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Digital soil mapping: case study from the Khouribga - Kasbat Tadla zone in Central Morocco

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Abstract

This work deals with the digital soil mapping as a time and cost effective alternative for soil type characterization. The e-Soter (Soil and terrain) approach was used and validated for in the Khouribga-Kasbat Tadla semi-arid rainfed agricultural area of Central Morocco, covering 217.000 ha. The GIS processing included physiography and parent material as two soil genesis factors, added to field data from 90 soil profiles. A subset of the ASTER-GDEM 30m spatial resolution digital elevation model (DEM) was used to map three physiographic indicators that are slope gradient, relief index and potential drainage density. The parent material classification was derived from 1/100.000 geological map. The e-Soter hierarchical classification was then used to derive e-Soter homogenous units that were spatially joined to soil profile data in order to define the most representative soil type and delineate soil homogenous units at the 100.000 scale. The resulting soil map was validated in the field using a transect approach, with three transects in areas that were not included in the initial field data collection. Statistical significance for similarity between the map outputs and the field observations was confirmed using four statistical indices (Chi square, Cramér’s V, Fisher’s exact and Kappa reliability test), which confirms the validation of the e-Soter approach as a digital soil mapping tool in the study area.

Keywords: Digital soil mapping, e-Soter, Soil parent material, Physiography, Central Morocco.

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Cartographie numérique des sols: cas d'étude de la zone de Khouribga - Kasbat Tadla au Maroc Central

Résumé

Ce travail traite d'une étude de cas de cartographie numérique des sols et son efficience dans la caractérisation des types sols. L'approche e-Soter (Soil and Terrain) a été utilisée et validée dans la zone semi-aride de Khouribga-Kasbat Tadla, sur une superficie de 217.000ha. Une analyse spatiale sous SIG a intégré la physiographie et le matériel parental comme facteurs de pédogenèse, en plus de données de terrain sur les types de sol de 90 sites. Le modèle numérique de terrain (MNT) ASTER-GDEM de 30m de résolution spatiale a été utilisé pour dériver trois indices physiographiques que sont le gradient de pente, l'indice de relief et la densité de drainage potentiel. La classification du matériel parental a été dérivée de la carte géologique au 1/100.000. La classification hiérarchique e-Soter a été ensuite utilisée pour dériver les unités homogènes de terrain qui ont été jointes spatialement aux données de terrain pour délimiter les unités homogènes de sol à échelle 1/100.00. La carte des sols résultante a été validée au terrain par l'approche de transect, avec trois transects passant par des sites non utilisés dans la collection de données de terrain initiales. Une similarité statistiquement significative a été observée entre les résultats de cartographie numérique et les observations de terrain, à travers quatre indices statistiques (Chi carré, V de Cramér, test exact de Fisher et coefficient Kappa), ce qui a confirmé l'adaptation de l'approche e-Soter comme méthode de cartographie numérique des sols dans la zone d'étude.

Mots-clés : Cartographie numérique des sols, e-Soter, Matériel parental, Physiographie, Maroc Central.

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الجغرفة الرقمية لرسم خرائط التربة : دراسة حالة منطقة خريبكَة ـ قصبة تادلة بالمغرب الأوسط

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ملخص

يتعلق هذا المقال بتطبيق تقنيات الخرائطية الرقمية في رسم خرائط التربة. حيث تم استعمال منهجية "e-Soter" في منطقة خريبكَة ـ قصبة تادلة، على مساحة 217000 هكتار. تم استعمال نظام معلوماتي جغرافي لدراسة التنوع الجغرافي لثلاثة مؤشرات تضاريس و مؤشر جيولوجيا، إضافة إلى بيانات حقلية موضعية، و ذلك لاستخلاص التوزيع الجغرافي للوحدات المجالية للتربة، حسب معايير منهجية "e-Soter". بعد ذلك، تمت دراسة فاعلية خريطة التربة التي تم ترسيمها، و ذلك عن طريق التنقيب الميداني و استعمال أربعة اختبارات إحصائية، حيث دلت هذه الاختبارات عن دلالة إحصائية كبيرة للمنهجية المستعملة. و بذلك تم تأكيد فاعلية منهجية "e-Soter" لرسم جرائط التربة في المنطقة المدروسة.

