ICARDA

FROM POLYGON-BASED SOIL UNIT MAPPING TO PROBABILISTIC MAPS OF SOIL PROPERTIES IN THE WEST ASIA-NORTH AFRICA REGION

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Presentation overview

- Soils of the region, potential and constraints for agriculture, and status of soil resource information in West Asia-North Africa
- From polygon-based to probabilistic mapping: a case study in NW Syria
- A way forward

Introduction:
West Asia-North Africa region

- a contiguous **dryland** area of approximately 7 million km^2 containing 20 countries (*)
- surprising diversity in agroecologies and farming systems due to multitude of landforms, climates, soil types and farming systems
- a sizable rural population despite its limited agricultural resources
- affected by major degradation of its land and water resources in its recent past (esp. land, water, vegetation)
- particularly vulnerable to the threat of climate change

(*) Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Occupied Palestinian Territories, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Yemen

Introduction

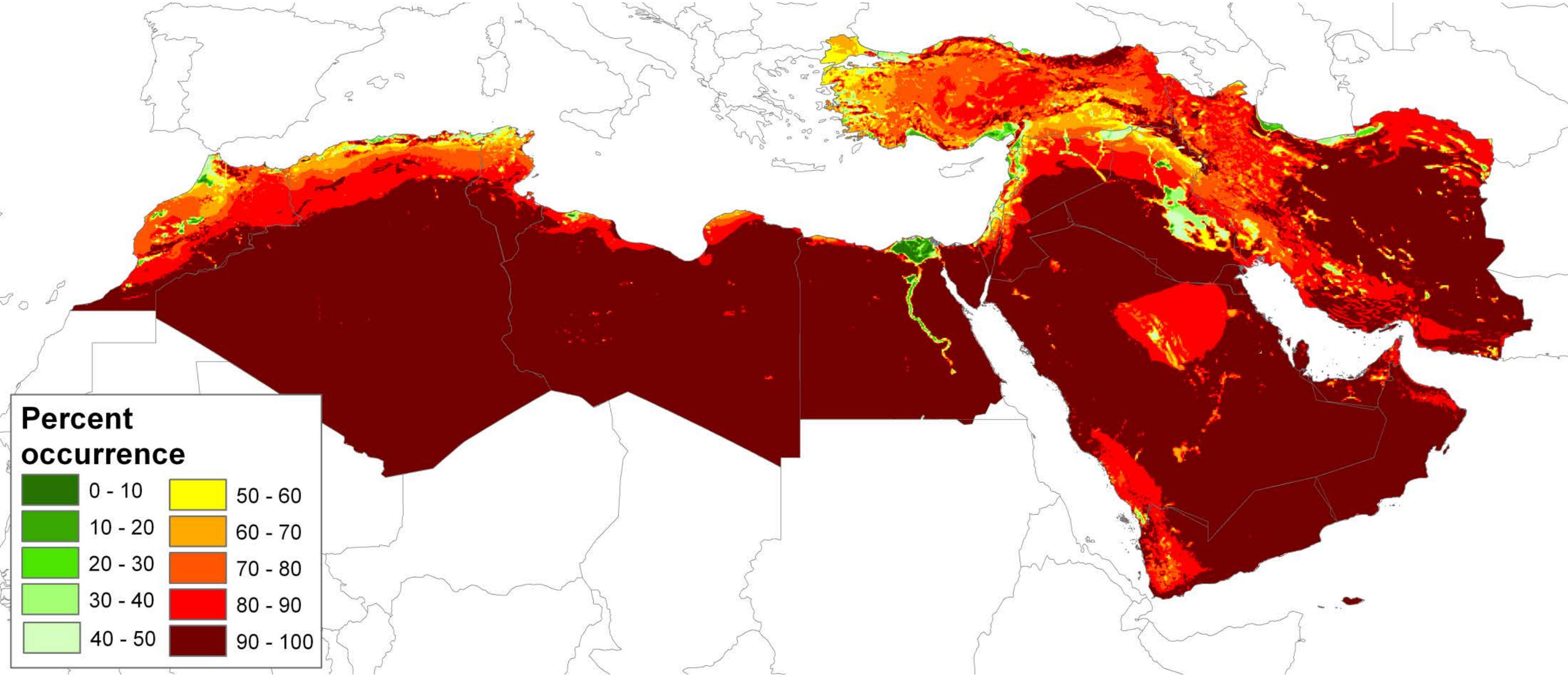
Countries, land and pop stats

Country	Rural Pop (x1000)	Share of total pop.(%)	Land Area (sq.km)	Water Area	Ratio W/L (%)
Algeria	11,868	34	2,381,741	0	
Bahrain	92	11	760	0	
Egypt	48,320	57	995,450	6,000	
Iran	22,900	31	116,600	7	0.0
Iraq	10,575	34	437,367	950	0.2
Israel	603	8	20,330	440	2.2
Jordan	1,390	21	88,802	540	0.6
Kuwait	49	2	17,818	0	0.0
Lebanon	543	13	10,230	170	1.7
Libya	1,447	22	1,759,540	0	0.0
Morocco	14,007	43	446,300	250	0.1
Occupied Palestinian Territories	1,232	28	6,000	220	3.7
Oman	822	28	309,500	0	0.0
Qatar	63	4	11,586	0	0.0
Saudi Arabia	4,705	18	2,149,690	0	0.0
Syria	10,160	45	183,630	1,550	0.8
Tunisia	3,394	33	155,360	8,250	5.3
Turkey	22,977	30	769,632	13,930	1.8
United Arab Emirates	1,033	22	83,600	0	0.0
Yemen	16,542	68	527,968	0	0.0
Total	172,722		7,093,953	26,307	0.4
Weighted total		43			

