Spatial identification of indurated volcanic tuffs (*tepetates*) for soil reclamation in the central altiplano of Mexico
Identification spatiale des tufs volcaniques indurés (*tepetates*) en vue d'une réhabilitation des sols dans l'altiplano central du Mexique
Identificación espacial de las tobas volcánicas endurecidas (tepetates) para una rehabilitación de los suelos en el altiplano central de México

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Tepetates are altered indurated and sterile volcanic tuffs. They are located among the neovolcanic ridge in central Mexico. They are a strong limitation for agriculture and represent a serious degradation of natural environment.

To assist the development of rehabilitation programs, maps have been produced by remote sensing methods and geographic information system (GIS) containing various thematic layers. The purpose was to localize the existing and potential areas of *tepetates*. An agro-socioeconomic data base was also integrated into the GIS. The obtained results show that 15 to 20% of the area is covered with outcrop *tepetates* or *tepetates* in process of erosion, but the classified image tends to underestimate erosion's risk areas. This is mainly due to remote sensing limits. The solution proposed is to define an adapted typology and to use other kind of satellite data. On the final result the selected areas coming from the request of the GIS and the ones coming from the Landsat TM data classification are located on the exactly same place. But the creation of this GIS is too costly and time-consuming according to the results obtained. In addition the agro-socioeconomic characterization of theses regions, did not yield any satisfactory results since it is linked to an inappropriate administrative cut-out.

The work carried out shows that 40 to 70% of the surfaces where poorest peasants' communities mostly live contain *tepetates*. Therefore, it is urgent to start restore theses rural zones.

Keywords : remote sensing, Landsat TM, GIS, indurated volcanic soil, *tepetate*, spacialisation, Mexico.
Mots clefs : télédétection, Landsat TM, SIG, sol volcanique induré, *tepetate*, spatialisation, Mexique.

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Tepetates, a nahuatl word (from "*tetl*" for stone and "*petatl*" for bed) is a term used by the mexican peasants to indicate a fragipan/duripan soil layer. In fact, *tepetates* are altered indurated and sterile volcanic tuffs. They are located among the neovolcanic ridge which is formed by volcanoes surrounding altiplanos in central Mexico. In a natural situation, those layers are covered by a deep black soil, but, due to particular environmental conditions as well as a historical and a socio-economical context, the top soil can be eroded. Under these conditions, the *tepetates* cropped out are a very strong limitation for agriculture and represent a serious degradation of natural environment.

To assist the development of rehabilitation programs of this regions, cartographic maps of these areas have been produced by applying supervised classifications of Landsat TM satellite images. To complete this approach, we developed a geographic information system (GIS) containing various thematic layers such as geological map, soil map, rain map, digital terrain model (DTM), land use, ..., based on thematic information

from 1/250 000 scale INEGI[1] maps. The purpose of this step was to localize the potential areas of new *tepetates,* that can not be detected by using only remote sensing methods, by crossing these information and applying requests. According to Dubroeuq et al. (1989) *tepetates* can only appear in certain conditions : between 2300 to 3000 meters high, under 900 mm of rain per year and on volcanic Quaternary deposits. Finally, an agro-socioeconomic data base was integrated into the GIS providing information that could be related with the rural communities concerned by the problem of outcropped *tepetates.*

The obtained results (over three different zones from 300 to 600 km2) show that 15 to 20% of the area is covered with outcrop *tepetates* or *tepetates* in process of erosion. The comparison of the classified image with a cartographic map obtained previously by extended field work cartography (Peña and Zebrowski, 1992), shows coherent results about outcrop *tepetates*, but the classified image tends to underestimate erosion's risk areas (10 vs 40%). This is mainly due to remote sensing limits and especially to the size of Landsat TM data pixel related to the heterogeneous landscapes such as *tepetates* in process of erosion. Indeed, the latter mix at the same time *tepetates*, bare soil and spontaneous vegetation, which, with a 30 meters pixel, make difficult the pure spectral signature analysis of small objects. The solution proposed is to define an adapted typology of the different landscapes concerned with *tepetates*, knowing the percentages of the main spectral objects combined together, and relating this to another classification. In addition the use of other kind of satellite data, like SPOT with its 20 and 10 meters pixel, would allow more precise results.

The final result of the crossing information contained in the GIS could not be compared, in term of surfaces of the areas of outcrop *tepetates,* with those obtained by remote sensing because of the small scale of the GIS layers which wasn't so precise. On the other hand, one can easily see on the final maps how the selected areas coming from the request of the GIS and the ones coming from the Landsat TM data classification are located on the exactly same place. But, somehow the interest of this GIS is limited to the definition of regions concerned by *tepetates* and to the comparison between the hypothesis of *tepetates* presence or absence with the soil scientists theory. But the creation of this GIS, by digitalization of paper maps and vectorization, is too costly and time-consuming according to the results obtained. Hence, using remote sensing and Landsat TM or other type satellite data is much more satisfactory, providing updated and precise information, compared to the GIS final layer, based on an outdated, less reliable data base.

The agro-socioeconomic characterization of theses regions, using data from the last national census introduced into the GIS, did not yield any satisfactory results. Actually, this data is based solely on average figures since it is linked to an administrative cut-out (the *municipio*), which usually include large areas containing very contrasted landscapes of natural and human uses.

Slopes, natural resources mismanagement, deforestation, intensive breeding, fragile soils and aggressive climate, lead to soil erosion and outcropping of *tepetates*. The work carried out shows that 40 to 70% of the surfaces of piedmonts areas contain outcrop *tepetates*, which is the place where poorest peasants' communities mostly live.

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[1] Intituto Nacional de Estatisticas Geografia y Informatica

Therefore, it is urgent to start restore theses rural zones. Given the financial and temporal limitations to create soil from these tuffs (1 500 $/ha for 30 h in average) and the total surface of *tepetates* in Mexico, it is necessary to identify the worse situations, both from an ecological and a human point of view. The crossing of satellite images and more details socioeconomic data could be a good solution in this identifications[2] .

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[2] This research is a part of the actual work of PhD of A. Servenay in the ORSTOM laboratory of the Maison de la télédétection - 500 av. JF Breton 34093 Montpellier France - with the University of Toulouse le Mirail, and in association with the institute of geography of the UNAM in Mexico.