الكلمات المفتاحية: خرائط التربة الرقمية، "e-Soter"،جيولوجيا، مؤشرات التضاريس، وسط المغرب

Introduction

The Northeast-Southwest oriented Atlas Mountain chain splits Morocco into two major soil domains, making the Northwestern part of the country one with the most diversity of soil types in the Mediterranean basin. Meanwhile, it is estimated that soil maps covering at various scales do not exceed 30% of the country area (Badraoui. 2006). As soil information systems are key elements in agricultural policies, classical soil mapping methods become time and cost consuming compared to new Digital Soil Mapping (DSM) approaches. In fact, DSM offers considerable cost and time efficiency for soil information system development and can also lead to improved pedological understanding (Arrouays et al. 2020).

DSM methods gained increasing implementation and application in assessing and mapping the world's soil resource, with many published scientific approaches and case studies detailing the techniques applied in comparison to the conventional soil mapping and pedology (Kidd et al. 2020). DSM methods are increasingly used in soil type mapping in various world agro-ecological zones and for the assessment of the spatial variability of different soil physical and chemical parameters (Mello et al. 2021; Kamimia et al. 2021). In particular, the physical parameter of soil moisture is assessed through the integration of DSM techniques along with remote sensing data (Devenport et al. 2008; Crow et al. 2005). Moreover, the development of machine learning algorithms and applications offers innovative forms of DSM application in soil assessment, especially in pedometrics, where statistical models tend do understand spatial patterns and temporal evolution using training datasets (Padarian et al. 2020; McBratney et al., 2019).

One of the DSM approaches that are used in soil unit mapping is the e-Soter (Soil and Terrain) approach that was developed and validated in different world pedo-landscapes, including the Mediterranean basin (Bock et al. 2015; Van Engelen et al. 2012; Dobos et al. 2006.). The e-Soter framework aims the identification of areas with distinctive or repetitive patterns regarding landform, lithology, slope and parent material (Van Engelen. 2012). Its originality is the stronger emphasis that it puts on the terrain-soil relationship in comparison with what is commonly done in traditional soil mapping (Van Engelen. 2012). Particularly, the soil parent material is important in its relationship to soil units' delineation. The extend soil parent material information derived from legacy data enhances the spatial prediction of soil associations and their properties such as texture and cation exchange capacity (Schull et al. 2015). Overall, the spatial differentiation offered by the e-Soter approach is suitable to serve for soil mappers to generate conceptual soil maps in a faster and more consistent way (Bock et al. 2015). Nevertheless, being a terrain-oriented approach, e-Soter classification naturally overlooks some inner-soil pedogenesis processes such as decarbonation, clay neo-formation and organic matter redistribution, which requires more field observation in the case of complex pedo-landscapes (Otto Spaargaren, personal communication, February 23, 2012).

This study demonstrates the effectiveness of the e-Soter approach in delineating soil homogenous units in an agricultural semiarid area of Central Morocco. The soil units were delineated as detailed below and the derived soil map was validated through field prospection and statistical tests.

Materials and methods

Study area

The study area is a part of the Moroccan phosphate plateau, covering parts of the Khouribga and Beni Mellal provinces, on a total area of 217.000ha (Figure 1). It is bordered by the Tadla irrigated plaine to the South and the Mid-Atlas mounatins to the East. The geomorphology is that of the Boujaad-Oued Zem undulating environment, with dominant Southwest slope direction. The area is under semiarid climate, with low average annual precipitations (350mm), high temperature seasonality and important water deficit due to high evapotranspiration levels (1355mm/y).The undulating landscape is dissected by several minor water streams, walong with the Bouguerraf river on the West and Oum Errabiaa river on the East.