FAO Statistics Handbook 2010
Wikipedia : http://en.wikipedi

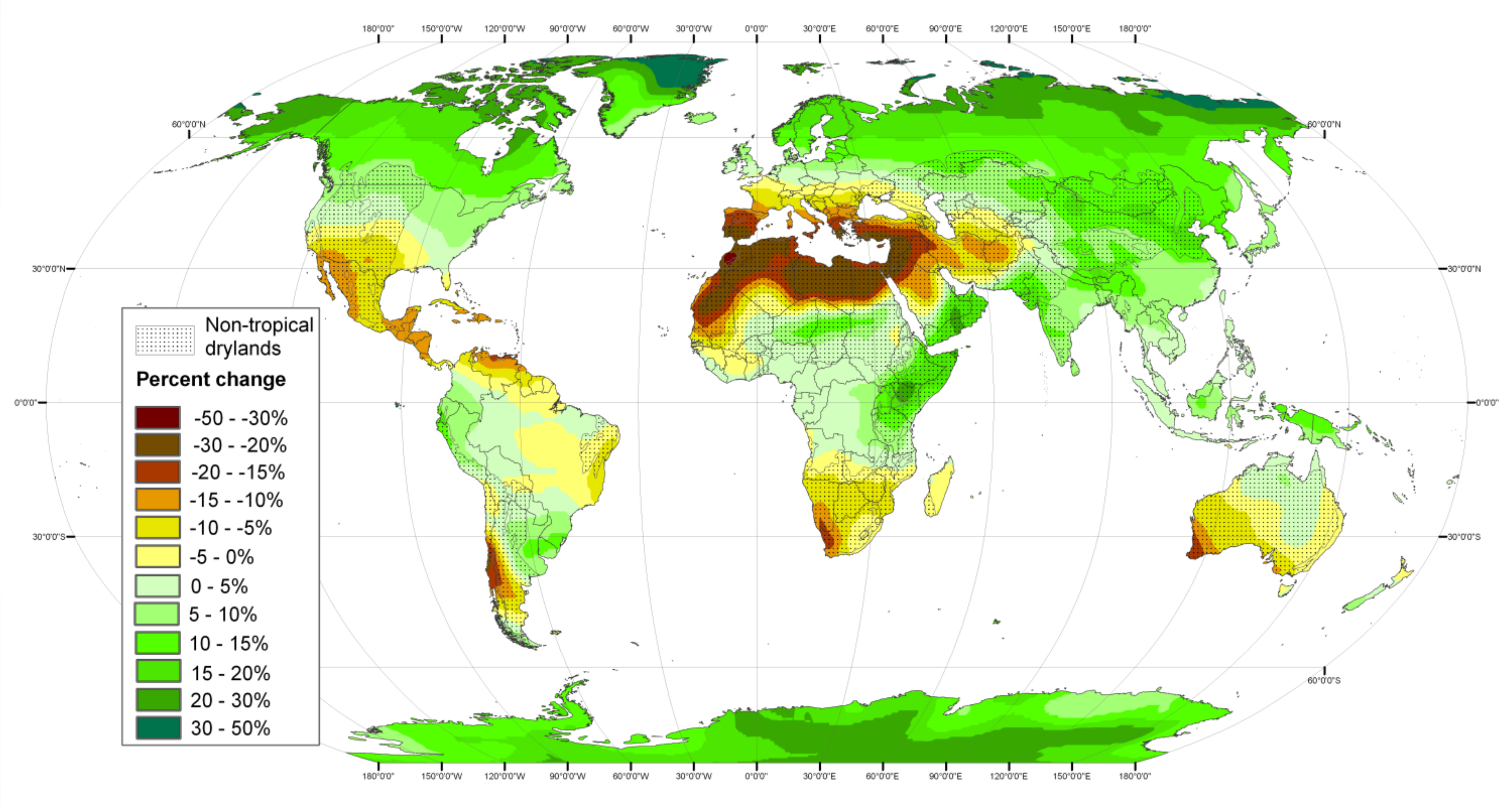
Agricultural resource poverty

- a structural component of environmental



More info:
http://crp11.icarda.cgiar.org/crp/public/map/details/MapID/80

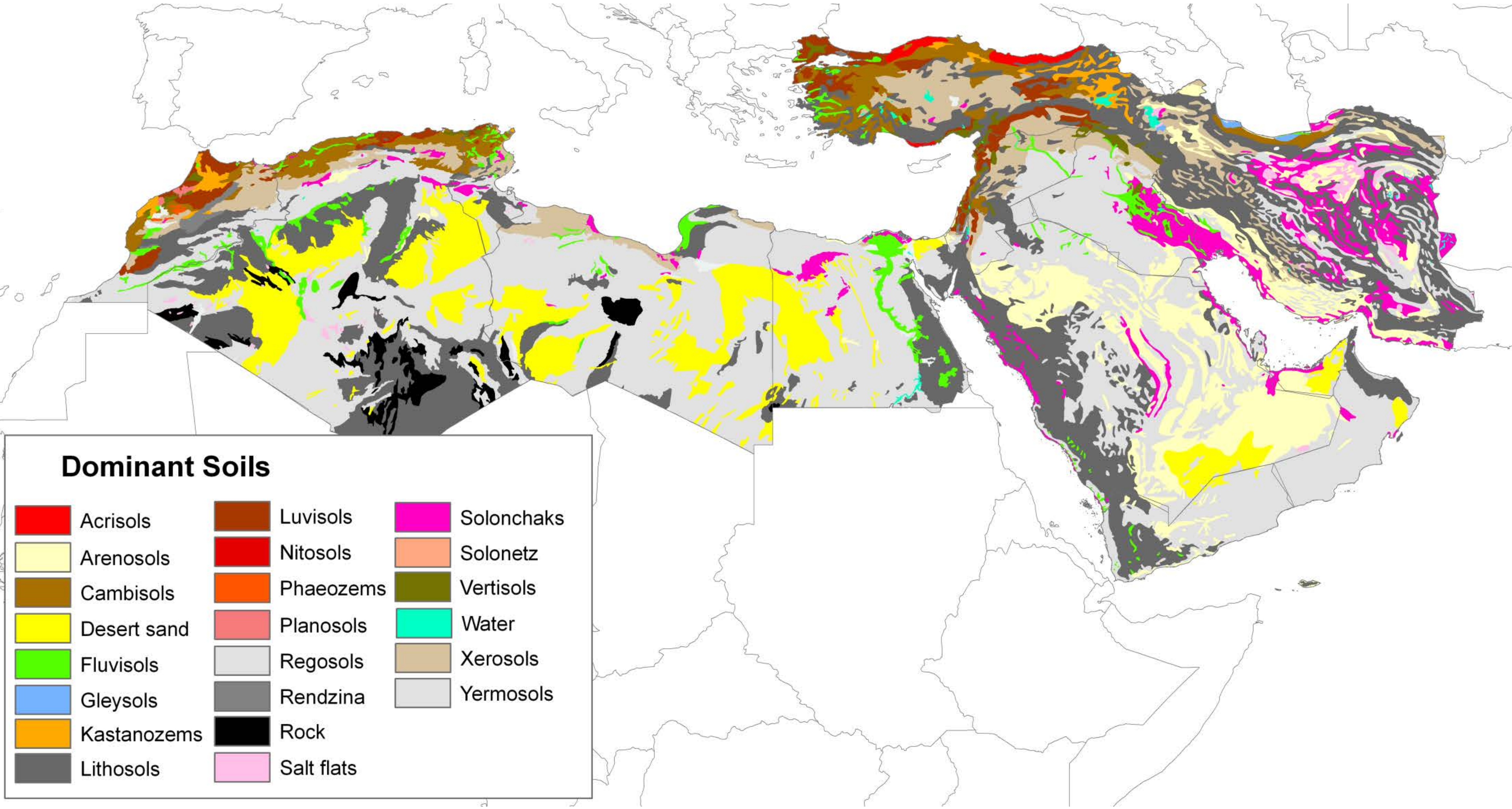
Introduction:
Vulnerability to climate change



Relative change of mean annual precipitation 1980/1999 to 2080/2099, scenario A1b, average of 21 GCMs (compiled by GIS Unit ICARDA, based on partial maps in Christensen et al., 2007)

