related soils (soil association in a pedological sense) and is represented by a reference soil profile, the description of which should deliver the necessary data for land evaluation. For all levels a minimum data set has to be collected.

The scale problem

Already the title "Global and national soils and terrain digital databases" indicates the possible scale ranges of 1:x00,000 to 1:x,000,000. On the other hand reasonable scales for land use planning are one order of magnitude smaller. In this frame, it appears reasonable to fix the resolution of SOTER to 1:1,000,000. However, in West Africa with a number of small coastal countries this scale is inappropriate, since countrywide maps of geology etc. have already a higher resolution. In addition, meaningful land use planning / land evaluation should be applied at higher resolution than countrywide maps. Our experience in West Africa revealed a necessity for an approximate 1:200,000 scale in order to meet the expectations of local partners.

One problem occurring at all scales is the restricted number of possible map units. This is especially true for hierarchically organised content. With respect to the global intention of SOTER this means: the smaller the resolution the more the spatial limits of the uppermost hierarchy level (Terrain Unit) must be agreed across state frontiers to avoid map legend inconsistency.

Experiences with SOTER working at an approximate scale of 1:200,000

Table 1 shows the derived map legend working on a scale of 1:200,000 in SW-Niger. The related map can be viewed under www.uni-hohenheim.de/~atlas308/b_niger /projects/b2_1_2/html. The legend shows that already three hierarchical levels with spatial attributes are needed to present a consistent map. Detailed studies in Southern Benin (Weller, 2002), Central Benin (Igue, 2000) and Northeast Brazil (Gaiser, *et al.,* 2002) revealed that from a scientific point of view the number of hierarchical levels should not be restricted since they depend on the morphological organisation of the terrain. However, having operational aspects and handling in mind, the number of hierarchy levels should be restricted.

Table 1 Extract of the SOTER map legend for SW-Niger (Graef, 1999).

Continental terminal	**Basement complex (sedimentary rocks)**
(P) Plateaux	(S) Hills or plateaux
(P1) flat	(S1) rocky ridges (<30m)
(P2) gently undulating (slopes < 3%)	(S2) small hills ((30-60m)
etc.	(S3) plateaux
(Hc) Higher-gradient slopes >3%	(Hs) Higher gradient slopes
(Hc1) medium gradient < 8%	(Hs1) medium-gradient <8%)
etc.	etc.
Basement complex (granites)	**Fluvial and eolian systems**
(B) Hills or plateaux	(Da) Dallol
(B1) rocky ridges and inselbergs	Da1) Dunes and eolian deposits >2m
(B2) plateaux	(Da2) zones with high ground water level
(Hb) Higher gradient slopes >3%	(E) Eolian systems
(Hb1) medium gradient <8%	(E1) fixed dunes
etc.	etc.

The comparison of separation criteria used in four different study regions shows that the number of necessary criteria is limited (Table 2). Dominant criterion is for the Terrain Unit level in all regions geomorphology. On the Terrain Component level the most important criterion, number and ranking of criteria is variable. Whereas in sedimentary environments a number of criteria were used, in the basement of Central Benin only lithology was applied. Though personal decisions of the survey conductor might be important for the chosen criteria, land with different surface organisation due to whatever reason leads to different map legend organisation at the Terrain Component level.

Table 2 Separation criteria for two SOTER hierarchy levels in four different regions.

	South Benin	Central Benin	Southwest Niger	Northeast Brazil
Terrain Unit	Geomorphology	Geomorphology	Geomorphology Slope angle	Geomorphology
Terrain Component	Geomorphology Hydromorphy Geology Slope angle Lithology	Lithology	Slope angle Geomorphology Lithology Geology Hydromorphy	Slope angle Hydromorphy

Our experience reveals that SOTER can be applied with success at a scale of 1:200,000 and that this resolution is reasonable for land evaluation in the investigated environments. However, keeping the global and regional applicability in mind and considering the necessity of a consistent map legend, a fourth level should be introduced at the top of the hierarchy (Figure 2). This level could be called Geo-structural Unit with geology, lithology and large-scale geomorphology as separation criteria.