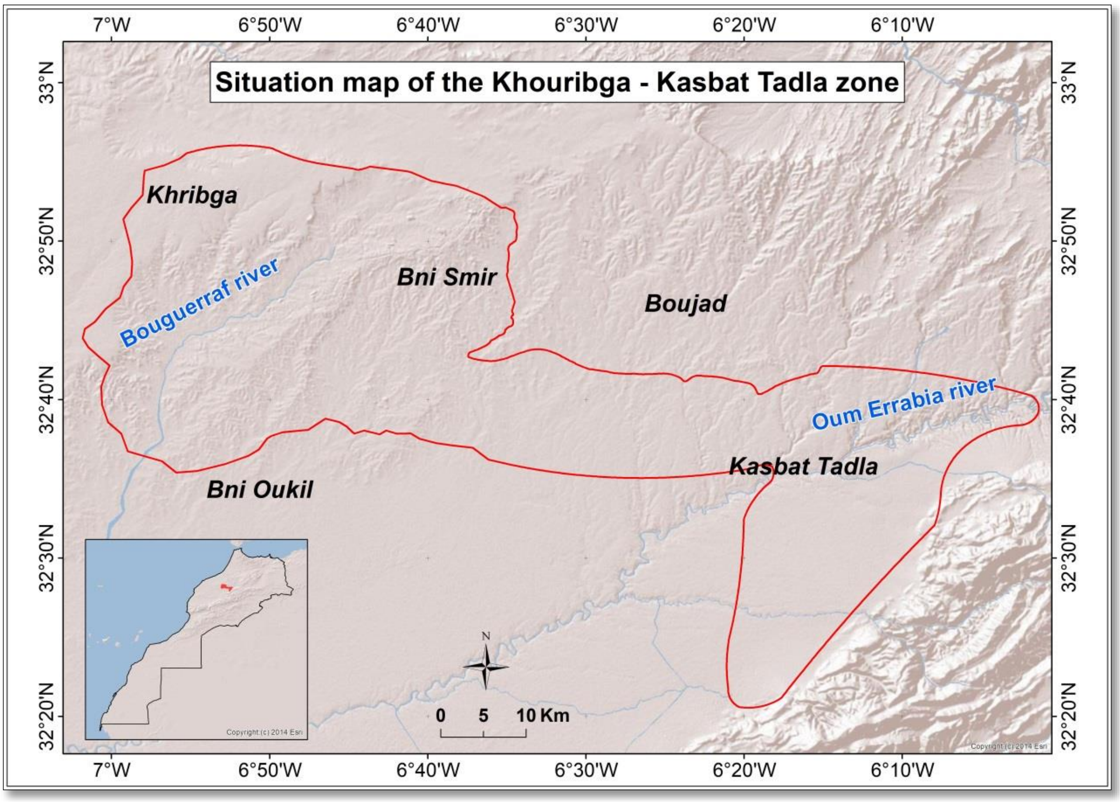

Figure 1: Situation map of the study area.

Methodology

The e-Soter DSM approach (Dobos et al. 2005, Van Engelen et al. 2012) was used for soil mapping at 1/100.000 scale, using geology and elevation data as inputs to derivate spatial homogenous soil units and soil profile data as ground truth for soil unit classification (Figure 2). A 1/100.000 scale geology map was used to derive parent material units and a 30m spatial resolution Digital Elevation Model (DEM) was used to derive physiographic units.

The e-Soter approache bases on the nature and the erosion/alteration level of the the parent material's bedrock. To do so, the 1/100.000 scale geological map was vectorized and the spatial units with same lithological attributes were joined and reclassified according to the e-Soter parent material hierarchy (Van Engelen et al. 2012).

The physiographic units express the landform effect on soil differentiation through three morphometric parameters: slope gradient, relief index and potential drainage density. The slope gradient map was derived from the DEM then reclassified into three classes representing three groups: (i) <15%: plains, depressions and valleys; (ii) 15-30%: dissected plains and medium escarpments; (iii) >30%: hills and high escarpments. The relief index represents the altitude variability within a surface unit, hence expressed in m/km^2. This parameter was derived using focal statistic algorithm, with 1km^2 as neighboring surface and standard deviation as computed statistic. The potential drainage density (PDD) represents the landscape dissection intensity by mapping accumulation zones presence within a reference area, generally represented by 10*10 pixels of the DEM. The spatial intersection of the raster layers representing the three morphometric parameters led to the delineation of the e-Soter physiographic units of the study area.

