Identification of potential areas for out-scaling sustainable land management options in West Asia, North Africa, and Central Asia

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Abstract - Water scarcity and land degradation are among the most important factors affecting agricultural production and sustainability in the West Asia and North Africa (WANA) region and in Central Asia (CA). Various sustainable land management (SLM) technologies that help conserve and better use natural resources and hence improve the incomes and livelihoods of farmers are available and being adapted to these regions. However, to achieve better adoption by farmers and to ensure positive results from implementation, the SLM technologies in WANA and CA need to be disseminated on a large scale. Identifying the potential areas to target the implementation of selected SLM practices is necessary to help decision makers and facilitate the out-scaling process.

With participation of specialists from the National Agriculture Research Systems, three agro-ecosystems, rangeland, irrigated, and rainfed, were defined for the WANA region, and the mountain agro-ecosystem was added for CA. Each agro-ecosystem was represented by a benchmark site where selected SLM technology was demonstrated. In WANA, these benchmark sites included the water harvesting Vallerani system (contour ridges and semicircular bunds) for rangeland, water-saving (raised-beds and deficit irrigation) for irrigated, and supplemental irrigation for rainfed agro-ecosystems. In CA, sites included pasture improvement for rangeland, raised-beds for irrigated, conservation agriculture for rainfed, and agro-forestry for mountain agro-ecosystems. The criteria used to identify potential areas for out-scaling consisted of land use, slope, water resources availability, precipitation, degree of land degradation, livestock density, soil depth, soil texture, and soil salinity.

Global spatial datasets, such as the FAO Land Degradation Assessment in Drylands project (LADA), soil data from the Harmonized World Soil Database (HWSD), and soil depth from the Soil Map of the World were used to derive the required database. Available national data provided by the participating countries were used as supplemental sources. The derived maps were validated and verified by an interdisciplinary team of experts and researchers from the countries in both regions.

Verification of the maps derived at regional level – using low resolution data, with more detailed data for some countries – indicated that potential areas for out-scaling SLM could be generally identified. However, for implementation purposes and to derive the extent of the potential areas, detailed data at national level is needed. Yet, the results are useful to guide decision makers to first identify the extent and distribution of the potential areas for each SLM and agro-ecosystem and, second, to prioritize the implementation. This will help in the out-scaling of SLM options to improve productivity and resilience.

Keywords: benchmark, agro-ecosystem, spatial analysis, biophysical criteria, knowledge dissemination, decision support mapping

II. Introduction

Evaluation of the spatial pattern of a landscape is necessary to achieve proper land use (FAO, 1996; Roetter et al., 2005; Baja et al., 2007). Recently, geographic information systems (GIS) provide tools and algorithms to determine land uses that are most appropriate for a given area (Collins et al., 2001), and hence provide support for making spatial decisions (Malczewski, 1999). The GIS system contains a set of procedures that facilitate the data input, storage, manipulation and analysis, and data output to support decision-making activities (Grimshaw, 1994). In this project, ArcGIS 10.2 was used for identifying potential areas for out-scaling specific technologies. The selection of potential areas to out-scale any particular use or management is determined by the criteria used to identify these areas, which might vary according to the quantitative and qualitative information available and also its interpretation through the different actors and decision makers (Hurni, 2000). This is related to natural processes and the built environment (Berry and BenDor, 2015). Three approaches could be used to identify areas for out-scaling sustainable land management options: computer-assisted overlay mapping, multi-criteria decision making (MCDM), and artificial intelligence (Chakma, 2014; Malczewski, 2004).

Malczewski (1999) stressed the complexity in attempting to acquire data and to process the data to obtain information for making decisions. This problem may require processing at a level that exceeds a decision maker's cognitive ability. To this end, the role of GIS and multi-criteria decision making (MCDM) techniques support the decision maker in achieving greater effectiveness and efficiency of decision making while solving spatial decision problems. GIS-based MCDM can be thought of as a process that combines and transforms aspatial data (input) into a resultant decision (output) (Malczewski, 2004). The MCDM procedures (or decision rules) define a relationship between the input maps and the output map.

The procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules (selected criteria and rating). Accordingly, two considerations are of critical importance for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into unidimensional values of alternative decisions.