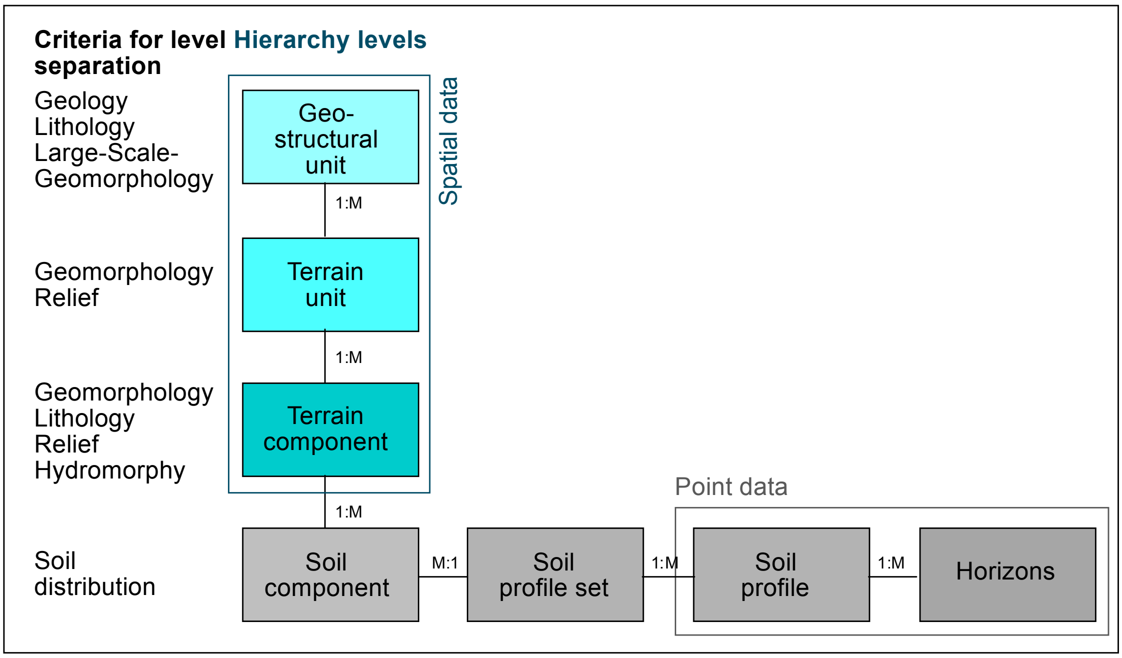


Figure 2 Proposal for the new SOTER structure.

Establishing SOTER maps and databases

Since SOTER is a concept and not a complete computer program or workplan, the methodology has to be and can be adapted to local conditions and available information. We worked in semi-arid to sub-humid tropical climate conditions in West Africa, explicitly in SW-Niger and South Benin. Figure 3 explains how the regional SOTER maps and databases were derived there.

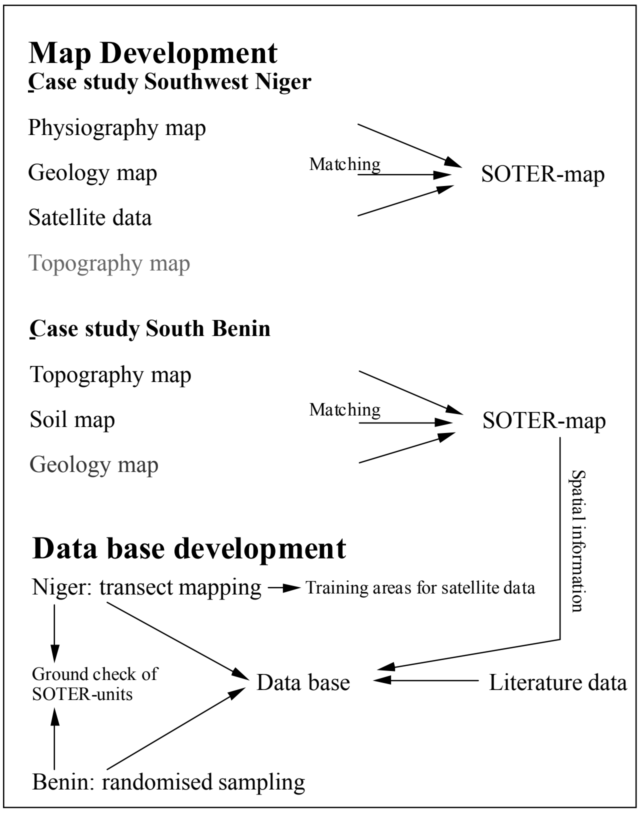


Figure 3 SOTER map and database development.