The e-Soter soil units were delineated by overlaying the parent material and physiographic units' layers. Field soil type data from 90 sites were then joined as point to polygon spatial link, to classify the soil units. The FAO World Reference Base for Soil Resources classification (FAO. 2006) was used.

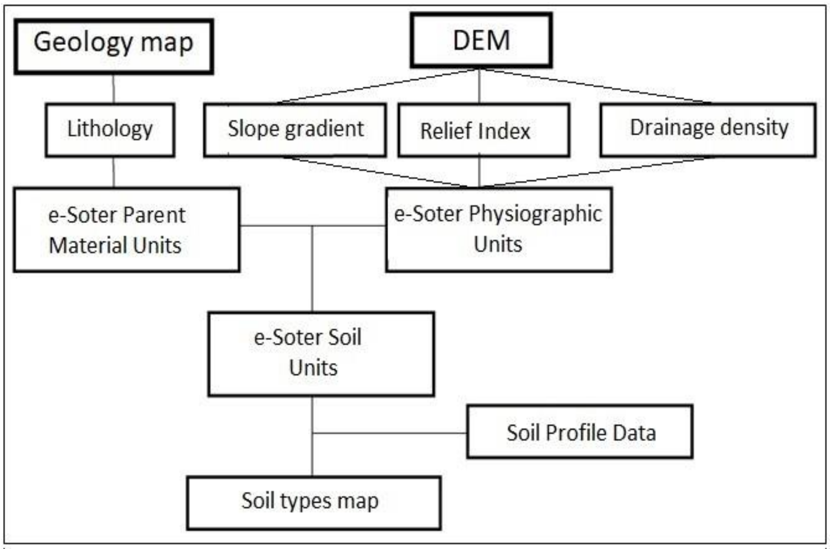

Figure 2: Methodology chart for e-Soter soil units mapping.

The produced soil map was validated through a field check campaign using transect approach and statistical significance testing of the resulted confusion matrix. Three statistical tests that are the most adapted to computed data/field data association data were used: Chi square, Cramér's V, Fisher's exact, along with the Kappa reliability test, using SAS software.

Results and discussion

Parent material units' delineation

The e-Soter hierarchy of lithology was applied to the geological map of the study area in order to delineate the parent material homogenous units (Figure 3). Considering the general environment of the Southern part of Central Morocco, particularly within the Moroccan Meseta, the lithology is dominated by alluvial and limy inputs. In fact, alluvia materials cover half of the study area, spreading in large parts in the East and Center, and along river banks in the West. Limestones cover 25% with a decreasing West-East gradient. The other parent material units are marls, siltstones (10% each), conglomerate (4%) and phosphate sediments (3%).

