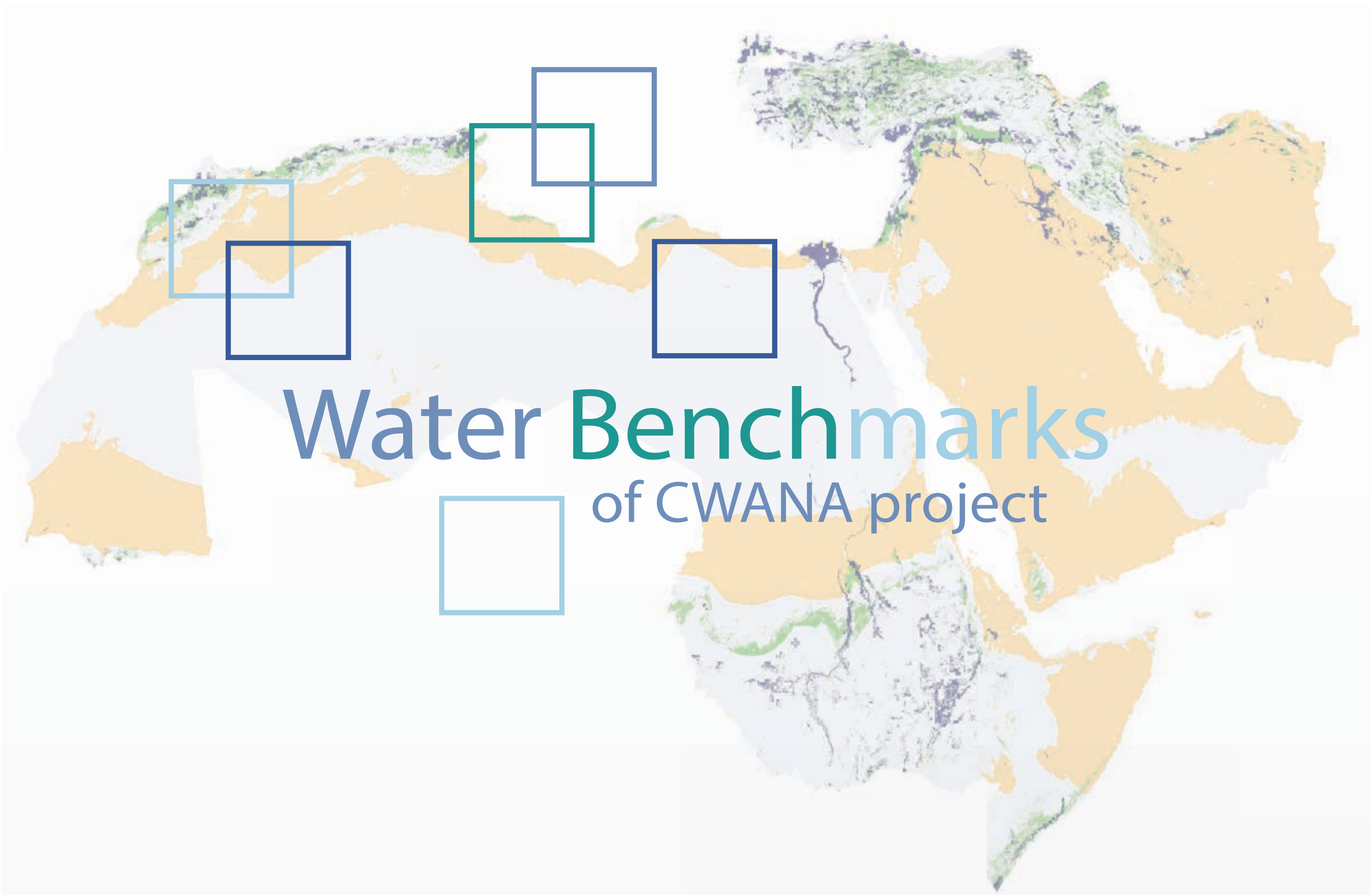

Water Benchmarks
of CWANA project

11

Similarity and Suitability Analysis to Assist the Out-Scaling of Sustainable Water and Land Management Practices in West Asia and North Africa

Feras Ziadat, Safa Mazahreh, Mira Haddad, Tarik Benabdelouahab,
Samar Attaher, Mohammed Karrou, Theib Oweis and Tarek Kandakji

ICARDA
Science for Better Livelihoods in Dry Areas

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Water Benchmarks of CWANA

Community-Based Optimization of the Management of Scarce Water Resources in Agriculture In CWANA

Similarity and Suitability Analysis to Assist the Out-Scaling of Sustainable Water and Land Management Practices in West Asia and North Africa

Editors

Feras Ziadat, Safa Mazahreh, Mira Haddad, Tarik Benabdelouahab, Samar Attaher, Mohammed Karrou, Theib Oweis and Tarek Kandakji