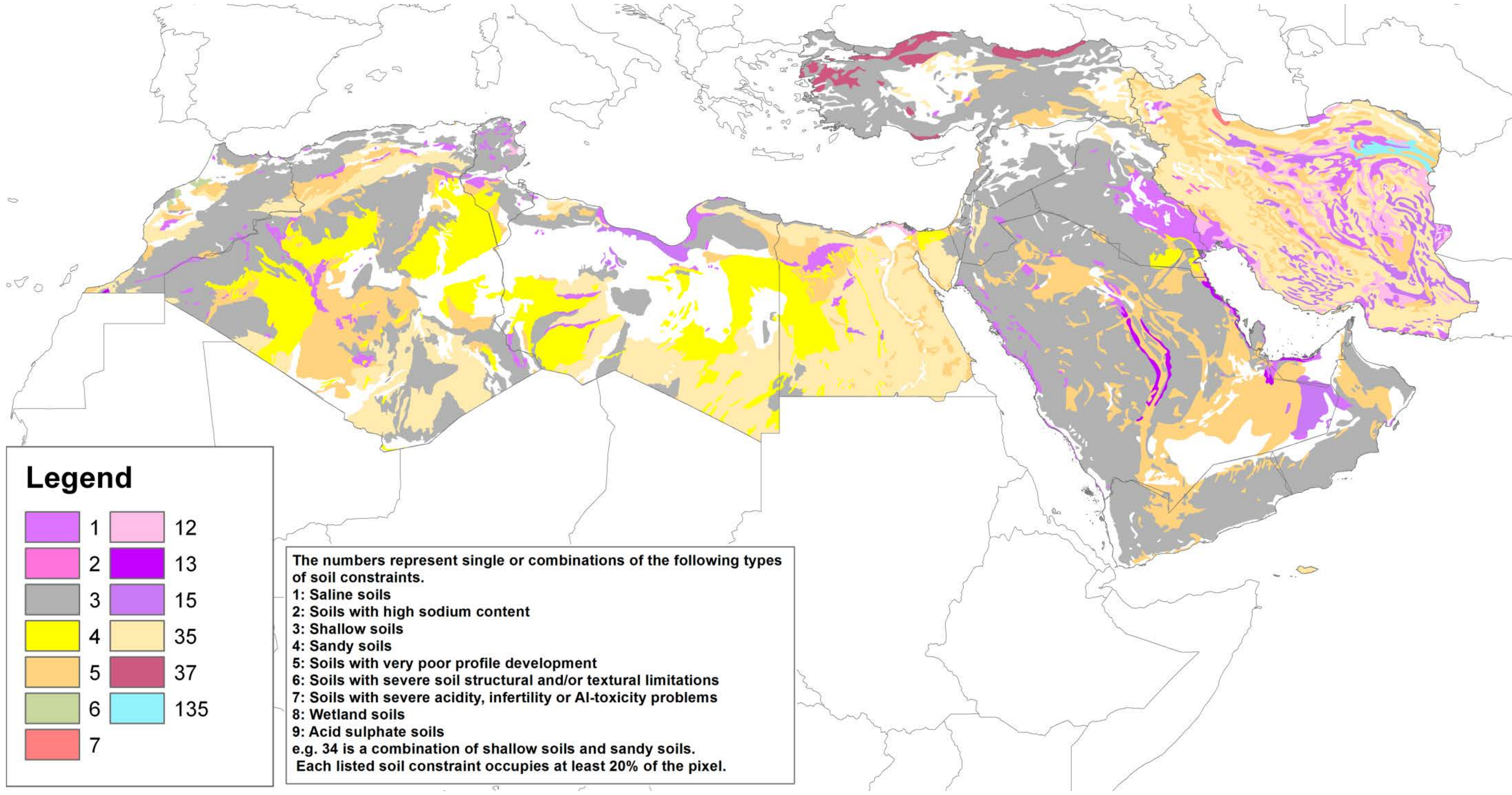
Introduction

Regional soil features: dominant soils



Introduction

Regional soil features: major soil problems



Status of soil resource information in West Asia -North Africa

- **A lot more available than inspired by conventional wisdom**

BUT

- Major differences in geographical scope, quality and scale (from 1:25,000 to 1:1,000,000 for country maps)
- Some of the information may be out of date
  - due to changes in state of degradation (e.g. salinization in irrigated areas, wind and water erosion, changes in flooding patterns)
  - major land improvements (e.g. terracing, de-rocking, new irrigation infrastructure)
  - urban encroachment
- Different classification systems
  - Soil Taxonomy, French classification, FAO, Russian classification, local systems
- **A MAJOR PROBLEM: Accessibility**
  - varies greatly between countries
  - access can be restricted to either maps, profile data or both

From polygon-based to probabilistic mapping

The issues (1)

- ‘Soil association-in-polygon’ data model is suitable for small-scale large-area assessments
- It can also be applied at many scales
  - on condition that every polygon is characterized by a different composition matrix that is optimal for each polygon
- This is usually not the case:
  - most studies using this model work with standardized soil bodies (classification units) in which the range of variability of individual properties is standardized or ignored
  - somehow the proportions of soil bodies in the composition matrix remain the same irrespective of the geographical location
  - this diminishes the reliability of the map and its power to be combined with other data sources

From polygon-based to probabilistic mapping

The issues (2)

- A new data model would be useful that expresses a **probability of occurrence of soil properties** rather than soil bodies based on the relative contributions of individual soil forming factors (the parent material, climate, topography, land use etc.) => <u>‘hot spot approach’</u>
- To avoid some mistakes of the past (studies looking for an application) it is recommended that focus should be on the development problems that could benefit from a soil-oriented solution
- A case study to illustrate the approach:
  - **Suitability for de-rocking in NW Syria**

About de-rocking in Syria

- 'De-rocking'
  - land development involving reclamation of rocky areas by removal of surface and subsurface rocks and stones through heavy equipment
  - Rock types: limestones, basalts
- Purpose
  - To create new agricultural land in areas where shallow soils and excessive rockiness are the key constraint
- Pro/con
  - 500,000 ha de-rocked since 1970s, often with external funding (IFAD, UNDP, GTZ)
  - Successful strategy in rural areas with severe land shortage and poor farmers
  - BUT with possible environmental implications

De-rocking process
(as used in IFAD* projects in Syria)

(3) raking rocks of over 30 cm diameter from the field, piling up the rocks at the field edges and leveling the field surface using a front-mounted toothed rake blade

(2) ripping to a depth of usually 90 cm to bring rocks to the surface, normally using a three-shanked ripper mounted on the rear of the bulldozer

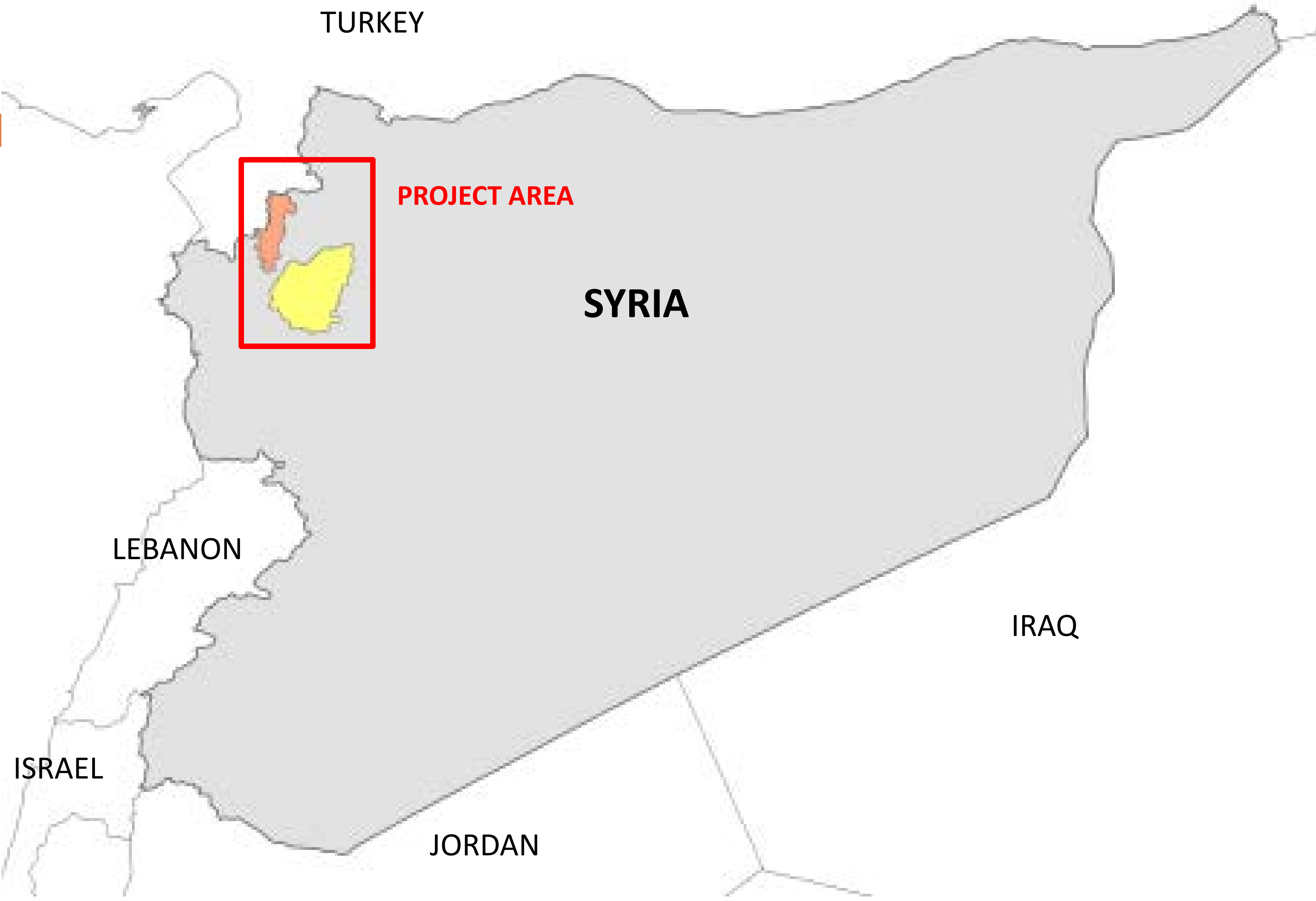
(1) initial clearing of the surface rocks using a front-mounted bulldozer blade

* International Fund for Agricultural Development

Outcome after de-rocking

After de-rocking, although still rough and stone-covered, fields can be planted to various crops

With time, manual stone removal and ploughing create an even seedbed



TURKEY
PROJECT AREA
SYRIA
LEBANON
IRAQ
ISRAEL
JORDAN

The hilly part of Jebel Zawia

The flatter part of Jebel Zawia. Hard nummulithic limestones in the foreground. A plain landscape does not automatically come with agricultural soils

The Rouge Valley in the foreground with intensive agriculture, Jebel Wastani in the background

Farming systems and poverty

- High population density
- Dominance of small holdings (on average 3.06 ha per family), small plot sizes, narrow fields, steep slopes and shallow soils
- Majority of the land under tree crops, especially olives
- Favourable climate: no serious precipitation or temperature constraints
- Shortage of land with adequate soils for agricultural use

→low per-capita income from agriculture and high reliance on off-farm income

• Area identified as one of the main rural poverty hotspots in Syria
• Priority area for agricultural development in conjunction with improvement of livelihoods

Soil is the key to improving agricultural productivity and farm income

From polygon-based to probabilistic mapping

Development issues related to de-rocking

- Avoiding undesirable environmental impacts of de-rocking
  - reduction in the diversity of the natural vegetation and land races of common food crops,
  - Disturbance of archaeological, historical and cultural sites by heavy earth-moving equipment
  - erosion