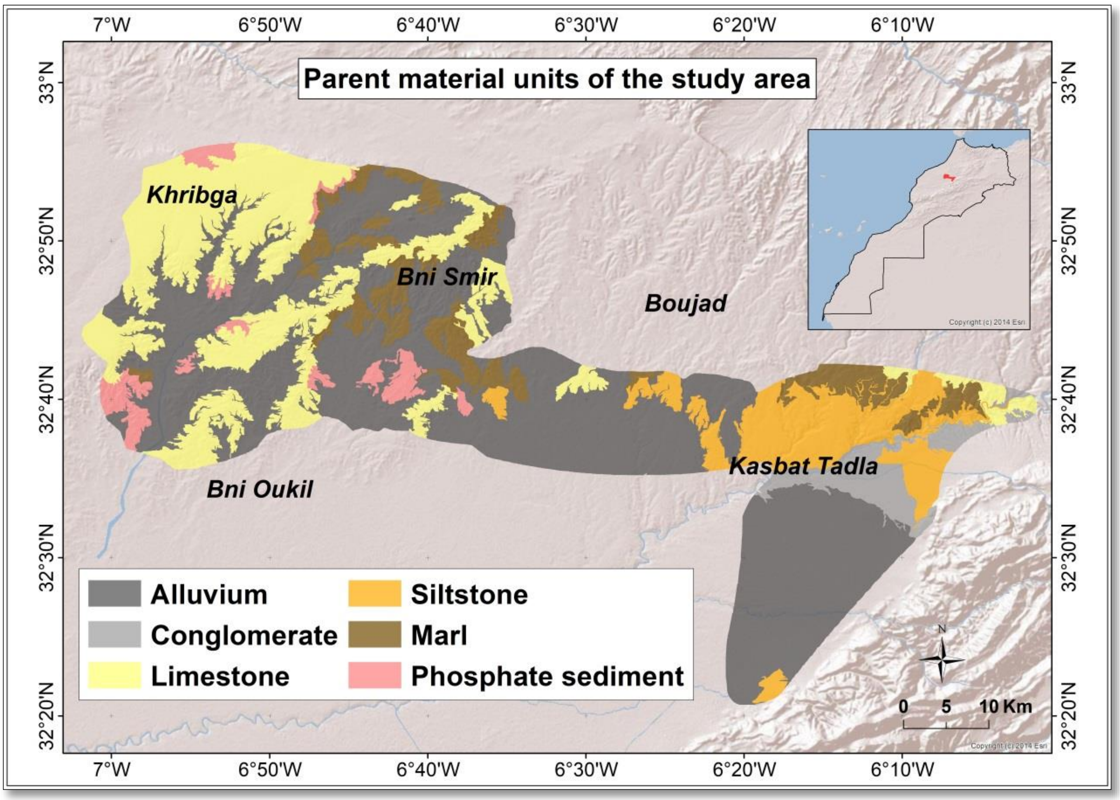

Figure 3: Parent material units' map of the study area.

Physiographic units' delineation

The slope gradient, relief index and potential drainage density (PDD) were mapped and classified according to the e-Soter standards (Van Engelen. 2012). The spatial variability (Figure 4) highlights the dominance of tabular and gently undulating environment, locally dissected by recent valleys' ongoing development, forming local depressions and undulating environment. The tabular relief dominance is confirmed by the three morphometric parameters. The slope gradient ranges from 0 to 35% and is at 98% below 10%, forming plains and plateaus. The dissected plains and medium escarpments (10% to 30% slope gradient), along with hills and high escarpments (+30% slope gradient) cover 1% each, the first one is sporadically spreading through the zone and the second forms streamline shaped units along the river banks. This spatial repartition is confirmed by the relief index, which while not reaching the first e-Soter classification threshold of 50m/km², represents a similar spatial pattern to that of the slope gradient. The highest relief index intensities are around 48m/km² and form thin shaped areas around the river banks. Concerning the PDD, the overall spatial pattern shows a concentration of high accumulation zones (+15) in the extreme East and the West of the study zone, forming wide clusters that cover 12%. The dominant e-Soter PDD class remains the first one (<10) at 82%. The resulted physiography spatial variability shows the dominance of low slopped valleys (86%), which goes in parallel with the alluvium parent material dominance. Plateaus unit comes second covering 13%, following the particular pattern of the high PDD intensity spatial distribution. They are associated to all the parent material units. Finally, the medium escarpments and dissected plains cover 1% of the zone, confirming its general geomorphology.

