Remote Sensing of Land Surface for Monitoring Arid Mediterranean Environment

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Abstract: Desertification is the major environmental threat in arid lands and remote sensing a major source of information to assess and monitor this phenomenon. Green vegetation cover change as estimated by vegetation indices is a good desertification indicator under humid and subhumid climates, however it generally fails at depicting the condition of arid steppic ecosystems. An approach taking into account all components of the land surfaces has been developped and results evidence the importance of soils features both for interpreting remote sensing data and for documenting desertification in the dryer parts of the Mediterrranean. Consequences for the implementation of environmental monitoring with current and future satellites are discussed.

Keywords: Soils, desertification, spectrometry, field data, Northern Africa

Satellites Watching Arid Lands

Arid lands are prone to land degradation phenomena regrouped under the term *desertification* a very serious threat considered as such since the first international conference on the topic in 1977. Among the measures designed to tackle it, the need to assess the extension and rate of propagation has been clearly identified and is still a priority (see UNCCD). The task is immense as most desertification endangered regions are large areas of rather low agricultural activity with modest infrastructures, they are usually not routinely subjected to detailed environmental monitoring. In the Mediterranean region the southern rim with its dryer climate is clearly the most affected area (fig 1a).

Since the launch of the first civilian satellites, remote sensing images have been made available and a great hope has been placed in this technology as a source of environmental information, particularly for desertification assessment as their images cover very large areas compared to traditional survey methods.

After the first attempts, it has been established that most of the satellites with optical sensors (the more resembling to aerial photography cameras) are very efficient at mapping green vegetation extension. This is not a big surprise as they have been designed for that, all of them record images at least in the red and near infrared spectral bands. Vegetation indices, based on the contrast between values in these two bands, express the 'greenness' of the landsurface (fig.1b), such as the widely used and long established NDVI (Price, 1987).

As a matter of fact, satellites are now routinely used to map green vegetation density and extension. This approach is effective from humid (with the limitation of less usable images because of the denser cloud cover) to semi-arid regions, where the vegetation is shorter but still green, such as in the northern Mediterranean countries. Several recent research programmes have demonstrated how the motoring of green vegetation cover with optical remote sensing helps to assessing its fluctuations and the corresponding desertification patterns. This has been successfully used to assess desertification in the sahelian countries where most of the vegetation is made of annual herbaceous easily detected with the NDVI, and thus its fluctuation and depletion (Tucker et al., 1991).

In northern Mediterranean regions detailed rangeland condition has been obtained through advanced processing of series of Landsat TM images for monitoring green vegetation cover changes (Hill et al., 2005 [these proceedings])

However in the arid regions of the south Mediterranean countries where desertification monitoring is so needed, there is not much green vegetation to monitor, apart from small patches of irrigated fields and oasis. Natural vegetation is a steppe dominantly composed of shrubs, cover is sparse. Greening occurs only sporadically following the rain, then shrubs grow new leaves and some annual plants develop in between the shrubs. These vast areas are usually used as rangelands, but many parts have been recently turned into rain fed agriculture. Still, only in rainy years the crops will have a significant cover, remotely sensed by satellites.

Thus, to use satellite imagery for desertification assessment in the context of the dry Mediterranean countries the question is what can be actually remotely sensed with the existing satellites and is it helpful for desertification monitoring.

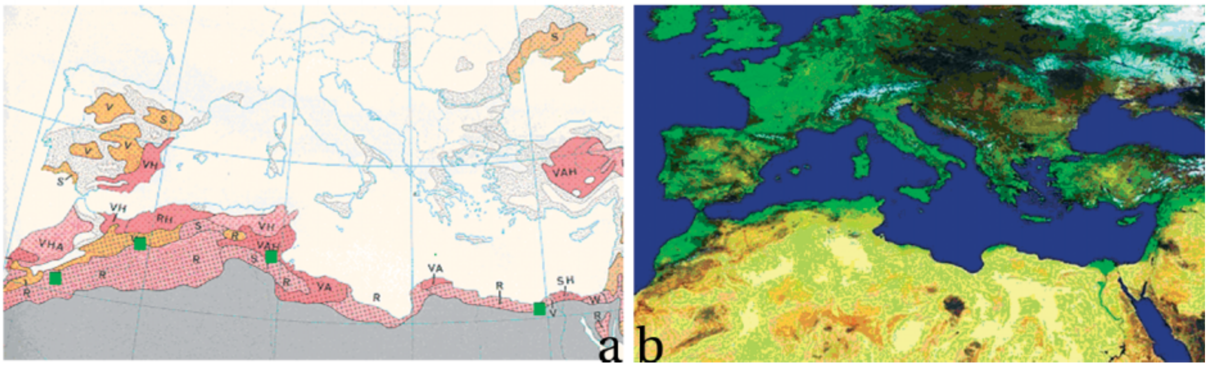


Figure 1 : a) extract of the desertification map of the world (UNCCD) compared to b) global green vegetation image (Spot-VGT : www.vito.be)