- Targeting de-rocking to suitable areas:
  - To avoid excessive wear-and-tear
  - To avoid too low soil yield

From polygon-based to probabilistic mapping

Addressing these development issues by a two-stage approach

- Stage 1: Avoiding undesirable environmental impacts of de-rocking
  - rapid screening **using GIS and Remote Sensing** for the identification of areas that are definitely unsuitable => **mapping 'unsuitability'**
- Stage 2: Targeting de-rocking to suitable areas
  - actual suitability mapping, confined to the areas that could not be excluded on the basis of the criteria used during the first mapping phase
  - Involving detailed and targeted soil characterization and Bayesian methods for probabilistic outscaling => **mapping suitability for de-rocking**

From polygon-based to probabilistic mapping

Phase 1 (Mapping Unsuitability): Materials and methods

- Compilation of secondary data (climate, terrain, geology, land use, farming systems)
- Analysis of geological maps => map of lithological groups
- Exploratory soil assessment
- New base map at 1:50,000 scale
- New land use/land cover map for Idleb Governorate
- Integration in GIS of factors and their thresholds that affect ‘unsuitability’

From polygon-based to probabilistic mapping

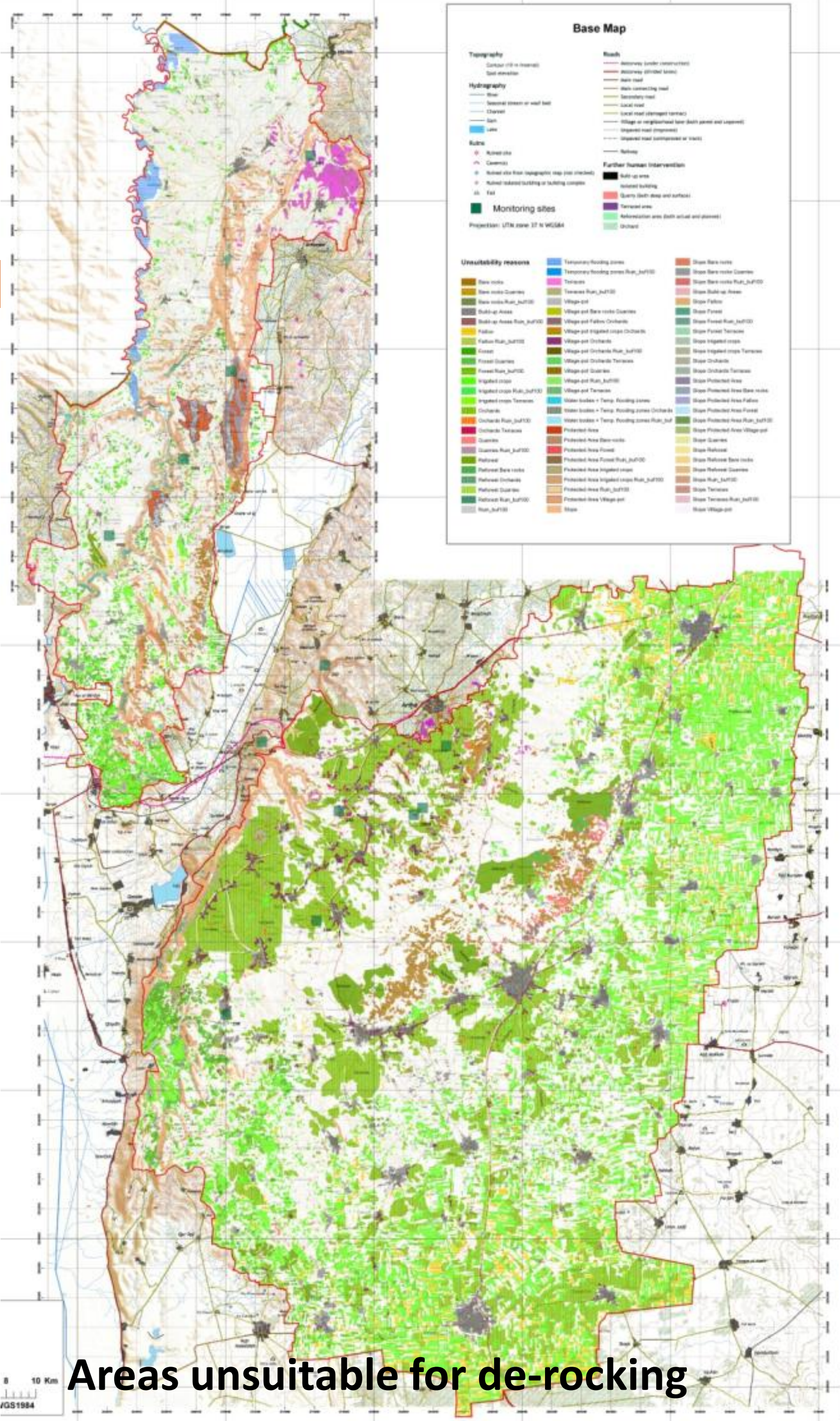
Phase 1 (Mapping Unsuitability): Criteria for ‘unsuitability’

- Too many rocks: land cover is ‘bare rocks’
- Too steep slopes: > 25%
- Presence of quarries
- Presence of historical ruins within a 100 m buffer zone
- Built-up areas and villages
- Already under crops (fallow, irrigated crops, orchards, terraces)
- Forest cover
- Potential to serve as conservation area

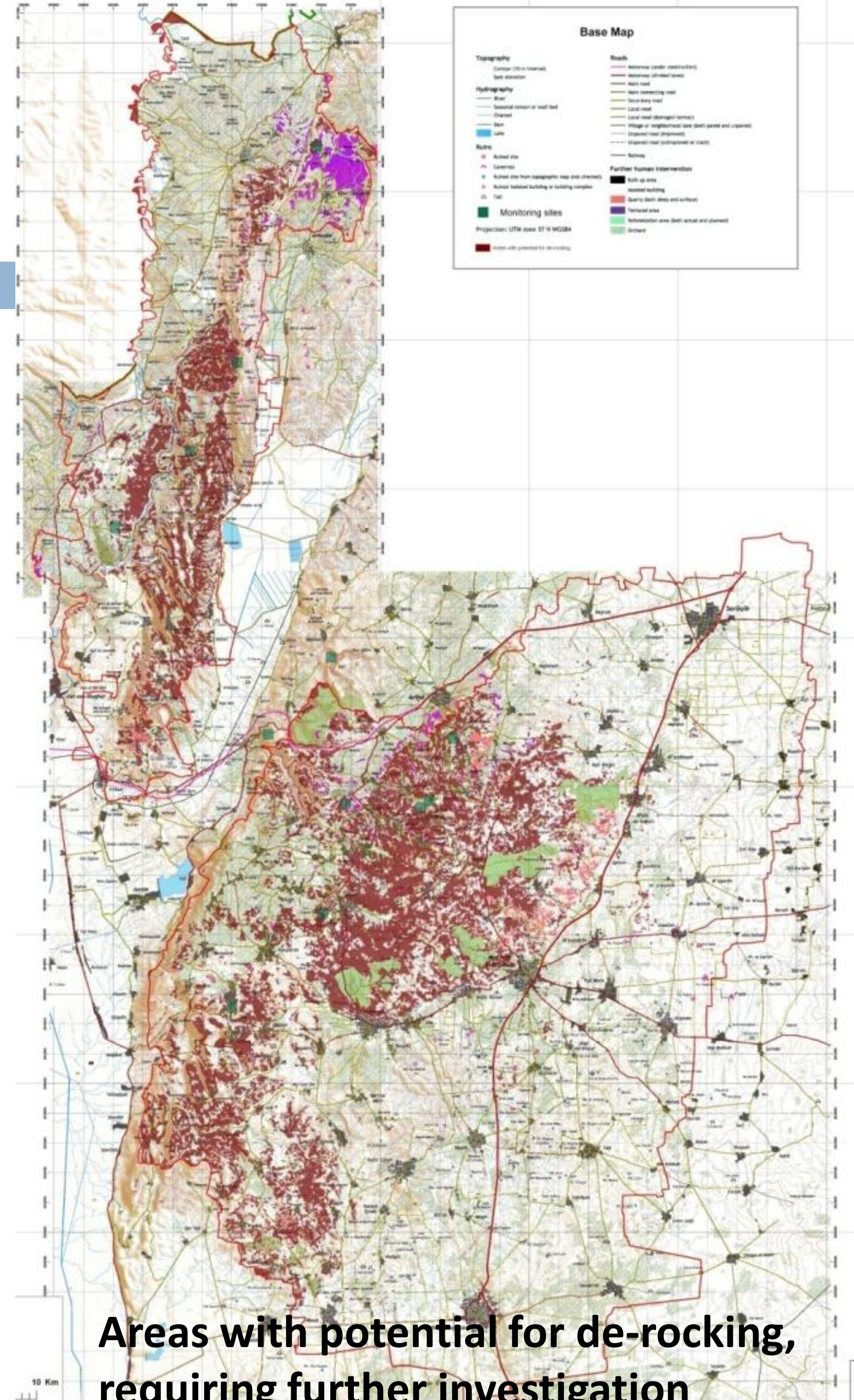
From polygon-based to probabilistic mapping