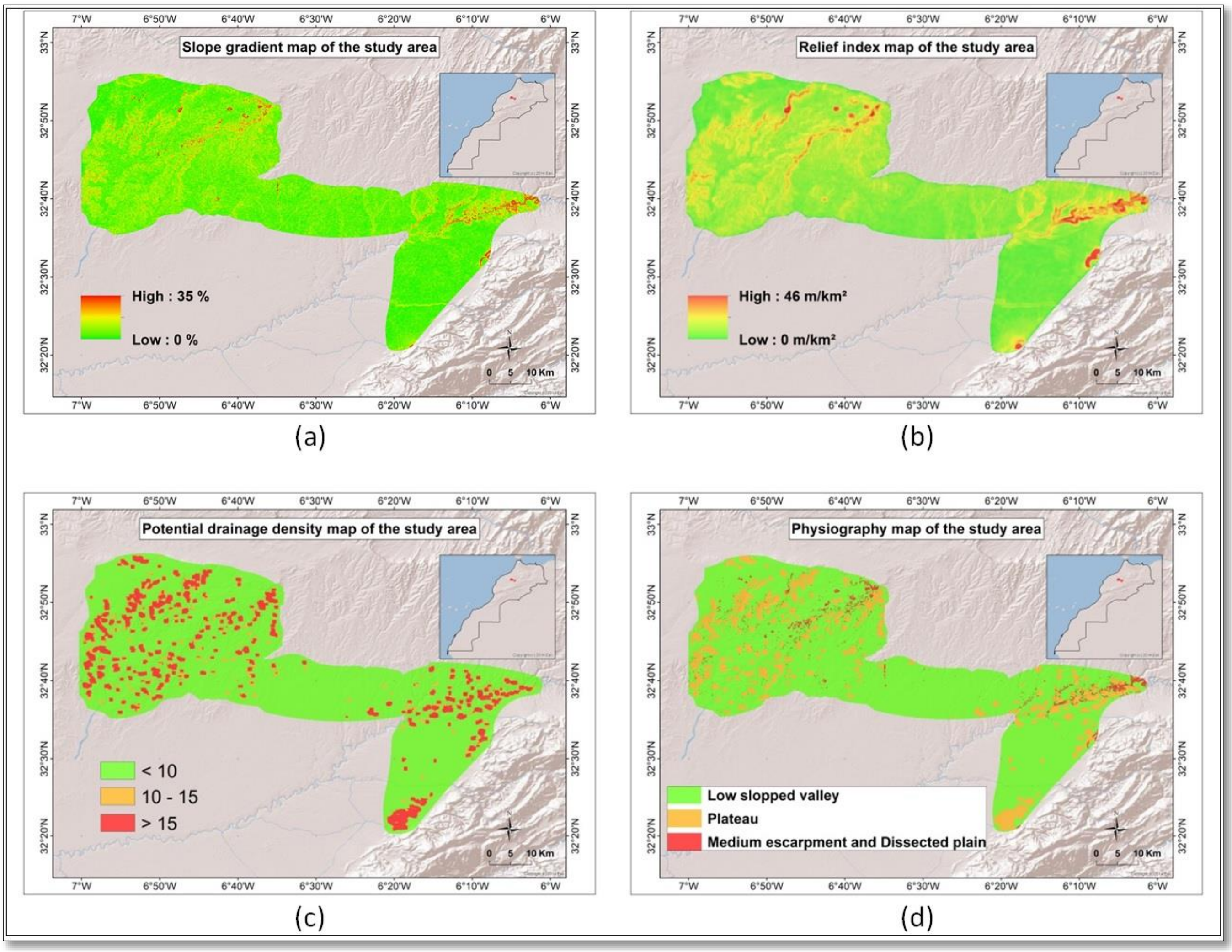

Figure 4: Maps of slope gradient (a), relief index (b), PDD (c) and physiographic units (d) of the study zone

Soil units' delineation

The soil map of the study zone was elaborated using an overlay of the parent material and physiography layers with a field data point layer with soil type attributes of 90 evenly distributed sites. Six Reference Soil Groups (RSGs) were identified in the field and mapped using a spatial join under GIS. The dominant RSGs are Regosols (40%) and Calcaric Chernozems (27%), this comes in compliance with the dominant alluvial and limy geology of the zone. Lithosols come third, covering 19% and corresponding mainly to the undeveloped limestone outcrops of the Western part of the zone. The limestone parent material led to the development of the Rendzinas RSG (6%) in more favorable biological conditions, while mature alluvia and limy environments of the study area lead to the development of Kastanozems (4%) and Rendzinas (3%) RSGs.