Remotely Sensing Mediterranean Arid Lands

As expected, whereas the classical approach using vegetation indices for green cover assessment has been successfully applied to sub-humid and semi arid parts of northern Africa (Maselli et al., 1998), it has failed in detecting the vegetation of the vast arid steppes spreading between the rather humid coastal regions and the extreme desert conditions of the central Sahara (Kennedy, 1989)

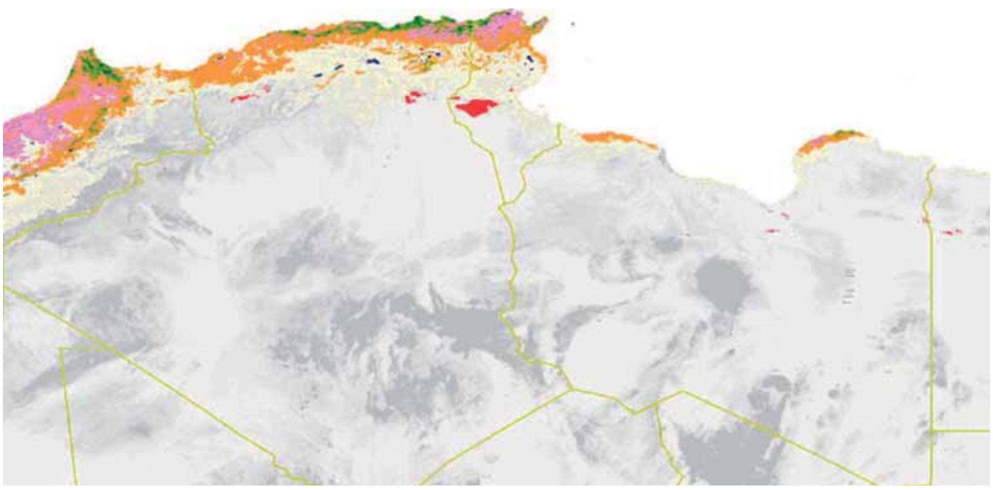


Figure 2. Extract of the Global Land Cover map of Africa (Mayaux et al. 2003)
Legend: *pink*:rain-fed agriculture, *beige:* open shrubland, *red*: salt hardpans,
light yellow: sparse grassland ('pseudo-steppe)
and in grey: bare soil (highly dominant in North African countries)

The dryer the climate, the sparser the vegetation, and in typical arid steppe ecosystems the vegetation cover is often less then 30% , a value which is also considered as a threshold for remote sensing as lower cover are difficultly detected with vegetation indices. The fact that the plants from the steppe are short woody shrubs with short leaves, make them even more difficult to detect with these indices, moreover certain types of arid soils are responsible for 'noise' in the vegetation indices (see fig.3)