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Lebanon

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Abbreviations and acronyms

AFESD	Arab Fund for Economic and Social Development
ARC	Agricultural Research Center, Egypt
AWC	Available water content
CFSR	Climate Forecast System Reanalysis
CGIAR CSI	CGIAR Consortium for Spatial Information
DEM	Digital elevation model
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic information system
ICARDA	International Center for Agricultural Research in the Dry Areas
ICOLD	International Commission on Large Dams
IGBP	International Geosphere-Biosphere Programme
INRA	National Institute of Agronomic Research, Morocco
IWMI	International Water Management Institute
LP DAAC	Land Processes Distributed Active Archive Center
MoA	Ministry of Agriculture
NARC	National Agricultural Research Center
NCARE	National Center for Agricultural Research and Extension, Jordan
NCEP	National Centers for Environmental Prediction
SRTM	Shuttle radar topography mission
SWAT	Soil and water assessment tool
TAMU	Texas A&M University
UNU	United Nation University
USAID	United States Agency for International Development
USGS	United States Geological Survey
WANA	West Asia and North Africa
WLI	Water and Livelihoods Initiative

Summary

Water scarcity and land degradation are among the most important factors that affect agricultural production and sustainability in the West Asia and North Africa (WANA) region. Through the Water benchmarks project, ICARDA has adapted techniques/technologies that can help conserve and better use natural resources (water and land) and hence improve the incomes and livelihoods of farmers. Among the proven interventions are water-harvesting practices in the Badia benchmark sites of Jordan (contour ridges and semicircular bunds using the Vallerani system), water-saving techniques (raised-beds and deficit irrigation) in the irrigated benchmark sites of Egypt, and supplemental irrigation in the rainfed benchmark site of Morocco.

Over the past several years, these technical practices were fine-tuned and tested and a number of packages for the best management of water and land, including reducing land degradation, were developed. To achieve better adoption by farmers and ensure positive results from their implementation, suitable techniques/technologies need to be disseminated on a large scale to similar areas of the WANA region. Identifying areas similar to those of the benchmark sites is a tool to facilitate the out-scaling process.

Similarity analyses are used to find areas with certain characteristics that match those of the benchmark sites. Similarity maps were generated at the regional level using expert criteria, defined by an interdisciplinary team of researchers from national and international institutes across the WANA region, and using the available datasets. Soil, climate, land use, and water resources are among the factors used to develop these criteria. The similarity maps developed at the regional level were verified using similarity maps developed at the national level based on the same criteria, but with more detailed information.Similarity maps for specific technologies for each benchmark site were also generated.

Suitability analyses are used within the similar areas at the national level, to identify areas where the water and land management packages developed can be applied with a high probability of success. The better management of natural resources will sustain more resilient and productive ecosystems. Rural farmers will enjoy more productive farms and will be less dependent on national subsidies for their livelihood inputs, saving the government critical funding in the long term and helping farmers to become more self-sufficient.

The professionals, planners, and decision makers can use the information and products generated from this study to target the out-scaling of the improved and adaptive technologies.

Introduction

Drought and water scarcity are the main factors that affect agricultural production in the West Asia and North Africa (WANA) region. These production constraints will be exacerbated by the effects of climate change, as this region is classified among the hot spots for increased temperatures and reduced rainfall (Giorgi and Lionello 2008).
Moreover, the pressure on natural resources will increase because of the high population growth, climate change, and the improper management of natural resources.

There is a common aim for a number of projects implemented by ICARDA (such as the Water Benchmarks project and the Water and Livelihood Initiative). And that is to develop and disseminate water and land management options that increase water productivity, optimize water use, and are economically viable, socially acceptable, and environmentally sound in the main agro-ecosystems prevailing in the region – rainfed, irrigated, and rangeland (Badia or steppe).