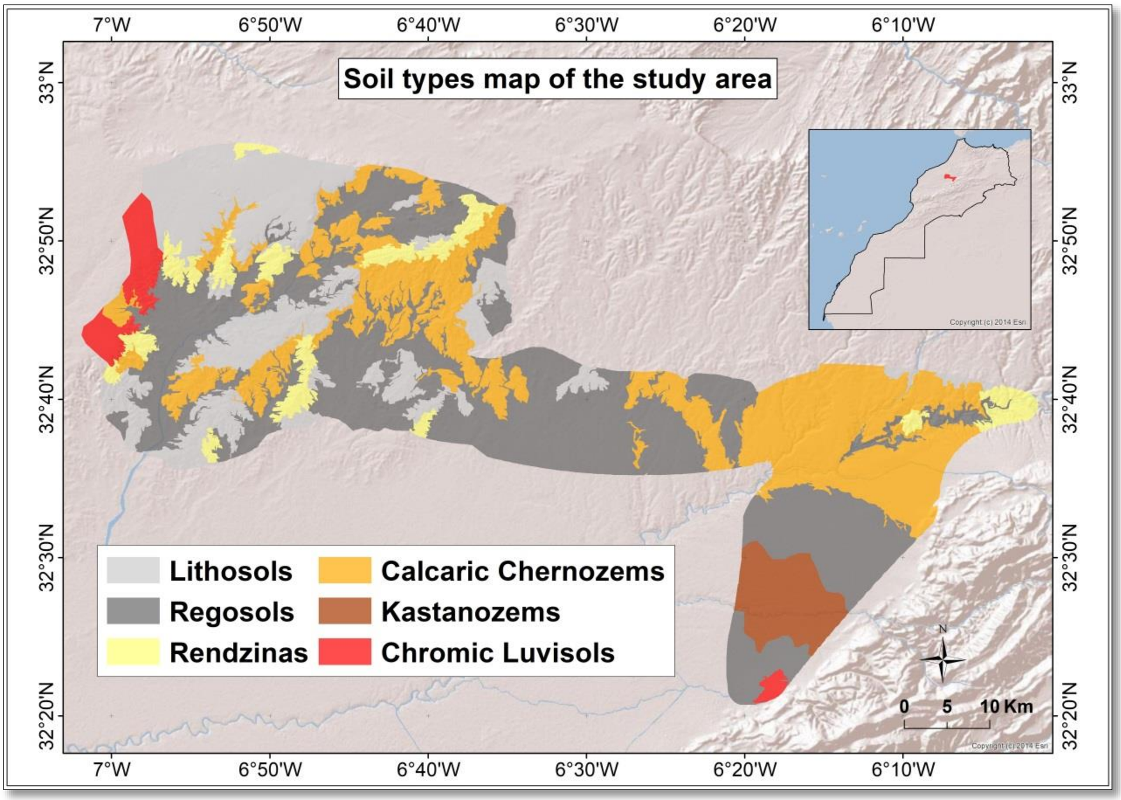

Figure 5: Soil map of the study area.

Validation of the soil map

The derived e-Soter soil map was validated in the field using the transect approach. Three transects defined 14 field check sites that were chosen such as to cross all the mapped RSGs, while remaining the furthest possible from the sites that were part of the map elaboration. The computed data vs. field data association was assessed through a confusion matrix (Table 1), along with three statistical significance tests (Chi square, Cramér's V, Fisher's exact) and Kappa reliability test.