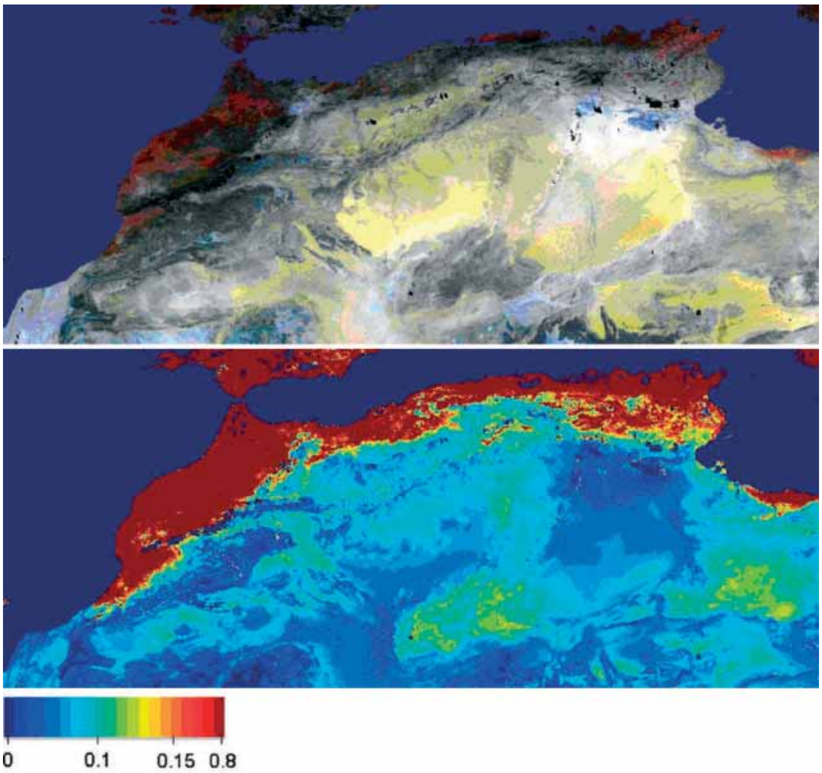


Figure 3. Evidence of soil artefacts in Spot-VGT imagery over dry Mediterranean areas
(10 days composited image, early Oct.2003, project POSTEL/CYCLOPES)
Image above: (Band 2,3,4 "false colour" composite) showing the green vegetation areas in red
Image below : NDVI computed for the same image,
values above 0.1 for bare soils and bare rocks in desert areas in the lower part are artefacts

Reconsidering the overall issue of environmental remote sensing of these arid biomes, a new approach as then been developed, trying to circumvent these limitations of the approach generally used over other biomes. It is based on considering both the global features of arid land surfaces and the sensors characteristics of the satellite to be used.

Integrated Land surface Condition Assessment

In the new approach we have developed to use remote sensing in desertification monitoring, instead of trying to monitor only the "green" component of the landsurface, we have taken into account the fact that the whole land surface is affected by the degradation (and recovery) phenomena involved. Thus, when characterising the land surface condition we are looking at all its diverse components : the mineral ones, soil but also stones, pebbles, outcropping rocks, surficial sand, and the vegetal components made of the different plants, including dry parts and litter.

Several techniques have been tested for assessing the relative abundance of each of these components in terms of percentage of the surface cover, among them the line intercept method based on the measurement of fraction cover intercepted by 20m lines randomly distributed on the studied land surface sample, as well as nadir viewing photographs from a pole or from other devices such as kites and balloons (fig.4).

Land condition surveys with this type of photography can then be conducted at regular interval to assess land condition changes such as total vegetation cover decrease, soil denudation, increased stoniness or sand encroachment. Indeed desertification processes have an impact not only on the vegetation cover but as well on the mineral components of the land surface, they are modified by aeolian erosion and deposition of wind blown material, whereas rain storms and sporadic runoff redistribute them in patches of various shapes. The resulting features such as shifting sands can be used as diagnosis criteria for undergoing desertification, provided the local mechanisms involved are known.

While looking at linking the ground features to remote sensing data, a second benefit of this integrated land surface assessment appears clearly. Indeed the satellite sensors measure light (or emitted radiation) reflected by the land surface, the light coming from the sun interacts with all surface features. Information collected on the ground about those very same features will improve significantly the interpretation of the images acquired by satellites, particularly the ones providing measures by optical sensors.

In order to characterise surface features, a series of field campaigns have been conducted on different test areas part of a desertification monitoring programme in Northern Africa (Escadafal et al., 1997). While describing the land surface components (nature and condition of rocks, soil and plants) their optical properties have been measured using portable spectroradiometers. The resulting set of information of various nature (descriptive and, quantitative) has been organised in a relational database allowing a thorough analysis and interpretation (Preisler et al., 1998).