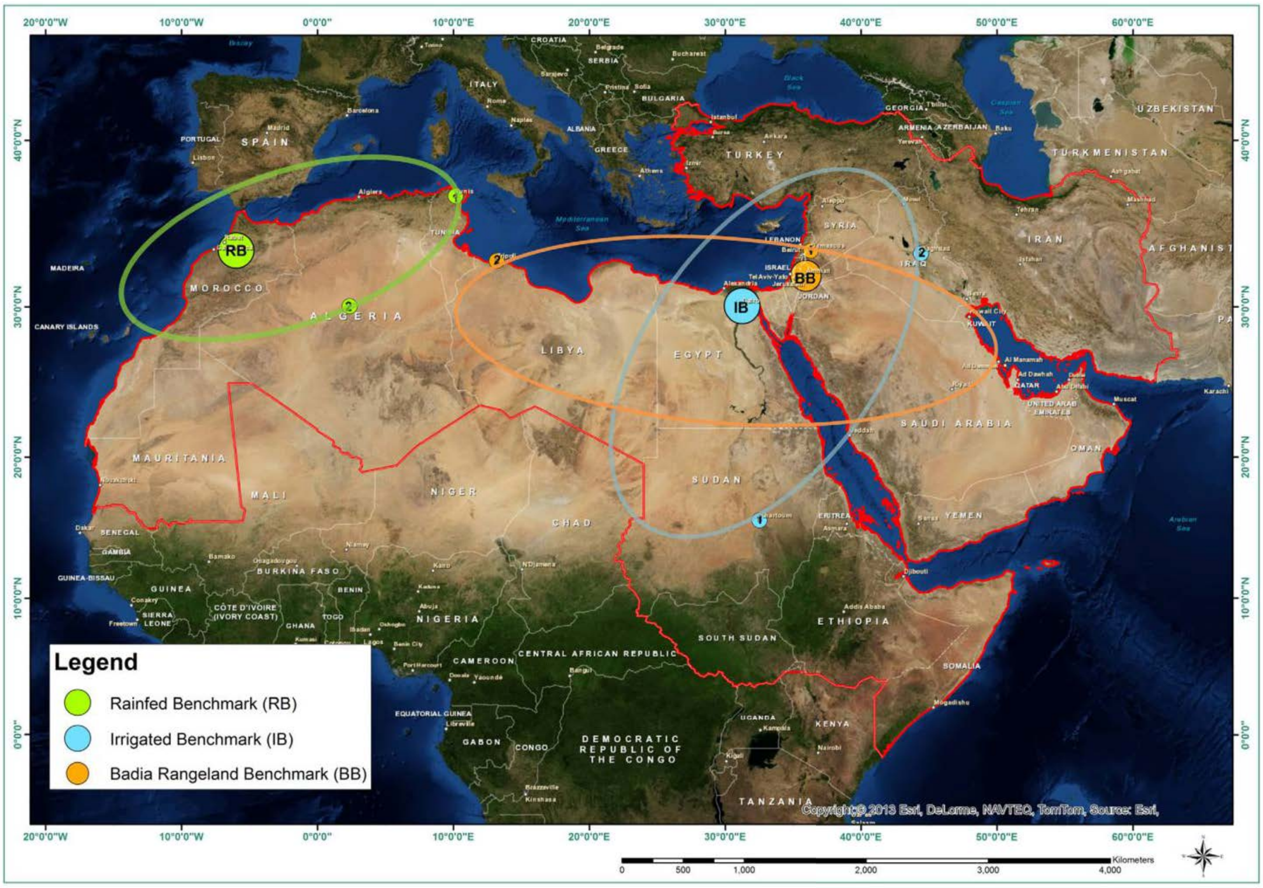
Since 2004, the Water benchmarks project has been ongoing in the:

Rainfed benchmark (Tadla region in Morocco) and satellite (Tunisia and Algeria) sites

Irrigated benchmark (old, marginal and new lands in Egypt) and satellite (Sudan and Iraq) sites

Badia benchmark (Al Majdyya and Al Maharib in Jordan) and satellite (Syria and Libya) sites

See Map 1: Locations of the benchmark and satellite sites.



(Base map source is: Imagery with Labels base map available in ArcMap version 10.1 - ESRI)

Map 1: Locations of the benchmark and satellite sites

With the full participation of the communities, the research during the first phase of the water benchmarks project (2004–2009) focused on the development and testing of improved techniques of supplemental irrigation in the rainfed areas, raised-bed and deficit irrigation in the irrigated systems and water harvesting in the steppe environments (rangelands).

During the second phase of the project, the focus was on the fine-tuning, out-scaling, and dissemination of the outputs of the first phase. For this purpose, similarity and suitability maps were prepared to help decision makers to target potential areas for successful out-scaling of the identified suitable techniques. This will foster the uptake of these technologies, which sustain the use of resources and improve the communities' livelihoods.

The selection of the technologies to be disseminated is based on their performance in field trials conducted in different environments. Trials on supplemental irrigation showed that this technique could increase yields while saving 30% of the irrigation water. In rangeland areas, the project has introduced mechanized methods to build water-harvesting structures, ideally suited for large-scale land rehabilitation programs. Simulated and observed results indicated that water-harvesting interventions reduced erosion and runoff and improved the vegetation cover and productivity of fodder shrubs. The project has also developed water-saving technologies, such as raised-bed planting. A survey study showed that the use of this technology tripled in Egypt in 2013.

In parallel with the bio-physical research, socioeconomic and policy studies conducted in the benchmark and other projects are helping to identify alternative policy and institutional options to accelerate the dissemination of water-efficient technologies, and create the incentives needed to encourage the sustainable use of water resources.

The similarity and suitability analysis will help in the dissemination of the interventions developed across the WANA region.

Challenges and opportunities of the key agroecosystems

Pastoral (rangeland) agroecosystems. (known as Badia in the Middle East):

The challenge in these areas is to enhance productivity and halt land degradation through improved management of the natural resources, particularly the most limiting resource, water. By concentrating (diverting or channeling) the runoff into target areas, water harvesting increases water availability to plants, controls soil erosion, reduces the impact of drought, improves the productivity and vegetation cover, and increases rainwater productivity.

In the Badia benchmark and satellite areas, the project developed innovative methods using a combination of new and conventional methods/tools to select water-harvesting sites. The willingness of the Badia farmers to adopt these technologies has significantly increased since the benchmark project started and the project has helped introduce a new concept – mechanized micro-catchment water harvesting – that is now being widely scaled out in Jordan's and Syrian's Badia areas.