A number of multi-criteria decision rules have been implemented in the GIS environment for tackling land-use and suitability problems. Furthermore, the combination of GIS capabilities with MCDM techniques provides the decision maker with support in all stages of decision making, that is, in the intelligence, design and choice phases of the decision—making process (Carver, 1991; Pereira et al., 1993; Laaribi et al., 1996; Malczewski, 1996; Malczewski, 1999; Thill, 1999; Chakhar and Martel, 2003; Chakhar and Mousseau, 2006; Malczewski, 2006).

For relatively small areas, a field survey carried out by experienced people will be the best technique to select the appropriate sites and to determine proper sustainable land use and management, for example, rainwater harvesting intervention (Ziadat et al., 2012). For larger areas the application of GIS and remote sensing could be the most relevant means (Prinz et al., 1998; De Pauw et al., 2007; Makhamreh, 2011). However, planning for large scale implementation requires quantitative information and knowledge of the spatial distribution of the land characteristics, which are often unavailable for arid environments (Prinz et al., 1998).

In ICARDA, the integrated water and land management program IWLMP uses GIS in defining potential areas for out-scaling specific technologies. The study of "Integrating expert knowledge in GIS to locate biophysical potential for water harvesting - methodology and a case study of Syria" aimed to provide a rapid GIS-based analytical technique to assess suitability for various water harvesting systems in Syria, with the ultimate objective to adapt the technique in order to allow assessment of potential at the level of central and west Asia and North Africa CWANA region (De Pauw et al., 2008).

Identifying potential areas for out-scaling specific SLM techniques within large geographical areas such as WANA and CA - the use MCDM inside a GIS environment and taking into consideration the expert knowledge and assessment – provide profound basis for supporting variable decision makers.

III. MATERIALS AND METHODS

A. Identifcation of agro-ecosystems type and charchtaristics

Different agro-ecosystems have been identified in both WANA and CA regions based on national and international expert's assessments and the knowledge gained from the ICARDA benchmark sites. For these agro-ecosystems specific SLM technologies have been chosen according to defined criteria, the criteria evaluated during several regional workshops and meetings. The water benchmark project for WANA region "Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in West Asia and North Africa" started in 2004 with the aim to increase adoption of improved technologies, and thus to improve water productivity and livelihoods in water scarce environments. The project targeted three agro-ecosystems: marginal rangelands (steppe), rainfed cropping systems, and irrigated areas. In each agro-ecosystem, a pilot research site was established to test and demonstrate new technologies. Moreover, two or more 'satellite' sites were established (for each pitot site) for complementarity and for wider dissemination. Research focused on the key water-related issues (or opportunity) in each environment; in the Rainfed agro-ecosystem (Tadla region in Morocco) with satellite sites in Tunisia and Algeria, the Irrigated agro-ecosystem (Old, Marginal and New lands in Egypt) with Satellite sites in Sudan and Iraq and the Badia agro-ecosystem (Al Majdyya and Al Maharib in Jordan) with satellite sites in Syria and Libya. (Fig. 1). The characteristics of the benchmark sites (research sites) where successful technologies were tested, were used to identify areas similar to articular agro-ecosystem (Table I). The requirements for each technology that ensure successful implementation and out-scaling were used to identify potential areas for out-scaling each technology (Tables II and III). These criteria were matched with land resources data to map the distribution of the agro-ecosystems and the areas for potential out-scaling of SLM.

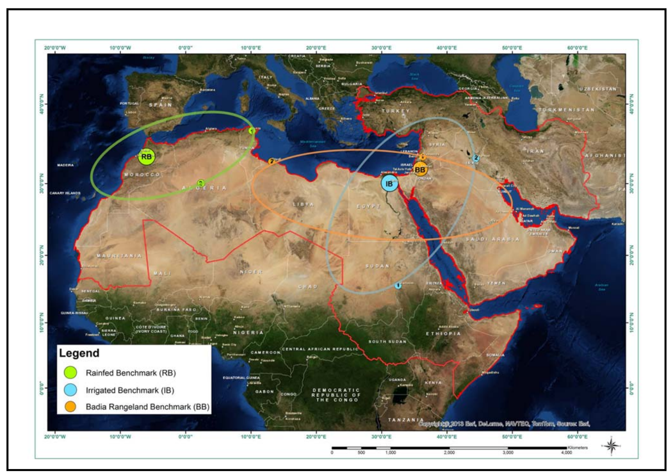

Fig. 1. Locations of the agro-ecosystem sites and satellite sites in West Asia and North Africa region