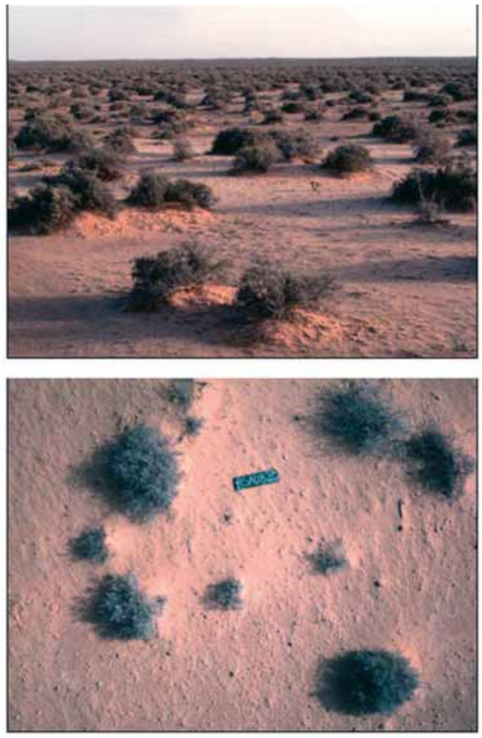


Figure 4: Typical north African steppe: compare the apparent density in oblique and nadir viewing

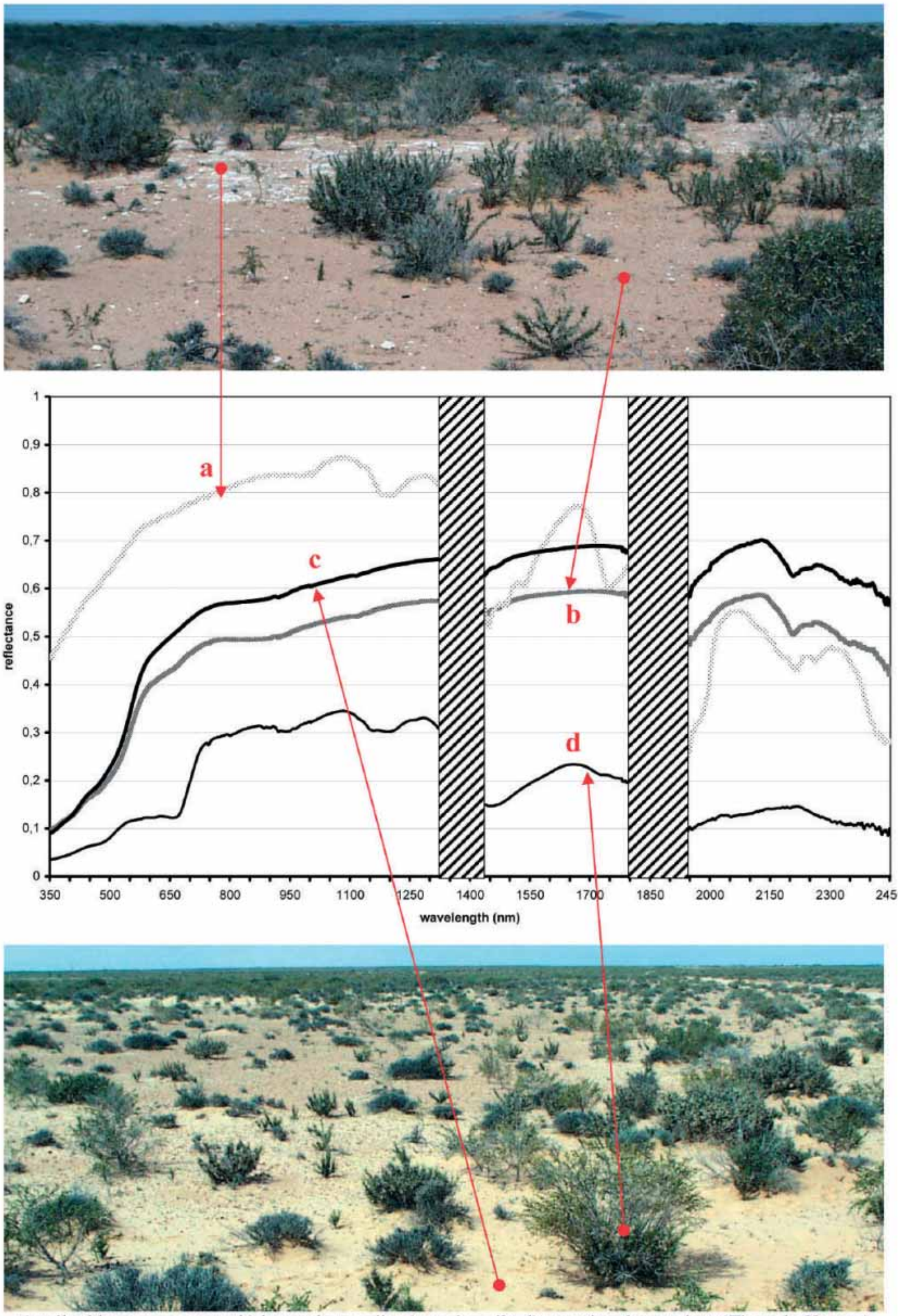
Investigations carried out in four north African test sites during the Cameleo project have shown that the soil components of the land surface have very diverse spectral features (see fig.5), potentially source of information (Escadafal & Megier, 1998). By contrast, in the vegetation index based approaches, soils are simply a background which influence is to be minimized so that the VI fluctuations reflect only green vegetation changes.