The project approaches are being institutionalized by the government of Jordan.

Photo 1: Vallerani water harvesting system (upper left). Grazing of fodder shrubs cultivated using the Vallerani system (upper right). High soil erosion in farmer's field without intervention (lower left). No soil erosion from field with water-harvesting intervention (lower right)

Rainfed agroecosystems

Rainfed production is dependent on a low and extremely variable rainfall and, therefore, productivity is low and unstable. This is further affected by frequent droughts and continuing land degradation. One option that has the potential to provide large productivity gains is the use of supplemental irrigation for rainfed crops, provided there is water available for irrigation.

The research focused on using and optimizing limited water resources in supplemental irrigation to increase and stabilize yields and water-use efficiency. The benchmark site is located in Morocco and the satellite sites in Algeria, Syria, and Tunisia.

In the rainfed benchmark and satellite sites, work in the farmers' fields has shown that wheat yields are increased 30% with the application of 50 mm of supplemental irrigation to advance the sowing date. Water productivity is nearly doubled (exceeding 2 kg of grain per cubic meter of water). Optimal supplemental irrigation management and scheduling were tested in the satellite sites.

water productivity at the farm, field,and basin levels.

The project focused its work on better irrigation methods and management to improve water productivity and sustainability of use. The benchmark site is located in Egypt and the satellite sites are in Iraq and Sudan.

In the irrigated benchmark sites, an alternative option to the inefficient furrow irrigation followed by farmers was introduced. This alternative is the raised-bed system. It has resulted in irrigation water use by farmers falling by 30%, along with correspondingly lower pumping and labor costs, without reduction in yield.

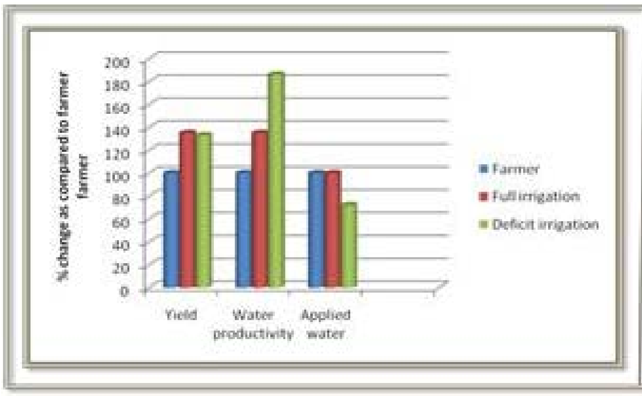


Photo 2: Comparison of yield, water productivity and applied water between farmers' practices versus improved practices (left). Community participation in supplemental irrigation trails (right)

Irrigated agroecosystems:

Saving water in irrigated areas is a top priority almost everywhere in the world; but it is of particular importance in the dry areas where water scarcity is extreme and increasing. Water saving in irrigated agriculture includes two components:
Reducing water losses at the farm level by improving
irrigation efficiencies, such as application, distribution, storage efficiencies, and Increasing

Farmers' incomes have been increased by 15% and water productivity by 30%. Net return per unit of water was increased by 20%. In sowing berseem, the dry method (without flooding) saved about 75 mm of water as compared to the wet method (Talwait). Deficit irrigation, using a sprinkler irrigation system on the sandy soil of the new land, increased water productivity by 38%. Water productivity and constraints to the improved system were assessed in the satellite sites.

Photo 3: Implementation of raised-bed package using a specially manufactured machine (left). Wheat cultivated using raised-bed technology (right)

Similarity analysis

In many countries of the WANA region, the dissemination of improved technologies does not usually take into consideration the specificities of the agro-ecosystems. Consequently, the efficiencies of the technology transfer programs remain low. The benchmark project has proposed an approach that helps identify areas similar to those where the improved technologies were developed. This approach starts with the selection and characterization of a benchmark site in an agro-ecosystem; then improved technologies are developed and evaluated in this site and, finally, similar areas to the benchmark site are identified and mapped to better target the out-scaling on a large scale.

Methodology

The process of similarity analysis is explained in Figure 1. The similarity maps were first generated using criteria initially suggested by a group of experts from the eight participating countries and ICARDA (Table 2), and using the available coarse resolution data for the whole WANA region. The similarity maps were prepared and the results were discussed in a workshop with the experts involved in the implementation of the work conducted at the benchmark sites. These experts also had an accumulated knowledge of the bio-physical conditions within their individual countries (Egypt, Sudan, Morocco, Jordan, Algeria, Iraq, Yemen, and Palestine). After the evaluation of the results by the participants, the criteria were revised for the three benchmark sites. Accordingly, and based on their experience, the participants suggested many modifications that helped to improve the analysis (Table 2). The participants were committed to sharing high quality data at the national level to improve the quality of the output maps. The modifications are explained below.

Rainfed benchmark – supplementary irrigation – Morocco:

The multi-disciplinary team suggested some modifications to the criteria Table 1:

- Rainfall: the maximum rainfall amount be reduced from 600 mm to 500 mm since areas that receive more than 500 mm may not need supplementary irrigation
- Slope: the slope remained up to 5%, to avoid soil erosion
- Crops: winter crops are chosen since supplemental irrigation is a method that can be used to compensate for the deficiency of rainfall during certain periods of winter.