Under semi-arid climate conditions in Niger Landsat TM satellite scenes were an excellent basis for map development. False colour images were processed with the channel combination 7-4-3, which proved to best represent geomorphic units. In addition, two already existing maps could be used: i. physiography map (1:100,000, INRAN, 1977), ii. a geology map (1:1,000,000, Greigert, 1961/66). On the other hand under sub-humid climate with high vegetation coverage satellite data were useless. There, topography maps were the basic data of choice supplemented by: i. a soil map (Volkoff, 1976) and ii. a geology map (Mie, 1989).

Development of the SOTER maps is a recursive process of overlaying map resources and field visits for map unit verification. Two different approaches were chosen for the ground checks. In Niger, 53 representative transects were investigated with regard to geomorphology and soil inventory. In southern Benin map verification and data collection was based on a random sampling approach with >200 sampling points in the intervention area. In both cases own data collections were supplemented by literature data. A crucial problem using literature data was that for most of the described sites and soils an exact geographical position was missing, so they had to be discarded.

The transect as well as the random sampling approach proved to be applicable. However, sound statistical analysis can only be performed with the latter. But the disadvantage of random sampling is the extraordinary high time investment in areas with low infrastructure (= roads). In addition, also random sampling leads to underrepresented geographical areas (Herrmann *et al.,* 2001). This might have led to partly large differences in the estimation of the spatial coverage of Soil Profile Sets based i. on the random sampling approach or ii. the total database including additional literature data and field visit information (Table 3). In future, random sampling should be done with a minimum number of points within regular grid cells.

Table 3 Spatial coverage (km^2) of selected Soil Profile Sets in South Benin calculated on the basis of i. a random sample set and assumed binomial distribution and ii. total available information including literature data and field visits.

Profile Set ID*	Random sample set				Total database
	Observations	Lower confidence limit	Upper confidence limit	Mean	Mean
CR1	8	172	766	395	364
CR2	36	1,269	2,390	1,776	1,782
LM2	2			99	97
LM4	1			49	418
TDB3	7	140	701	345	410
TDB7	45	1,658	2,878	2,220	2,368
VC1	25	811	1,233	1,777	658

* for more detailed information please look at www.uni-hohenheim.de/~atlas308/c_benin/projects/c2_1_2/html/

Land evaluation based on SOTER

As already stated, SOTER is a tool to be used in land evaluation and land use planning procedures. However, in the original structure (Figure 1) the requested minimum data set is too small for sound land evaluation. There, for the representation of the Soil Component, only one reference profile is requested, though the Soil Component reflects potentially rather complex soil associations. We propose to introduce an additional profile set (Figure 2 and Weller and Stahr, 1995). On the basis of this new structure a SOTER database can simultaneously be used as a national soil database.

How SOTER can potentially be used in land evaluation is schematically presented in Figure 4. In our land evaluation approach each point in the intervention zone is related to the next available climate station by a Voronoy mosaic. The derived spatial units are overlayed with the SOTER units (either on the Terrain Unit or Terrain Component level depending on the task). For all resulting evaluation units the suitability is calculated with a modified Storie Index on the basis of the parametric FAO/ITC-Ghent evaluation (Sys *et al.,* 1993) method using the existing climate and SOTER point data. Derived maps can be viewed under www.uni-hohenheim.de/~atlas308/c_ benin/projects/c2_2_2/html and www.uni-hohenheim.de/ spice.