Phase 1 (Mapping Unsuitability): Summary of results

- From the land use perspective, the only remaining land resources for creating new agricultural land through de-rocking are the **rangelands**, covering 19.2% of the study area, more in Jebel Wastani (26.4%) and less in Jebel Zawia (16.9%).
- Within the rangelands another 28% is unsuitable for de-rocking due to additional constraints, mainly related to slopes exceeding 25% (16% of the rangelands), reforestation areas (6.6%), and proposed conservation areas (2.5%)
- On the basis of the criteria used, in total **85%** of the project area could be excluded as **unsuitable for de-rocking**, and **only 15% may have a potential for de-rocking, requiring further investigations**



Areas unsuitable for de-rocking



Areas with potential for de-rocking, requiring further investigation

From polygon-based to probabilistic mapping

Phase 2 (Mapping Suitability): Overview

Limited soil survey

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Compilation of ‘evidence’ layers

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Probabilistic maps of soil depth and rockiness

⇩

User-defined thresholds for suitability

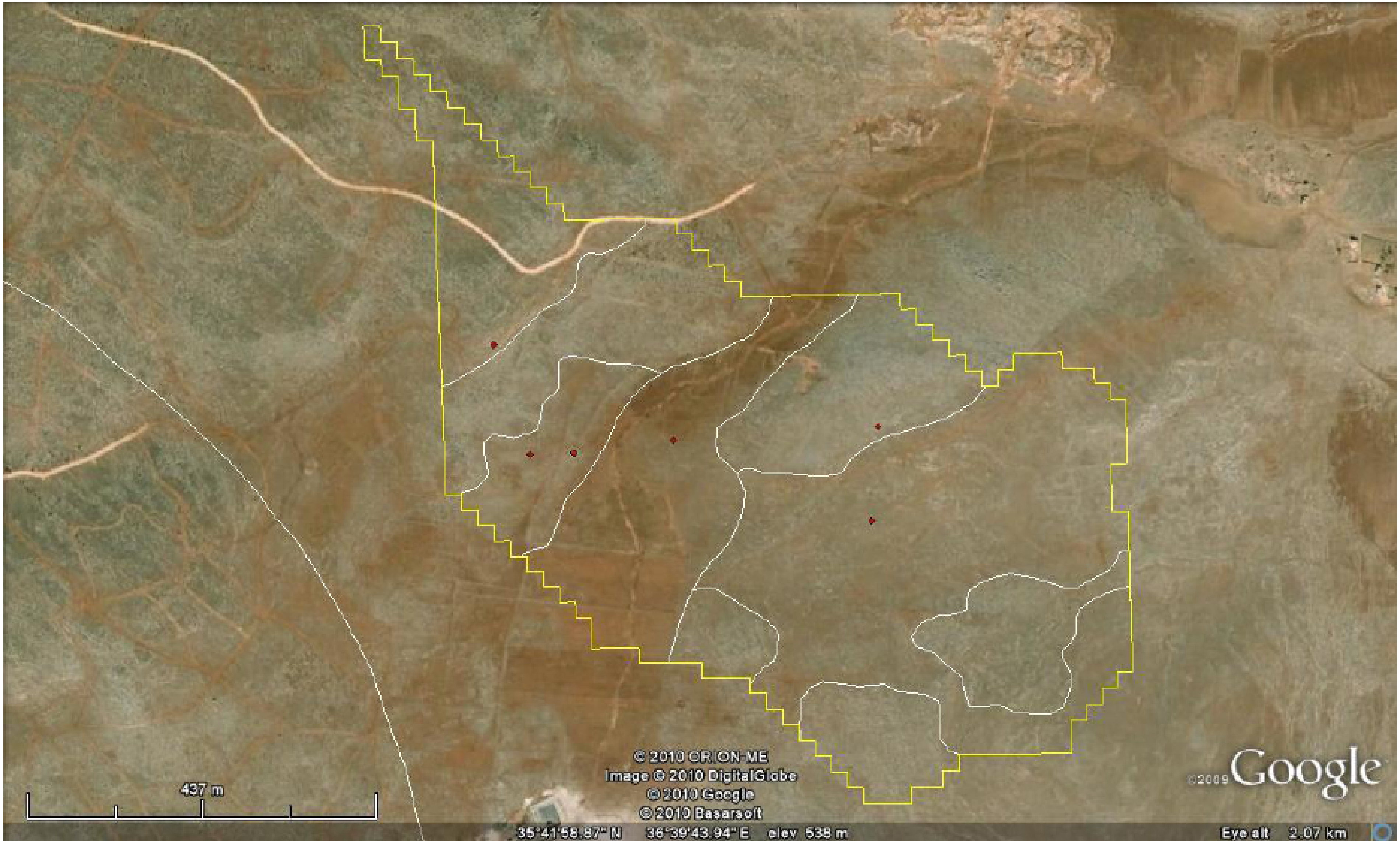
⇩

Suitability maps for de-rocking

Phase 2 (Mapping suitability): : Limited soil survey
1. General approach

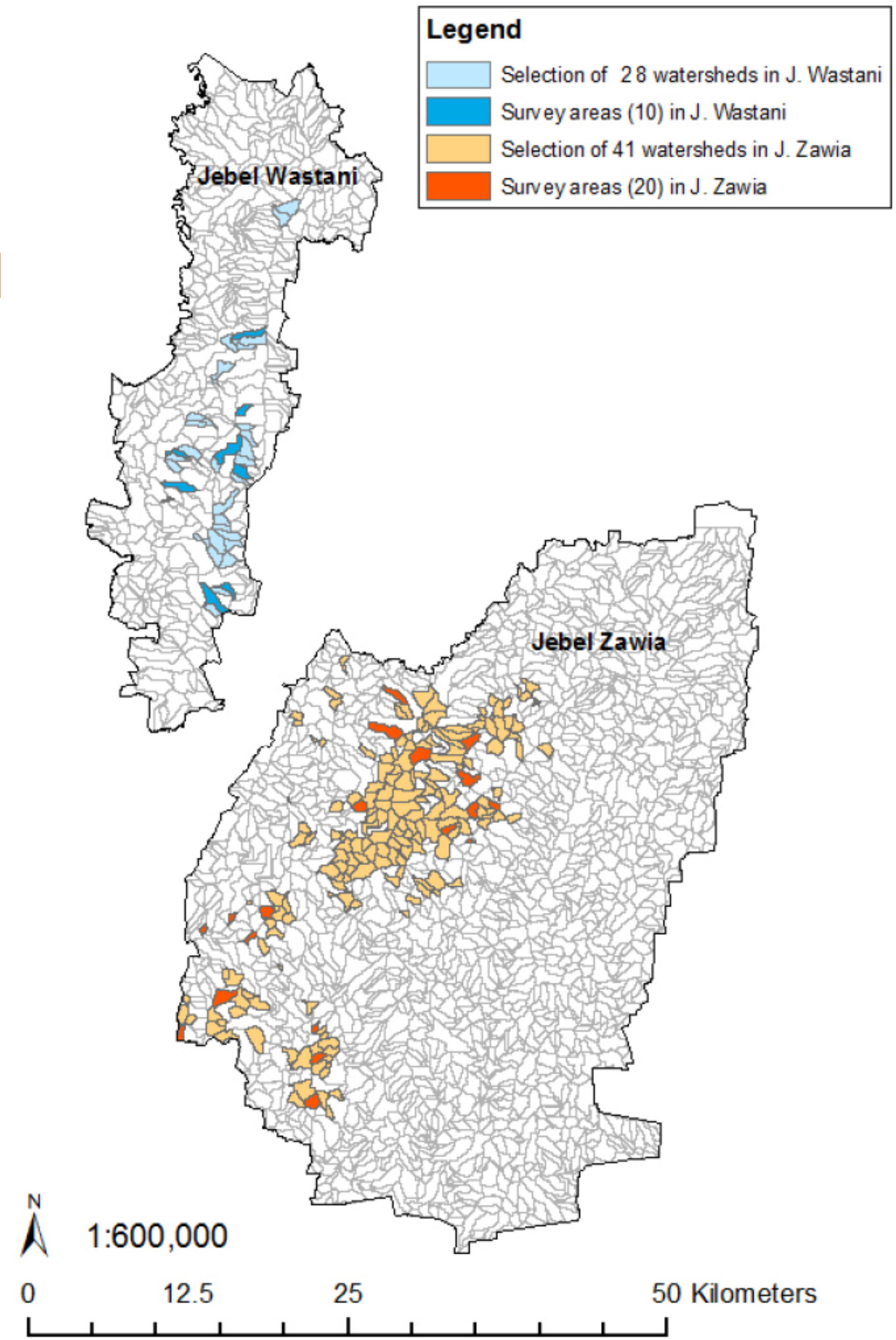
- Objective:
  - Good understanding of patterns of soil depth and rockiness by focusing on a limited number of representative watersheds
- Watershed chosen as the basic unit for locating <u>transect walks</u>
- All soil observations along transect walks