Irrigated benchmark – raised-bed technology – Egypt:

The multi-disciplinary team suggested the following changes:

- Rainfall: the rainfall amount be changed from less than 100 mm to less than 250 mm, since some parts of Egypt and other countries receive between 200 and 250 mm and they use raised-bed technology
- Soil: the soil should not be sandy (less than 90% sand), in order to avoid water drainage and increase water storage.

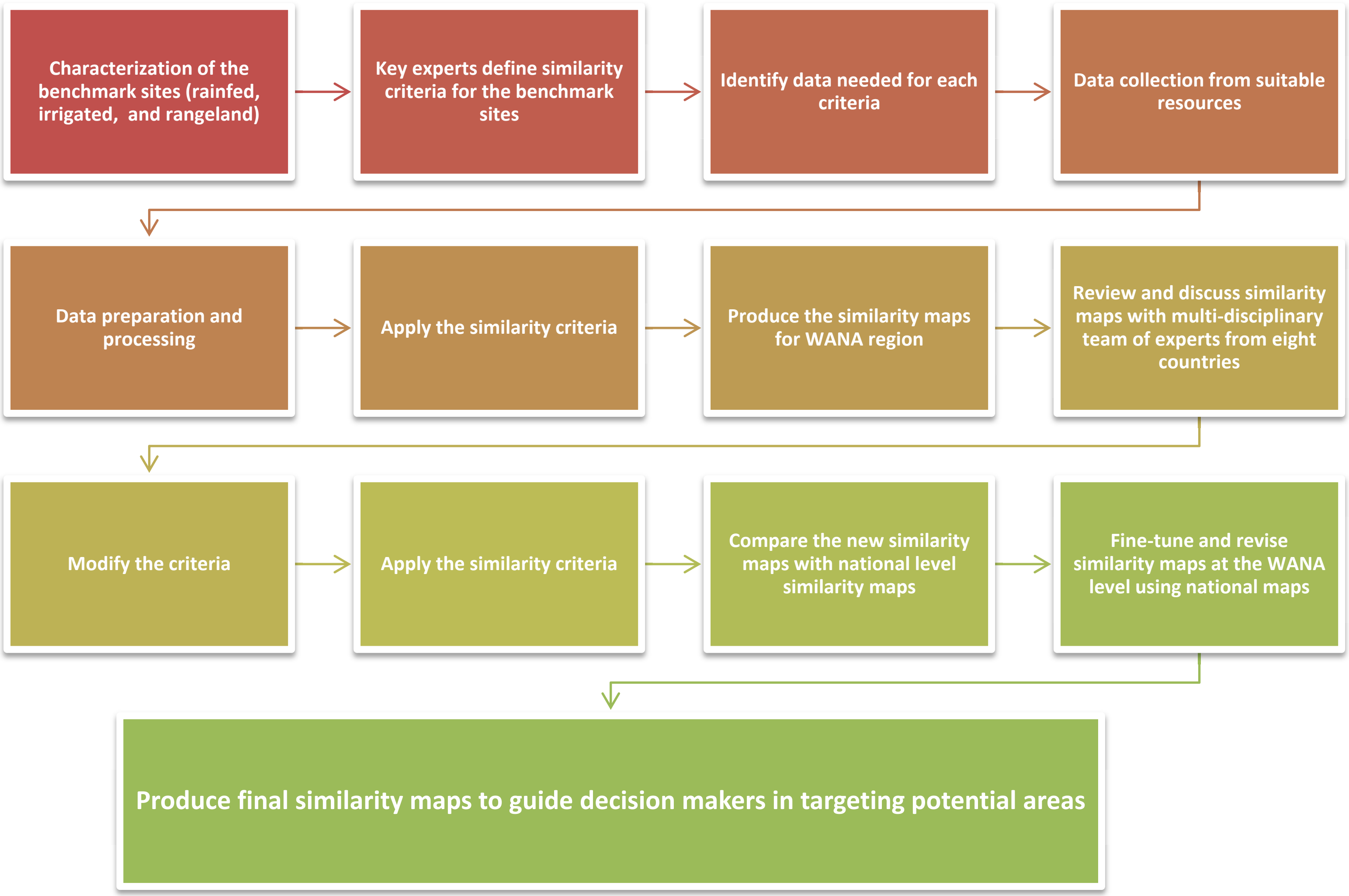


Figure 1: Similarity analyses process

Pastoral (rangeland) benchmark – water harvesting – Jordan:

The rangeland benchmark criteria were subjected to some changes, such as in the slope. The soil texture was added as sandy soils are not suitable for runoff and water storage Table 2. It was agreed that a soil depth of 60 cm is very suitable for storing water under the water-harvesting system.

Characteristics of the benchmark sites

Since the project started in 2004; a lot of good experience and scientific knowledge has been accumulated in the field. With this field experience and scientific knowledge the best land and environmental characteristics for water and land management practices have been developed and adopted. Table 1 shows the important criteria that define the benchmark sites.