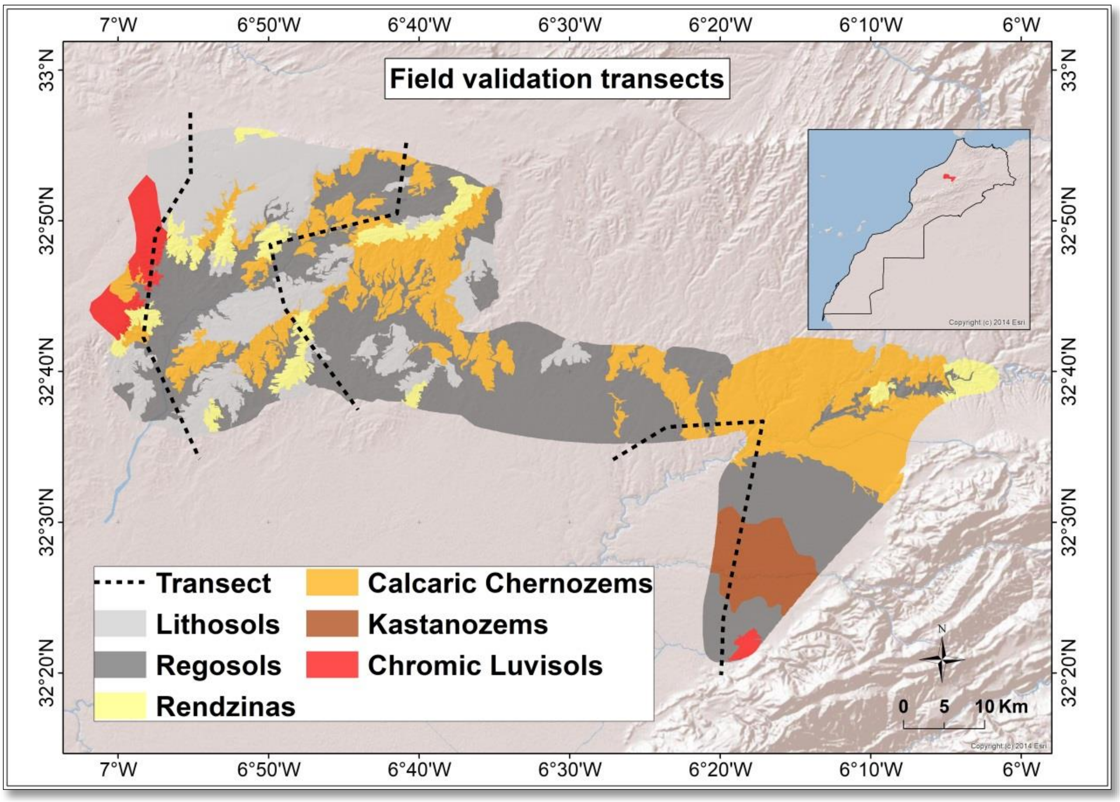

Figure 6: Field validation transects

Table 1: Confusion matrix in frequency (red) and percent (blue).

	Calcaric Chernozem	Chromic Luvisol	Kastanozem	Regosol	Lithosols	Rendzina	Total
Calcaric Chernozem	3 21,43	0 0	0 0	0 0	0 0	1 7,14	4 28,54
Chromic Luvisol	0 0	3 21,43	0 0	0 0	0 0	0 0	3 21,43
Kastanozem	0 0	0 0	1 7,14	1 7,14	0 0	0 0	2 14,29
Regosols	0 0	0 0	0 0	2 14,28	0 0	0 0	2 14,28
Lithosols	0 0	0 0	0 0	0 0	1 7,14	0 0	1 7,14
Rendzina	0 0	0 0	0 0	0 0	0 0	2 14,28	2 14,28
Total	3 21,43	3 21,43	1 7,14	3 21,43	1 7,14	3 21,43	14 100

The table 1 shows that 12 out of the 14 field observation matched with computed classification. The two misclassified sites concern RSGs that share some fundamental characteristics in common. The first one is a Calcaric Chernozems that was mapped as Rendzina, the two RSGs sharing limestone as parent material; and the second was Kastanozem that was mapped as Regosol, this is due to Regosols being the developing form of most of the other RSGs of the WRBSR classification.

Concerning the statistical significance, the Chi-square test showed a probability of 0.39 (<5%), rejecting the independence hypothesis and thus confirming the association between the mapped and observed data. This was confirmed by the Cramér's V test that showed an association intensity of 0.93 and the Fisher's exact test that resulted to a probability of $2.51*10^{-4}$. Finally, the Kappa reliability index was below 0.05, which indicates the mapped and observed data high association.

Conclusions

The e-Soter DSM approach for soil mapping was applied at 1/100.000 scale for a semiarid area of the Central Morocco. The soil genesis parameters (parent material and physiography) were mapped on GIS as derived layers from a DEM and a georeferenced geologic map. The e-Soter homogenous soil units' layer was overlaid to a point layer with field data attributes to delineate the soil map of the study zone. The map was validated through a field transect and statistical tests that confirmed the significant accordance in soil type determination between the digital delineation using the e-Soter approach and the field observation.

This study case showed the effectiveness of e-Soter DSM approach for soil unit mapping at medium scale, especially in semi-arid areas where the landform is the determinant pedogenesis factor. Time and cost saving soil mapping processes are benefic in developing and updating soil information systems that provide relevant elements for medium scale development programs such as agricultural policies, environmental conservation and adaptation to climate change.

Acknowledgment

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