Limited soil survey
2. Selection of watersheds



Limited soil survey
3. Field observations

- 34 transect walks along major terrain gradients and lithological materials
- On average 7 observation points per transect
- Auger observations focusing on:
  - Soil depth
  - Texture
  - Color
  - Rock percentage at the surface
  - Rock type + hardness class
- Soil property maps for each selected watershed based on the combinations of above 5 properties

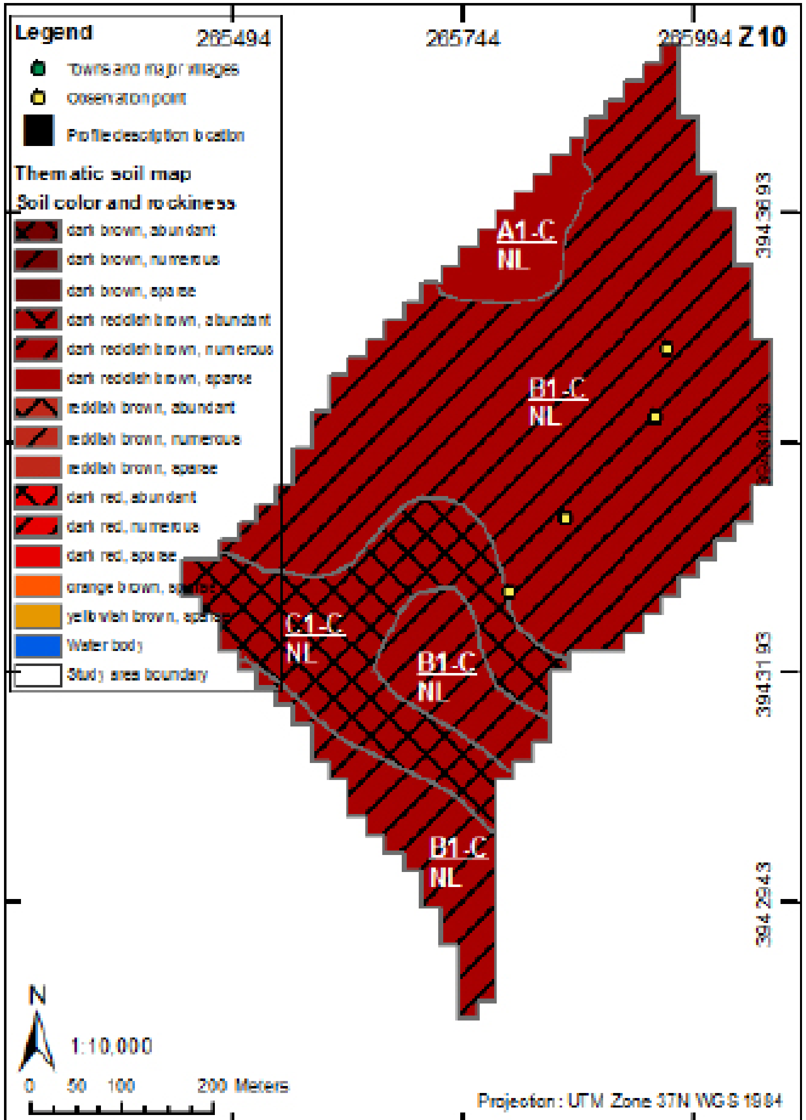


Results limited soil survey

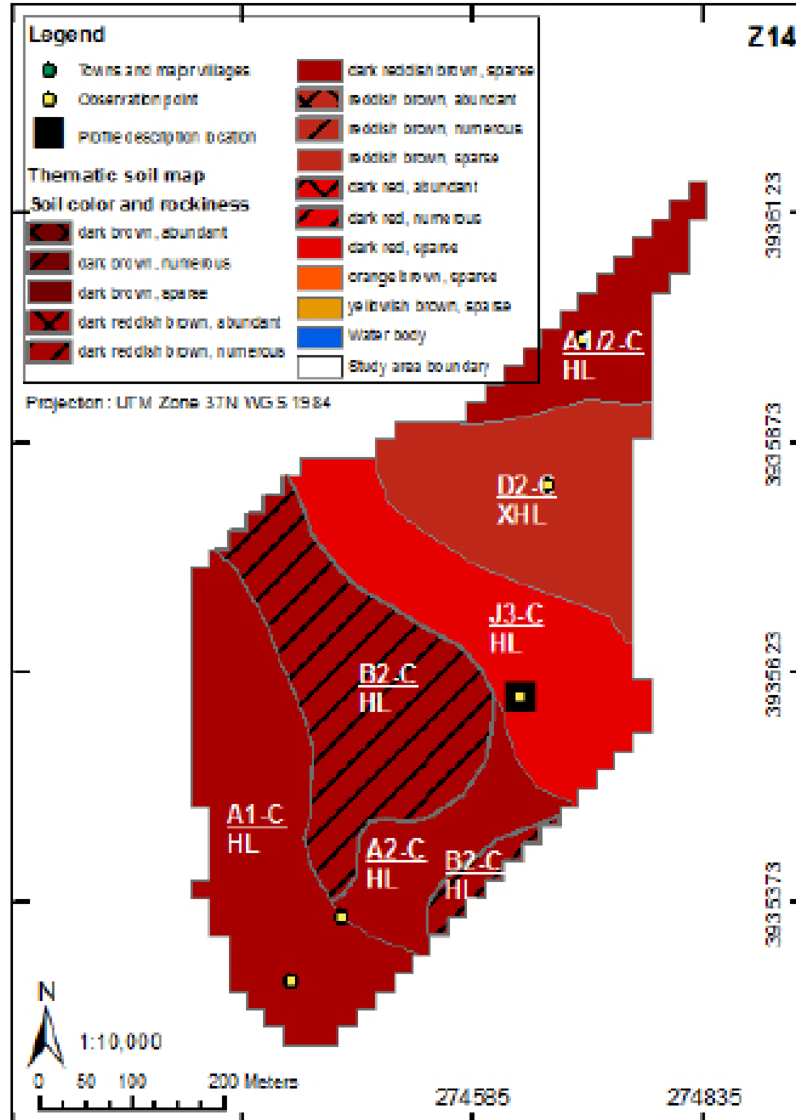
1. Selection of watersheds

Results limited soil survey

2. Soil mapping in selected watersheds



Thematic soil map of survey area Z10



Thematic soil map of survey area Z14

Use of Bayesian inference methods in GIS
1. General

- Application in GIS of Bayesian statistics to a set of ‘evidence layers’ incorporating local and expert knowledge
- Based on Bayes Theorem:

$$p(h \mid \varepsilon) = \frac{p(\varepsilon \mid h) * p(h)}{\sum_i p(\varepsilon \mid h_i) * p(h_i)}$$

where
p(h/ε) = the probability of the hypothesis being true given the evidence (posterior probability)
p(ε/h) = the probability of finding that evidence given the hypothesis being true (conditional probability)
p(h) = the probability of the hypothesis being true regardless of the evidence (prior probability)

Use of Bayesian inference methods in GIS
2. Principles

- **Soil properties** are mapped instead of ‘soil bodies’
- The mapping is done in the same way a classical soil surveyor builds up a **mental concept of soil distribution** by exploiting relationships between soil occurrence and various environmental variables (e.g. elevation, rainfall, geology, slope), supported by a limited sample set, including real soil profiles
- The mapping of individual soil properties is **probabilistic**, leading to fuzzy instead of crisp classifications (e.g. maps showing the probability of depth class 0-25 cm, 25-50 cm, 50-100 cm in pixel x instead of pixel x= class 0-25).
- The mapping is based on the **‘weights of evidence’ method**, first proposed by Bonham-Carter and Agterberg (1990) and modified by Corner et al. (2002) in the **Expector software**.