B. Data sources

To conduct comprehensive analysis for identifying the potential areas for out-scaling, different spatial datasets are needed. For large scale applications – as it is the case for the particular operations in WANA and CA region – the use of data from online sources seems feasible. The different datasets available were explored carefully, compared to each other, and discussed with different scientists and experts in order to have representative layers. The data were selected due to their relevance and appropriateness for the SLM analyses (Table IV).

TABLE I. IMPORTANT CHARACTERISTICS OF AGRO-ECOSYSTEMS SITES IN WEST ASIA AND NORTH AFRICA REGION

Agro-ecosystem	Criteria	Detailed
Rainfed in Morocco	Rainfall (mm)	250 – 600
	Land is cultivated	Crop lands
	Slope (%)	up to 25
Irrigated in the Nile Delta, Egypt	Water resources	Permanent water resources
	Land is cultivated	Crop land
	Soil texture	All soil texture classes
	Slope (%)	< 5
Rangeland in the Jordan Badia	Rainfall (mm)	50 – 300
	Land is cultivated	< 50 % vegetation cover
	Slope (%)	0 – 50
	Soil texture	All soil texture classes

TABLE II. CRITERIA USED TO IDENTIFY POTENTIAL AREAS FOR OUT-SCALING SPECIFIC TECHNOLOGIES WITHIN THE THREE AGRO-ECOSYSTEMS IN WEST ASIA AND NORTH AFRICA REGION

Technology/Agro-ecosystem	Criteria	Detailed
Supplemental irrigation/ Rainfed	Rainfall (mm)	250 – 500
	Water resources	Available for supplemental irrigation
	Land is cultivated	Crop lands
	Crops	Winter crops based system
	Slope (%)	up to 5
Raised-bed technologies/ Irrigated	Rainfall (mm)	< 250
	Water resources	available for supplemental irrigation
	Land use	Land that is cultivated
	Soil texture	Not Sandy
Vallerani water harvesting/ Rangeland	Rainfall (mm)	100 – 300
	Soil depth (cm)	60 cm and more
	Land use	< 30% vegetation cover
	Slope (%)	up to 20
	Soil texture	Not Sandy

TABLE III. CRITERIA USED TO IDENTIFY POTENTIAL AREAS FOR OUT-SCALING SPECIFIC TECHNOLOGIES WITHIN THE FOUR AGRO-ECOSYSTEMS IN CENTRAL ASIA REGION

Technology/Agro-ecosystem	Criteria	Detailed
Fig. 1. Conservation agriculture/ Rainfed	Fig. 2. Rainfall (mm)	Fig. 3. 300 – 600
	Slope (degree)	< 7
	Land use	Cropland
	Soil (texture), clay content (%)	20 – 75 physical clay
Raised-bed technologies / Irrigated	Land use	Irrigated land
	Slope (degree)	0 – 5
	Water availability	Sufficient water resources
	Soil (texture), clay content (%)	10 – 75
	Soil salinity (dS m–1)	< 8
Mountain agro-forestry/ Mountain	Slope (degree)	>7
	Rainfall (mm)	> 500
	Altitude (m)	800 - 3000
	Land use	Exclude unsuitable areas (e.g. rocks and gullies)
	Soil depth (cm)	> 50
Pasture improvement/Rangeland	Land use	Rangeland, pasture
	Degradation degree	Areas with weak, medium to strong degradation, and bareland
	Livestock density per ha	Areas with high and moderate livestock density
	Watering points per ha	Existence of watering points

C. Data preparation

Available data from different sources vary in resolution and format. Thus, data harmonization has been undertaken to ensure uniformity of the data and to run the analysis for defined resolution and quality.