Spatial verification of similarity results using data from participating countries

The suggested modifications to the criteria of the similarity analysis were re-checked by the multi-disciplinary team and were then used in the geographic information system (GIS) software to generate new similarity maps. These were also overlaid with other maps, in various formats, that had been brought by the participants from the different countries.

Because of differences in the pixel size and resolution of the data used for land use and soil data, some lands in the irrigated benchmark area in Egypt were not covered by the similarity maps. This issue was solved by using better data collected at the national level. This highlighted the importance of verifying the results of the regional analysis using data at the national level.

A comparison of the maps for the WANA region with those at the national levels was used to fine-tune and adjust the former. The generated maps identified the potential areas for the out-scaling of the technologies developed at the three benchmark sites.

Table 1: Important benchmark site characteristics

Benchmark	Criterion	Range/classes
Rainfed in Morocco	Rainfall	200–600 mm
	Land that is cultivated	Crop lands
	Slope	Up to 25%
Irrigated in the Nile Delta, Egypt	Water resources	Permanent water resources
	Land that is cultivated	Crop lands
	Soil texture	All soil texture classes
	Slope	< 5%
Rangeland in the Jordan Badia	Rainfall	50-300 mm
	Land that is cultivated	< 50% vegetation cover
	Slope	0–50%
	Soil texture	All soil texture classes

Table 2: Benchmark criteria

Benchmark	Criterion	Original	Adjusted (by the multi-disciplinary team)
1. Rainfed	Rainfall	250–600 mm	250–500
	Water resources	Available for supplemental irrigation	Available for supplemental irrigation
	Land that is cultivated	Crop lands	Crop lands
	Crops	Winter crops based system	Winter crops based system
	Slope	Up to 5%	Up to 5%
2. Irrigated	Rainfall	< 100 mm	< 250 mm
	Water resources	Available for supplemental irrigation	Available for supplemental irrigation
	Land that is cultivated	Crop lands	Crop lands
	Soil texture	All classes except sandy	Less than 90% sand
3. Rangeland	Rainfall	100–300 mm	100–300 mm
	Soil depth	60 cm	60 cm
	Land is cultivated	< 30% vegetation cover	< 30% vegetation cover
	Slope	Up to 30%	Up to 20%
	Soil texture	All classes except sandy	Less than 90% sand

Data collection process

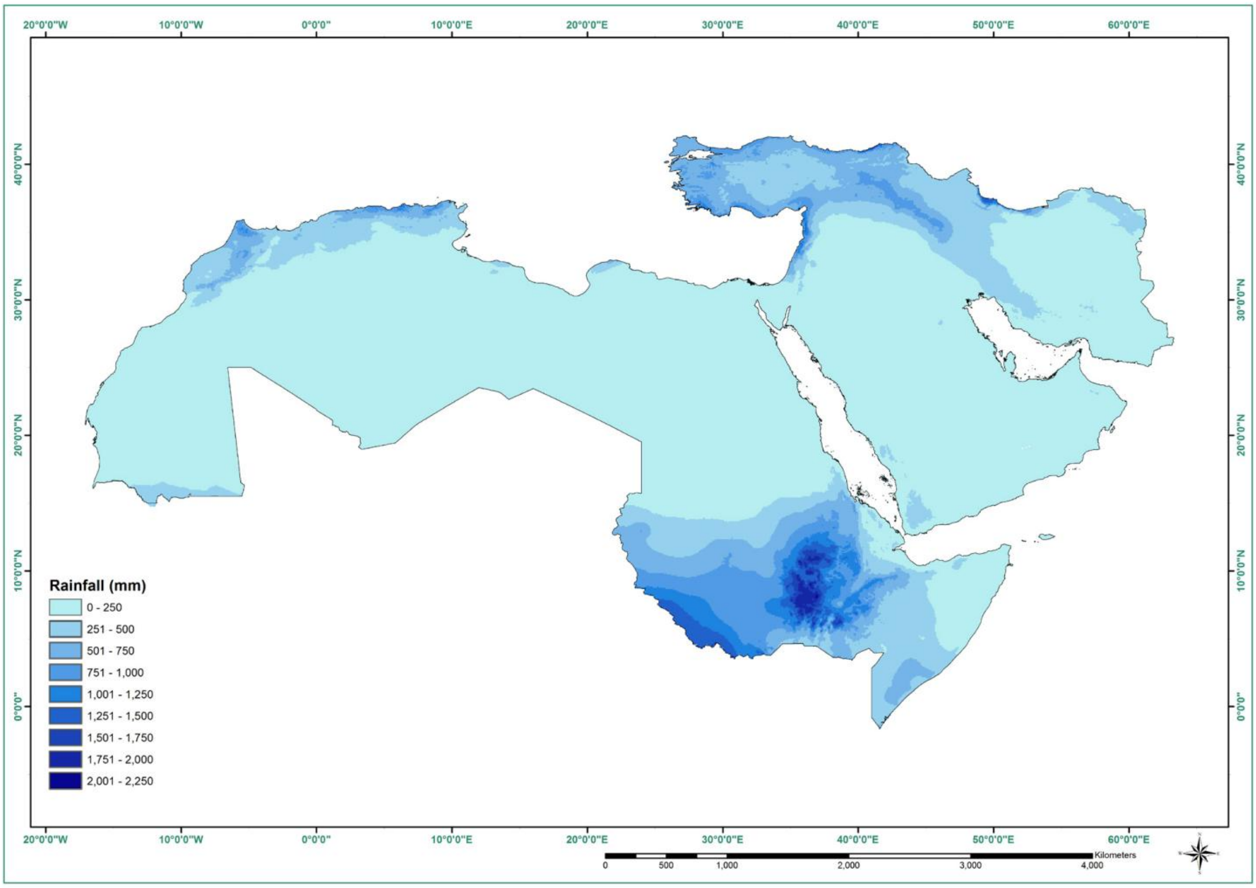
To conduct the similarity analysis according to the different benchmark criteria, the data were collected from various sources – Texas A&M University (TAMU), United States Geological Survey (USGS), Food and Agriculture Organization of the United Nations (FAO), and the United Nation University (UNU). A summary of the data needed for the similarity analysis is provided in Table 3.