Use of Bayesian inference methods in GIS
3. Bayes implementation in Expector

- In Expector a hypothesis is expressed as a soil attribute class
- the evidence is presented in GIS format through 'evidence layers'.
- The probability of a given soil attribute class (hypothesis level) j being true in the presence of n evidence layers, each with their own number of map classes i, is assessed through the equation:

$$p(h_j \mid \varepsilon_1, \varepsilon_2, \ldots \varepsilon_n) = \frac{\{\prod_i \frac{p(h_j \mid \varepsilon_i)}{p(h_j)}\} * p(h_j)}{\sum_j p(h_j \mid \varepsilon_1, \varepsilon_2, \ldots \varepsilon_n)}$$

where
$p(h_j|\varepsilon_i, \varepsilon_2 \ldots \varepsilon_n)$ = the probability of hypothesis j being true given all evidence layers $\varepsilon_1, \varepsilon_2, \ldots \varepsilon_n$ combined
$p(h|\varepsilon)$ = the probability of the hypothesis being true given the evidence of map class i
$p(h_j)$ = the prior probability of each hypothesis j

Phase 2: Step 2

Limited soil survey

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Bayesian Inference method: Compilation of ‘evidence’ layers

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Bayesian Inference Method: Probabilistic maps of soil depth and rockiness

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User-defined thresholds for suitability

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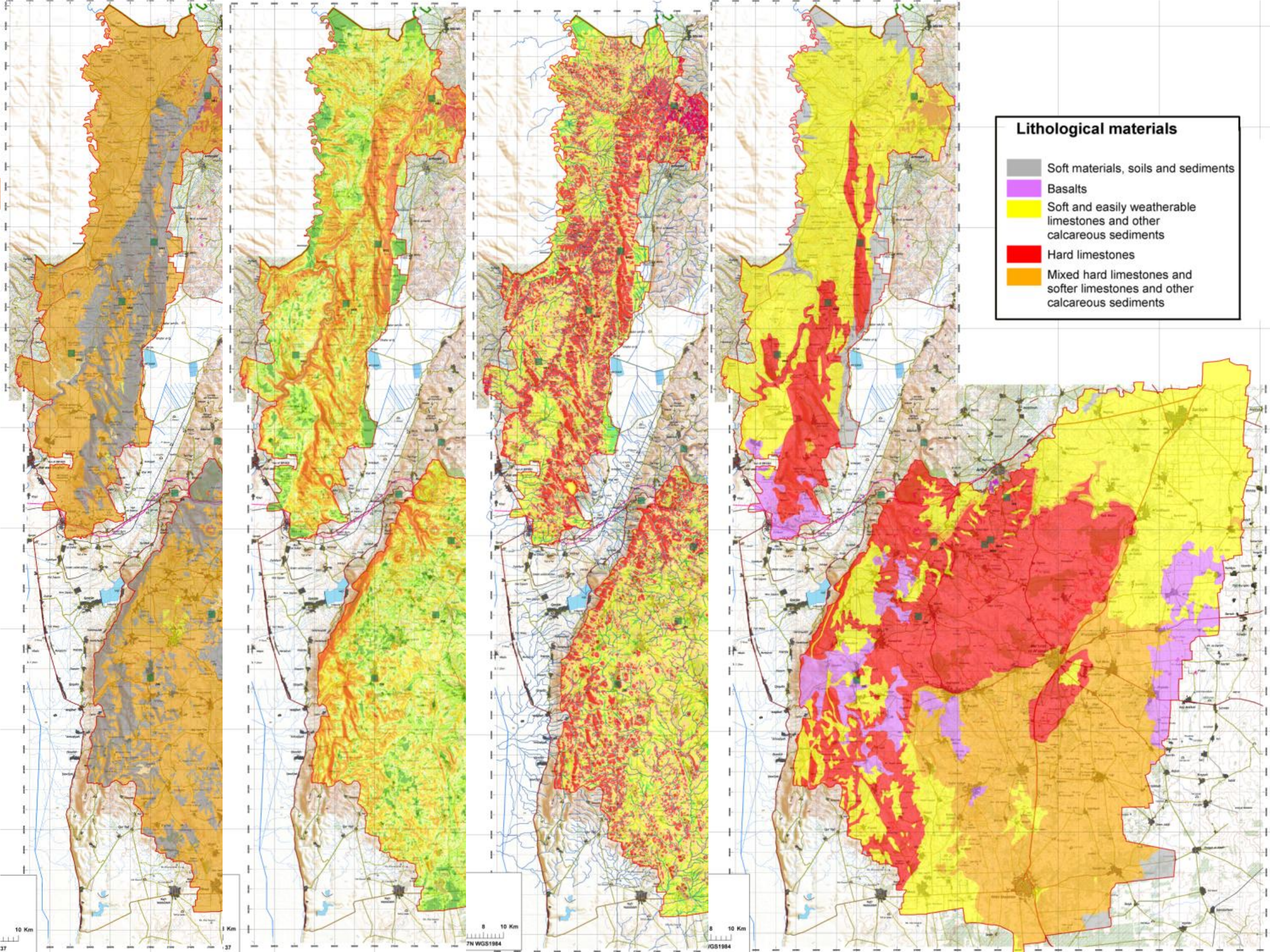
Suitability maps for de-rocking


Lithological materials
Soft materials, soils and sediments
Basalts
Soft and easily weatherable limestones and other calcareous sediments
Hard limestones
Mixed hard limestones and softer limestones and other calcareous sediments
10 Km
10 Km
WGS1984

Phase 2: Step 3

Limited soil survey

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Bayesian Inference method:
Compilation of ‘evidence’ layers

⇩

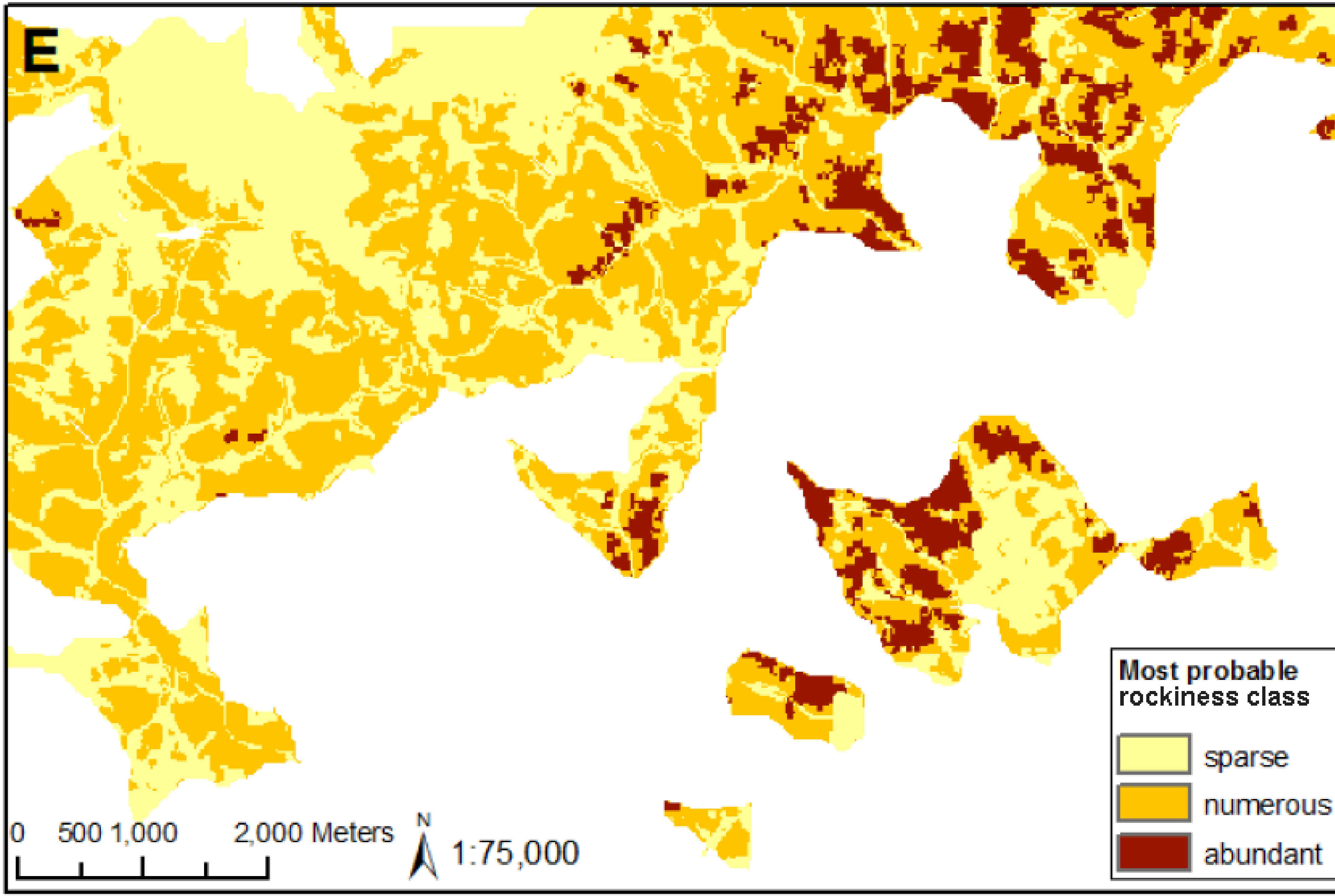
Bayesian Inference Method:
Probabilistic maps of soil depth and rockiness