Resampling, raster calculation, and conditional functions were among the GIS spatial analysis tools used to extract the needed data layers. As an example - to extract the land use needed for the potential areas for raised-bed technology within areas suitable for irrigated agro-ecosystem, the following code was used for the GIS raster calculator (IF-statement):

Con ((“lu_t1_500m” == 12) | (“lu_t1_500m” ==14),”lu_t1_500m”) = LU

D. Mapping production

After processing each data set, raster calculator function was used to produce a uniform layer that includes all the criteria representing the spatial distribution of each agro-ecosystem. For example, to produce the potential areas for Vallerani water harvesting technique within the rangeland agro-ecosystem areas, the following code was used (AND-statement) :

"Rainfall" & "Soil_Depth" & "LU" & "Slope" & "Soil_Texture"

TABLE IV. DATA USED FOR IDENTIFYING THE POTENTIAL AREAS FOR OUT-SCALING SPECIFIC SLM TECHNOLOGIES IN WANA AND CA REGIONS

Criteria	Detailed
Rainfall	WorldClim – Global Climate Data http://www.worldclim.org/download Global Weather Data for SWAT Http://globalweather.tamu.edu/
Land use	Land Processes -Distributed Active Archive Center LP DAAC, United States Geological Survey USGS Https://lpdaac.usgs.gov/products/MODIS _products_table/mcd12q1 Food and Agriculture Organization of the United Nation FAO, The Land Degradation Assessment in Drylands project LADA, Global Land Degradation Information System GLADIS - Simplified output, Land use systems of the world - v1.1 http://www.fao.org/nr/lada/gladis/lus/ FAO, Effective Soil Depth (cm) Map, Class 10 http://data.fao.org/map?entryId=c3bfc940-bdc3-11db-a0f6-000d939bc5d8 FAO – GeoNetwork, Digital Soil Map of the World http://www.fao.org/geonetwork/srv/en/metadata.show?id =14116
Soil	FAO, Effective soil depth (cm) map http://data.fao.org/map?entryId=c3bfc940-bdc3-11db-a0f6-000d939bc5d8 WaterBase project Http://www.waterbase.org/download_data.html FAO, GeoNetwork, digital Soil Map of the World http://www.fao.org/geonetwork/srv/en/metadata.show?id =14116 Harmonized world soil database HWSD –Version 1.2 http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
Water	World Wildlife Fund WWF, Conservation Science Data and Tools, Global Lakes and Wetlands Database GLWD http://worldwildlife.org/pages/global-lakes-and-wetlands-database FAO - AQUASTAT – global water information system Http://www.fao.org/nr/water/aquastat/main/index.stm Environmental Systems Research Institute ESRI; World Water Bodies and World Linear Water http://www.arcgis.com/home/item.html?id=e750071279 bf450cbd510454a80f2e63; and http://www.arcgis.com/home/item.html?id=273980c20b c74f94ac96c7892ec15aff
DEM	The Consultative Group for International Agricultural Research - Consortium for Spatial Information CGIAR CSI – Shuttle Radar Topography Mission SRTM 90 m digital elevation data http://srtm.csi.cgiar.org/ (this data used to extract the altitude (m) and the slope (degree)
Degradation degree	FAO, LADA, GLADIS - Simplified output, Classes of land degradation http://www.fao.org/nr/lada/gladis/glad_ind/
Livestock density per ha	FAO, LADA, GLADIS - Simplified output, Classes of land degradation Beta version, Livestock density http://www.fao.org/nr/lada/gladis/lus/

III. RESULTS

Two results for WANA region are available, one for the distribution of the three agro-ecosystems (similar to the three research sites) and the other for the distribution of potential areas for out-scaling specific technologies within the three agro-ecosystems. The resulting maps indicate clustered areas that represent similar characteristics as the areas where specific agro-ecosystems are distributed.

Thus, maps (Figures 2-4) show significant areas where specific technologies may be out-scaled. This varies from country to country and could be used to build specific information dissemination and out-scaling campaigns for each one. The analysis for the selected SLM shows areas less than those suitable to the agro-ecosystem because these are more specific (Table V). They show areas where selected SLM technologies can be applied within the whole area. However, other SLM practices could be implemented within the areas similar to those of the agro-ecosystem sites.