The lowest raster size of the collected data was 500 m by 500 m, so all the rasters have been re-sampled in a GIS environment using the Resample function to proceed with the similarity analysis.

Rainfall data

The rainfall data was collected from the global weather data for the SWAT, published by TAMU AgriLife Research, Cornell University, International Water Management Institute (IWMI), National Oceanic and Atmospheric Administration, and ICARDA.

The data is organized by the National Centers for Environmental Prediction (NCEP) and Climate Forecast System Reanalysis (CFSR) and it was completed over the 32-year period, 1979 through 2010. The database provides global coverage of annual precipitation, as well as other climatic parameters, on an hourly basis, presented in raster format with a size of 8000m. The raster was re-sampled to a raster size of 500 m and clipped to the study area (Map 2).



Data source: Texrs A&M University – Global weather data for SWAT website: Http://globalweather.tamu.edu

Map 2: Rainfall distribution within WANA region

Land use data

Data for land use was collected from the USGS website, which provides the data for land cover type yearly L3 global 500 m sin grid. The moderate resolution imaging spectroradiometer (MODIS) land cover type product (short name, MCD12Q1) provides data characterizing five global land cover classification systems as listed below. It also provides a land cover type assessment and quality control information.

1. Land cover Type 1: IGBP global vegetation classification scheme
2. Land cover Type 2: University of Maryland (UMD) scheme
3. Land cover Type 3: MODIS-derived LAI/FPAR scheme
4. Land cover Type 4: MODIS-derived net primary production (NPP) scheme
5. Land cover Type 5: plant functional type (PFT) scheme

The MODIS Terra + Aqua land cover type yearly L3 Global 500 m sin grid product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method. The MODIS land cover type product contains five classification schemes, which describe land cover properties derived from observations spanning a year's input of terra- and aqua-MODIS data.

The primary land cover scheme identifies 17 land cover classes, defined by the International Geosphere-Biosphere Programme (IGBP), which include 11 natural vegetation classes, 3 developed and mosaiced land classes, and three non-vegetated land classes.

Each land cover type has land cover type descriptions as shown in Tables 4 and 5.

Table 3. Data needed for the similarity analysis and their sources

Data	Source
Rainfall	Global weather data for soil and water analysis tool (SWAT) Http://globalweather.tamu.edu/
Land use	Land Processes Distributed Active Archive Center (LP DAAC), USGS Https://lpdaac.usgs.gov/products/MODIS_products_table/mcd12q1
Soil	Soil depth 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 Soiltexture FAO GeoNetwork, digital Soil Map of the World http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116 Othersoildata Harmonized world soil database (HWSD) –Version 1.2 http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
Water	Global lakes and wetlands database 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 World linear water and world water bodies Layers available with ArcGIS 10.1 from Environmental Systems Research Institute; these layers can be downloaded from http://www.arcgis.com/home/item.html?id=e750071279bf450cb-d510454a80f2e63 and from http://www.arcgis.com/home/item.html?id=273980c20bc74f94ac-96c7892ec15aff
Digital elevation model	CGIAR CSI – SRTM 90 m digital elevation data http://srtm.csi.cgiar.org/

Table 4: *Land cover types description (1 through 4 classification schemes)