⇩

User-defined thresholds for suitability

⇩

Suitability maps for de-rocking


E
Most probable rockiness class
sparse
numerous
abundant
0 500 1,000 2,000 Meters
N
1:75,000

Phase 2: Step 4

Limited soil survey

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Bayesian Inference method:
Compilation of ‘evidence’ layers

⇩

Bayesian Inference Method:
Probabilistic maps of soil depth and rockiness

⇩

User-defined thresholds for suitability

⇩

Suitability maps for de-rocking

Technical and environmental suitability criteria for de-rocking

- Standards set by IFAD in its development projects for operating de-rocking equipment
- These criteria can be modified after an environmental impact assessment (e.g. lower slopes on erodible soils)

Soil/landscape property	Suitable range
Slope	$\leq 25\%$
Rockiness	10 – 65 %
Soil depth	≥ 30 cm

Matching de-rocking suitability criteria to probability maps using thresholds

Probability maps soil depth
•Very shallow (<30 cm)
•Shallow (30-75 cm)
•Deep (>75 cm)

Probability maps rockiness
•Sparse (<10%)
•Numerous (10-65%)
•Abundant (>65%)

Threshold probabilities

Soil depth
Primary suitable:
Probability class [Shallow or Deep] ≥ 90%
Secondary suitable:
Probability class [Shallow or Deep] 75-90%

Rockiness
Primary suitable:
Probability class [Numerous] ≥70%
Secondary suitable:
Probability class [Numerous] 50-70%

Phase 2: Step 5

Limited soil survey

⇩

Bayesian Inference method:
Compilation of ‘evidence’ layers

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Bayesian Inference Method:
Probabilistic maps of soil depth and rockiness

⇩

User-defined thresholds for suitability

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Suitability maps for de-rocking

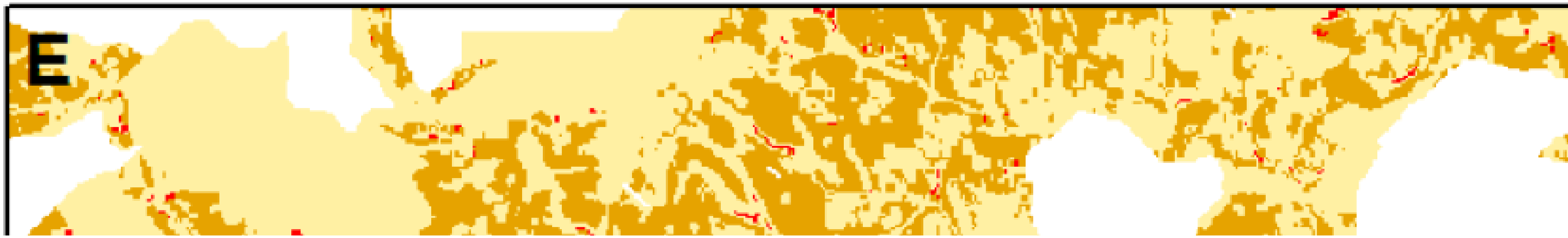
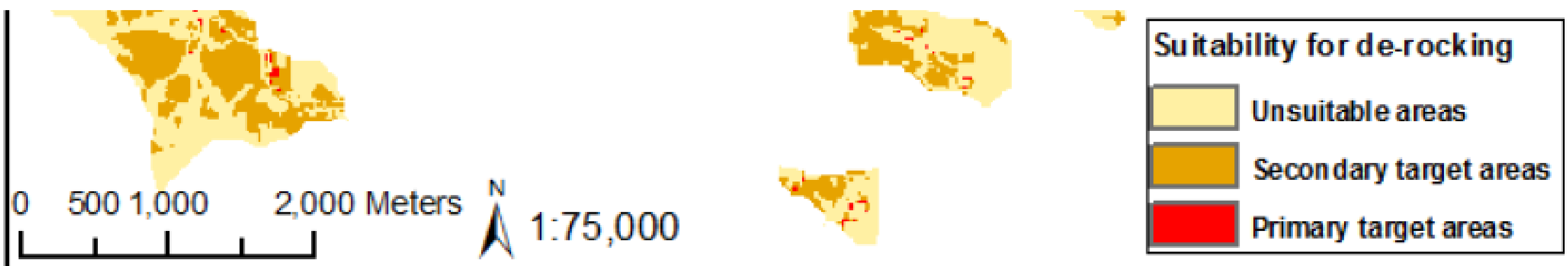


Table 5.3 The extent of areas with overall suitability, regardless and including the slope criteria

	Suitability (regardless slope criterion)		Suitability (including slope criterion)	
Suitability class	Area (ha)	Area (% of total)	Area (ha)	Area (% of total)
S1 (primary suitable)	375	2.0%	375	2.0%
S2 (secondary suitable)	4,890	25.6%	4,740	24.8%
N (unsuitable)	13,835	72.4%	13,985	73.2%
Total mapped area	19,100		19,100	



Synthesis of the case study

What was done differently?

- Started from the data and analysis needs of the development problem at hand
- used a multi-disciplinary approach (soil science, botany, remote sensing, GIS, geology, farming systems/livelihood approach, development perspective etc.)
- undertook new mapping where absolutely necessary (soils, LULC, base map) and made maximum use of remote sensing techniques and platforms (Landsat, Quickbird)
- kept new soil survey work to the minimum and cost-effective
- used simple statistical models to generate pixel-level probabilistic data of only those soil properties relevant

Synthesis of the case study

What was done as before?

- Retained all classical soil science/land resource assessment expertise/experience
  - still building up a mental concept of soil distribution by exploiting relationships between soil occurrence and various environmental variables (e.g. elevation, rainfall, geology, slope), supported by a limited sample set, including real soil profiles, based on whatever quality-controlled legacy data are available and limited field work
- Did not give up on the polygon-based data model of associations/complexes for the evidence layers

A way forward

1. Gap filling for the HWSD: West Asia-North Africa

- necessary to improve knowledge of soil distribution in a large part of the globe that is currently under-represented in the HSDB
- data are available for large parts of the region
- BUT the main challenge to overcome is access to the information
- only feasible by maximum involvement of national partners through training, sub-contracts for specified deliverables, data sharing agreements

A way forward

2. Outscaling the probalistic soil property mapping approach to a country (1)

- Soil properties (e.g. depth, texture, organic carbon) are mapped instead of 'soil bodies', as in soil classification systems, which yield holistic but abstract and not necessarily homogeneous entities, difficult to use with crop models.
- The mapping is done in the same way a classical soil surveyor builds up a mental concept of soil distribution by exploiting relationships between soil occurrence and various environmental variables (e.g. elevation, rainfall, geology, slope), supported by a limited sample set, including real soil profiles.
- The mapping of individual soil properties is probabilistic, leading to fuzzy instead of crisp classifications

A way forward

2. Outscaling the probalistic soil property mapping approach to a country (2)

- Possible evidence layers to be used:
  - Legacy soil maps and profile databases
  - Land use/land cover map derived from <u>recent</u> Landsat imagery
  - Topographic indices derived from the 90m resolution SRTM DEM
  - Lithology (derived from geological maps)
  - Precipitation
  - Spectral signature data (if available)
- Potential candidate countries: Jordan, Lebanon, Syria