To verify the results for the WANA region, additional data from national agriculture research systems NARS in Jordan, Morocco, and Egypt were used to run the same analysis but using more detailed data. Professional version of Google Earth and the Global Land Cover data base (2009) from the European Space Agency were used to support the verification process. In general, an acceptable agreement between the two methodologies was found – even though the data used for entire WANA region analysis has much lower resolution compared to the datasets used at the national level. In CA the analysis of identifying potential areas for out-scaling the selected technologies shows highly variable distributions of the four agro-ecosystems according to the different countries (Fig. 5).

Most of CA countries, Uzbekistan, Kazakhstan, Kyrgyzstan, and Tajikistan provided data about the area of rainfed and irrigated land to support the analysis at regional level (Table VI). The national data was checked for consistency and was used as input to revise and fine-tune the mapping (Fig. 6).

To verify the results, the experience and knowledge of national experts and representatives from NARS was taken into consideration during a regional workshop, using the professional version of Google Earth for presenting and discussing the results.

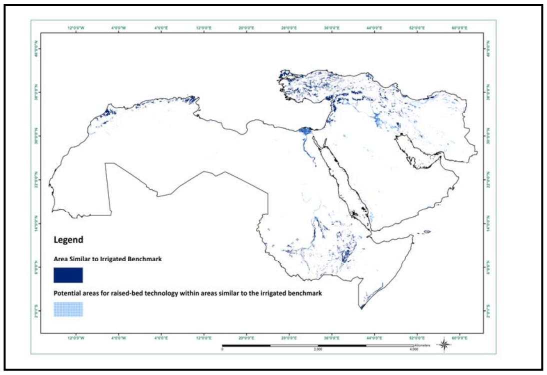

Fig. 2. Distribution of areas similar to the irrigated agro-ecosystem and potential areas for out-scaling raised-bed technology

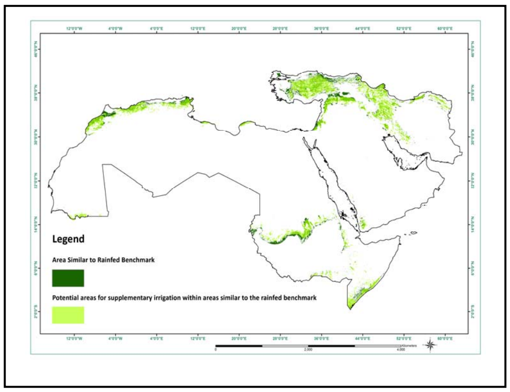

Fig. 3. Distribution of areas similar to the rainfed agro-ecosystem and potential areas for out-scaling supplementary irrigation

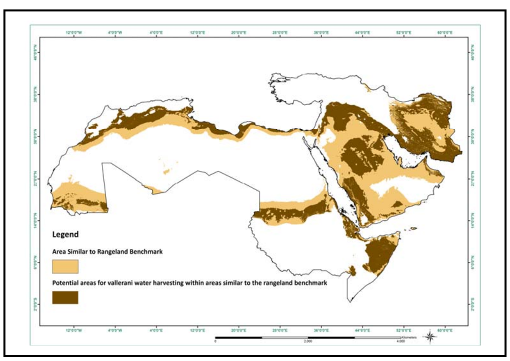

Fig. 4. Distributioon of areas similar to the rangeland agro-ecosystem and potential areas for out-scaling Vallerani water harvesting

TABLE V. POTENTIAL AREAS FOR OUT-SCALING SELECTED TECHNOLOGIES IN WEST ASIA AND NORTH AFRICA REGION

Description	Area (km2)
Rainfed Agro-ecosystem Area for out-scaling supplementary irrigation within the rainfed agro-ecosystem	349,046.7 147,447.9
Irrigated Agro-ecosystem Area for out-scaling raised-bed technology within the irrigated agro-ecosystem	249,328.1 754,11.2
Rangeland Agro-ecosystem Area for out-scaling Vallerani water harvesting within the rangeland agro-ecosystem	6,893,160.3 3,240,797.2