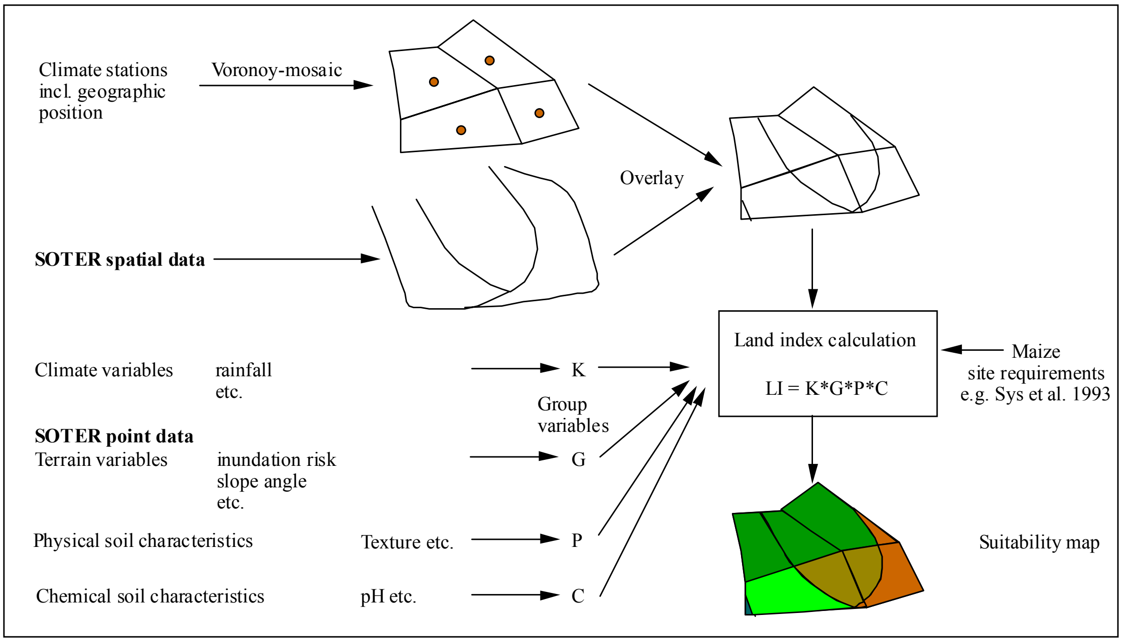


Figure 4 Land evaluation procedure based on SOTER.

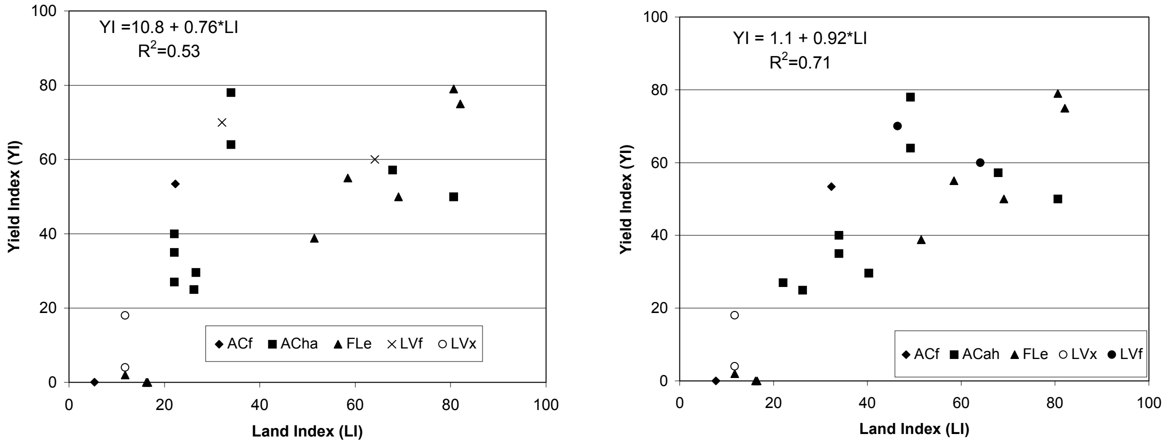
The given flow chart highlights potential problems. First of all, climate data are considered in the SOTER approach, but they are not an integral part of the data structure. This leads to the second problem: the final evaluation units are not a SOTER hierarchy level. In future it should be a matter of debate, how climate information could be better integrated into the SOTER data structure.

A third problem is how to deal with extreme spatial and temporal variability of climate data. I.e. in tropical areas we have to consider large differences in annual rainfall within short distances and also variable patterns over time. Actually, for the presented SOTER intervention zones the terrain information has a meanwhile higher spatial resolution than the climate information.

A fourth problem appears with the application of the Voronoy mosaic for derivation of "spatial climate units". Strict application leads to the situation that climate data from valley floors are used also for evaluation of certain highland regions (see www.uni-hohenheim.de/~atlas308/c_benin/projects/c2_2_1/html) which would be better connected to the next "highland climate station" and vice versa. Therefore, algorithms must be introduced to correct the Voronoy mosaic with respect to extreme topographic differences.

Finally, if the general crop requirements provided by Sys *et al.* (1993) were used for calculating the land index for locally adapted crops in SW-Niger or NE-Brazil, the correlation between land index and crop yield was unsatisfactory (Figure 5a). The relationship could be improved to an acceptable level (Figure 5b) by correcting the site requirements (decrease with respect to pH and organic matter, Gaiser and Graef, 2001).

Unfortunately, for most local crop varieties the real site requirements are unknown so far.