Long Term Monitoring

After some rather naives attempts, one of the major conclusions of the first researches on using satellite imagery for desertification studies has been that one image provides certainly information of the land condition, but is rather insufficient to perform a diagnosis. Indeed desertification is more a process than a particular state, and assessing it requires to be able to determine the evolution of land condition with time (e.g. stable, improving or worsening).

In the arid areas, this task is more complicated than it may seem because of the high climatic variability. As an example in the met station of Gabes (southern Tunisia) the annual precipitation observed during the more humid year is 14 times the one of the dryer year. Human impact on the land varies accordingly, when the soils are wet large surfaces are ploughed, when dry periods occur just after that, adverse effects such as strong wind erosion may occur (Floret et al., 1992).

Thus the key to desertification monitoring in those areas is long term observations. When looking at doing this with remote sensing, this is narrowing the type of usable data. Today optical imagery from the Landsat and Spot programmes is the only data set of sufficient spatial resolution encompassing a significant time span. The first publicly available images is those of the MSS sensor on Landsat1 in 1972. The benefit of the field method for land surface assessment mentioned above, describing the features having an impact on the way sun light is reflected towards the optical instruments of those satellites, is thus more obvious.



a) soil with gypsum crust ; b) loamy bare soil ; c) sandy veil ; d) greening desert plant (*Thymela Hirsuta*)

Figure 5. Example of arid land surface components and their spectral reflectance properties
(field measurements in Southern Tunisia,
dashed : non transmitting bands of the atmosphere)

In principle a series of Landsat images would allow us to monitor land surface changes during a time span of more than 30 years. However experience has proven there are big limitations that have to be taken into account when building such a series:

- ancient Landsat images covering areas outside the USA have been only partially archived, and conservation has been poor, very few of the images acquired by these satellite in the 70's and 80's are still in image providers catalogues and available for purchase. Spot programme has a more consistent archive, but it starts only in 1986 (Spot1) and is still rather costly to use.

- encompassing more than 30 years involves the combination of a minimum of two types of images from the MSS and the TM sensors, a task requiring diverse techniques of resampling as their resolution and spectral bands are different

- calibration factors and furthermore the atmospheric parameters of these ancient satellite images are usually not available. Thus alternative intercalibration methods have to be deployed, based on pseudo-invariant features, despite their limitations.

- comparing long series of images of different sensors requires meticulous geometric correction schemes, avoiding error propagation.

- finally, even if Landsat images are acquired with a constant nadir viewing angle, the illumination angle varies. At the time of the Landsat and Spot satellite overpasses, under Mediterranean latitudes the sun elevation is much lower in winter than in summer, thus the bidirectional reflectance properties of the land surface should be taken into account. Sun elevation has even a stronger effect on areas with relief such as hills or mountains, because of the strong variation on shadow size.

Despite these constraints , the long term monitoring efforts for land degradation assessment have been tempted in different areas, good examples in the Med region are the Georange and Cameleo projects, both supported by the European Commission. Considering the Tunisian test site of this last one, figure 6 displays examples out of a series of images obtained after geometric correction and intercalibrations described above (Albinet, 2004).