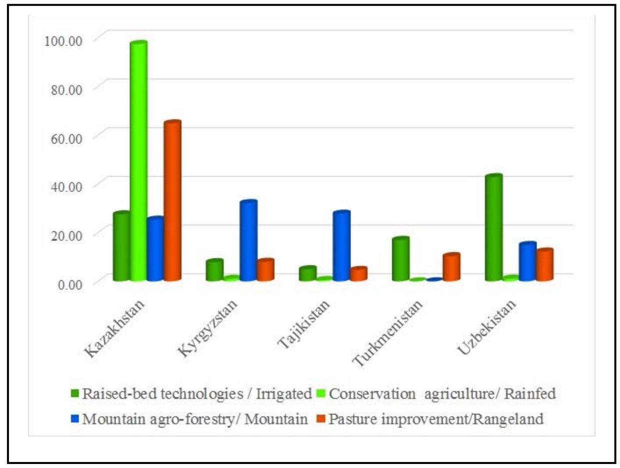

Fig. 5. Potential areas for out-scaling selected technologies in CA region (as perecent of the area of the counties)

TABLE VI. NATIONAL DATA USED FOR FINE-TUNING THE THE SLM ANALYSIS MAPS IN CA REGION

Country	Data sources
Uzbekistan	Soil map of the Republic of Uzbekistan, produced by GOSCOMZEMGEODESCADASTRE in 2008 Atlas of Soil Cover of the Republic of Uzbekistan, printed by GOSCOMZEMGEODESCADASTRE in 2010
Kazakhstan	Socio-economic atlas of Republic of Kazakhstan, Vol. 2, Land use map, produced by Institute of Geography in 2010
Kyrgyzstan	Land use map of Kyrgyz Republic. The report Ms. Kelgenbaeva Kamila. The results of IP-SLM, CACILM Phase I (Information system component, 2008–2010)
Tajikistan	Atlas of the Tajik SSR, Soil and Land use Map, produced by the Department of Geodesy and Cartography under the Council of Ministers of the USSR in 1968

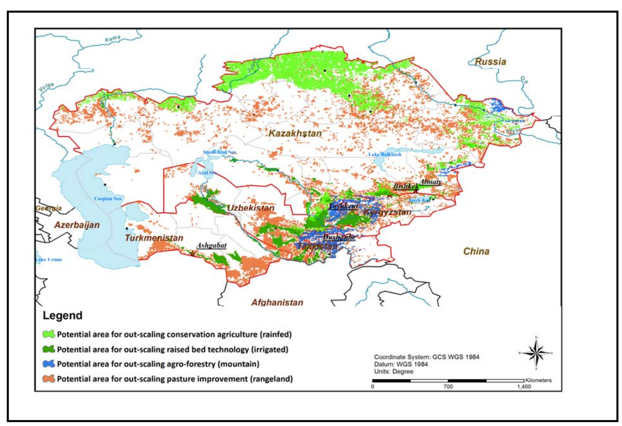

Fig. 6. Potential areas for out-scaling different sustainable land management technologies within four agro-ecosystems in Central Asia (irrigated, rainfed, rangeland, and mountain)

IV. Conclusion

The study discloses the potential to identify areas for out-scaling SLM options based on the available coarse resolution data for WANA and CA. These maps could be used to support the allocation of areas within different agro-ecosystems for dissemination and promotion of proper water and land management options. Identification of proper criteria for characterizing each agro-ecosystem is important for generating reliable results. . A comparison of the outcomes based on the online available data sources with those derived for the national level using similar criteria supported our fine-tuning process. The resulting maps cover the whole area of interest with acceptable accuracy. Eventually, those maps can be used to guide decision makers at regional and national levels. The participation of national experts in formulating the criteria for verifying and fine-tuning of these maps was important and will supports the dissemination of the results and foster implementation by decision makers. At regional level, donors and/or development programs could benefit from these results by identifying areas to put more efforts into out-scaling of technologies that will lead to higher impact. Investments could be directed based on these results to maximize the benefits and success of adopting different technologies. At the local level, farmers, land users, and extension services could use these results to identify potential intervention(s) that will optimize productivity and improve livelihood. This will also help farmers and extension services to suggest new technologies to areas with similar environmental conditions to those where these technologies were tested. Eventually, this will help in adopting these technologies for a wider range and better uptake.

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