*Abbreviations in the figures reflect soil types according to the FAO Soil Map of the World (1994)

Figure 5 Relationship between calculated land index and yield of cowpea using different crop requirements: a. crop requirements adapted from Sys *et al.* (1993), b. crop requirements corrected for pH and organic matter*.

Other applications based on SOTER

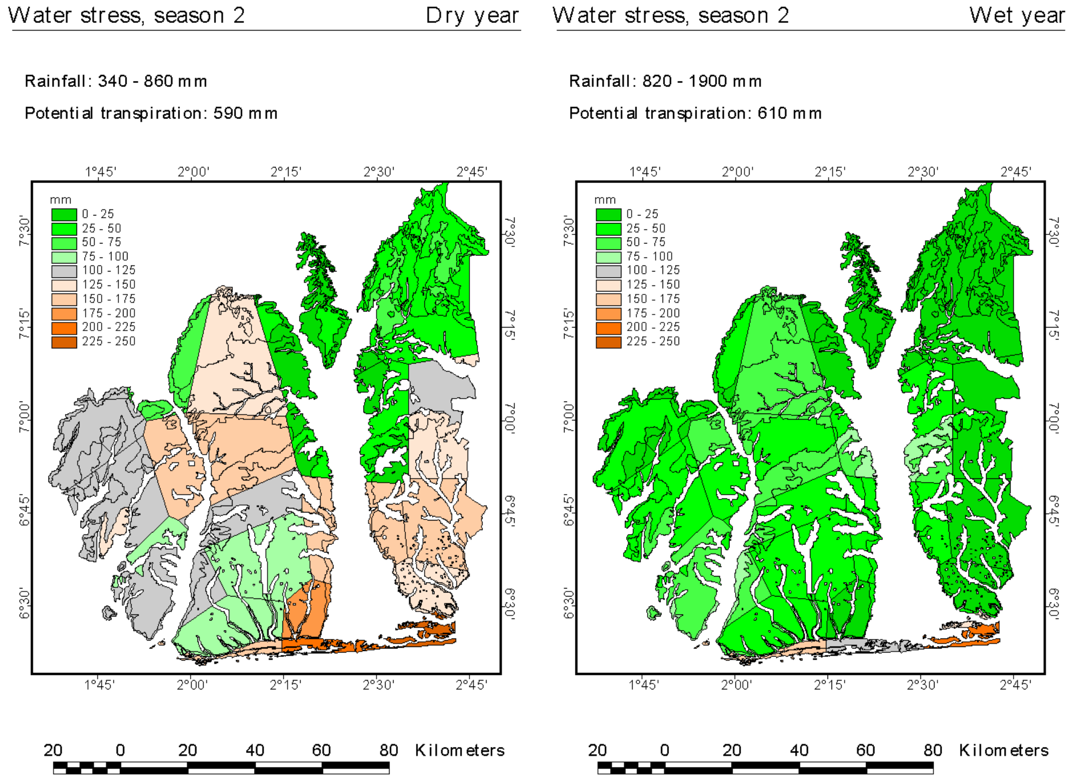
SOTER can be applied beyond land evaluation in the strict sense, once the database is established. One recent application was the calculation of regional water balance components in South Benin (Figure 6). Though the output is not calibrated versus hydrological data so far, it is useful for temporal evaluation and scenario development since other information is totally lacking.

Other planned applications are i. the use of SOTER for the estimation of mineral dust production potential in arid and semi-arid regions supplying input data for global meteorological circulation models, and ii. the implementation as an integral part into a regional Mediterranean decision support system with respect to the potential risk of parasitic weed infestation.

Final comments

SOTER has proved to be a flexible tool for land evaluation and land use planning purposes. However, for smooth applications some changes in the principle and data structure are desirable. In addition, there is an enormous need for testing and validating the applications under different environmental conditions, which is a prerequisite for their use at the regional scale.

At medium scale resolution data acquisition has advantages compared to soil map elaboration. But - as it is true for other concepts - evaluations based on SOTER are only as good as the underlying data. Since in certain situations soil maps are used to derive SOTER units, the digital soil maps should be attached to SOTER so that the SOTER database can act as a national soil database at the same time. Finally, climate information should be elaborated as a real integral part of the database.



For more detailed information please visit:www.unihohenheim.de/~atlas308/c_benin/projects/c2_2_1/html/

Figure 6 Water stress as difference between potential and actual evapotranspiration (in mm) in the short rainy season of South Benin calculated on SOTER database information.

Acknowledgements

The authors gratefully acknowledge funding from DFG, BMBF and DAAD.

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