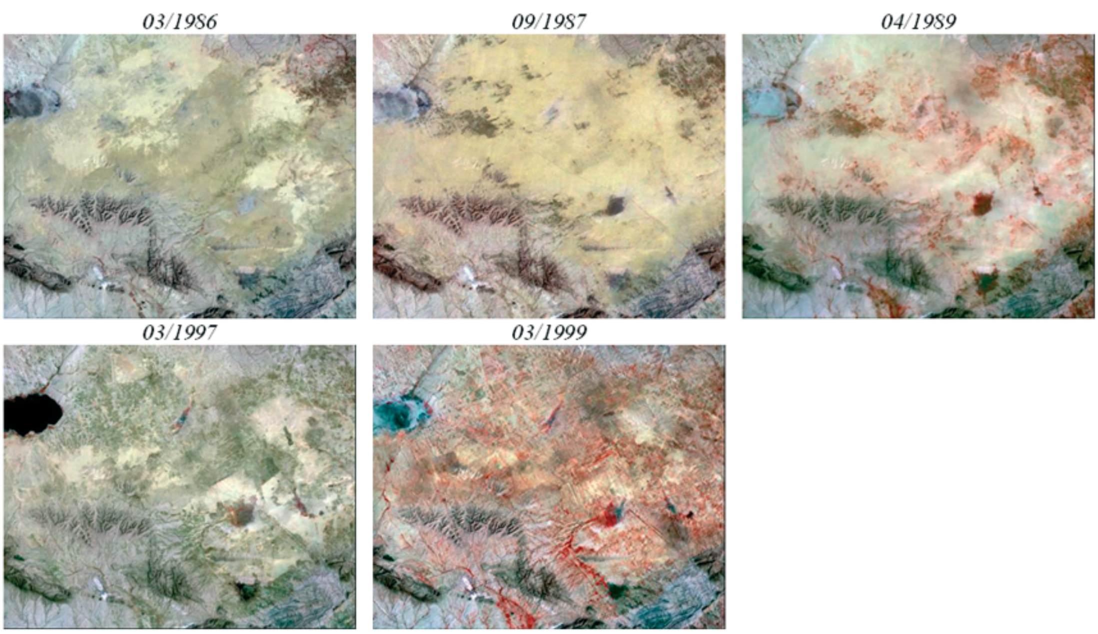


Figure 6. Series of five georeferenced and intercalibrated Landsat TM images over the Tunisian test site of Menzel Habib (standard false colour composite, area 30x40km)

In *light yellow* bare sand, in red, denser green vegetation, in greenish *grey denser* shrub vegetation. See the changes throughout seasons and years

Prospective: Geomatics for Regional Desertification Monitoring in the Mediterranean Partner Countries

The discussion above demonstrate the need for a more intensive use of existing data (the use rate of the image providers is rather low so far). Simultaneously the increasing number of sensors in orbit on various platforms, with a variety of spatial resolution and of spectral bands is allowing to get rich and richer information on the land surface condition. In addition to optical sensors, active microwave sensors (such as SARs) provide data on the land surface roughness, whereas passive microwave sensors will estimate soil water content (SMOS satellite, e.g.).

Combining larger and more diverse sets of data is a current trend in environmental assessment programmes under implementation at various scales in Europe and surrounding countries. Whereas numerical methods have been applied first to remote sensing imagery, now they can be expanded to less regularly gridded data such as ground collected information, and data previously established in 'analog' format, such as paper maps, point samples, ... (so called 'ancillary' data). Tools to combine all these different types of geo-spatial information, are regrouped in software programmes called geographic information systems. These systems allow not only to project data with different original geocoding onto only one reference system, but also to combine them in various ways appropriate to retrieve information relevant to specific environmental issues such as soil susceptibility to erosion, environmental threat on rivers and water bodies, etc.

However the "data crunching" power of these tools should not blind us, and the hope for various "push button" indices on environmental assessment is a rather naive high-tech approach of already well known concerns about the land and water quality and its changes with time. A sound understanding of the ecological phenomena actually occurring on the ground is not to be substituted by fancy computer programming, but to be seconded by those techniques. Interpreting the results of the various data processing algorithms and combinations still requires human expertise.

In the case of desertification monitoring over arid Mediterranean regions discussed here, so far no 'global desertification index' could be computed by automated processing of series of satellite images. Detected changes have to be analysed and interpreted in the context of recent climate oscillations (dry and humid years) as well of the local soil condition. Land surface changes will be quite different in a sandy steppic plain and in rocky hilly areas, e.g. and desertification diagnosis can vary from one region to another.

Sometimes a vegetation increase will indicate worsening condition, when it is involving the development of plants of lower quality. Conversely, sand movement often appear as a desertification signal, however degraded soils will recover after being invaded by shifting sands allowing a better water balance and psammophytic plants to grow.

As a conclusion, having these remarks in mind, the efforts undertaken at regional level to exchange methods and data and to make them compatible are not an attempt to get automated land and water condition indices from the desktop, but a step towards a regional vision and comparison, taking into consideration existing differences and accumulated knowledge.

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