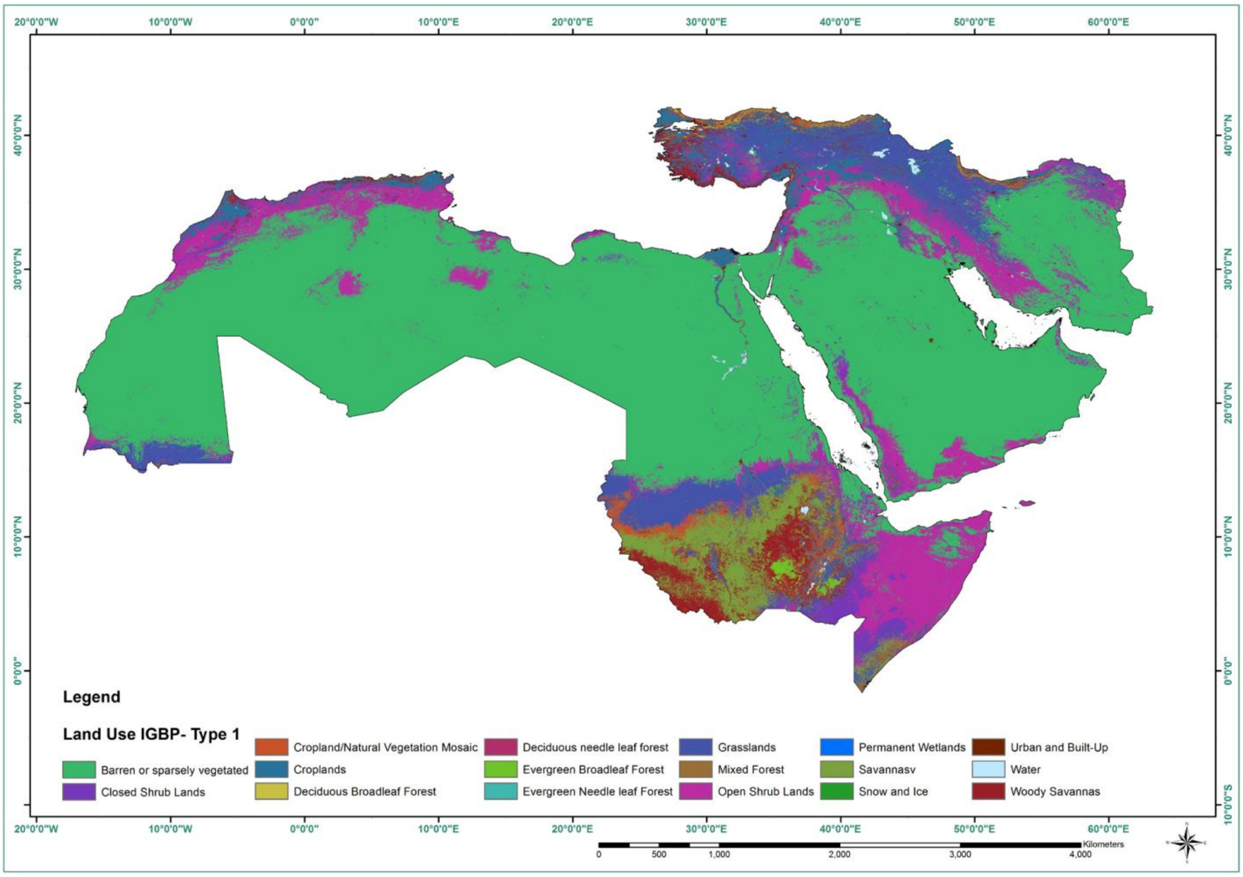
CLASS	IGBP (Type 1)	UMD (Type 2)	LAI/FPAR (Type 3)	NPP (Type 4)
0	Water	Water	Water	Water
1	Evergreen needleleaf forest	Evergreen needleleaf forest	Grasses/cereal crops	Evergreen needleleaf vegetation
2	Evergreen broadleaf forest	Evergreen broadleaf forest	Shrubs	Evergreen broadleaf vegetation
3	Deciduous needleleaf forest	Deciduous needleleaf forest	Broadleaf crops	Deciduous needleleaf vegetation
4	Deciduous broadleaf forest	Deciduous broadleaf forest	Savanna	Deciduous broadleaf vegetation
5	Mixed forest	Mixed forest	Evergreen broadleaf forest	Annual broadleaf vegetation
6	Closed shrublands	Closed shrublands	Deciduous broadleaf forest	Annual grass vegetation
7	Open shrublands	Open shrublands	Evergreen needleleaf forest	Non-vegetated land
8	Woody savannas	Woody savannas	Deciduous needleleaf forest	Urban

CLASS	IGBP (Type 1)	UMD (Type 2)	LAI/FPAR (Type 3)	NPP (Type 4)
9	Savannas	Savannas	Non-vegetated	
10	Grasslands	Grasslands	Urban	
11	Permanent wetlands			
12	Croplands	Croplands		
13	Urban and built-up	Urban and built-up		
14	Cropland/natural vegetation mosaic			
15	Snow and ice			
16	Barren or sparsely vegetated	Barren or sparsely vegetated		
254	Unclassified	Unclassified	Unclassified	Unclassified
255	Fill value	Fill value	Fill value	Fill value

Table 5:. Land cover types description (Type 5 classifications)**

CLASS	PFT (Type 5)
0	Water
1	Evergreen needleleaf trees
2	Evergreen broadleaf trees
3	Deciduous needleleaf trees
4	Deciduous broadleaf trees
5	Shrub
6	Grass
7	Cereal crops
8	Broadleaf crops
9	Urban and built-up
10	Snow and ice
11	Barren or sparse vegetation
254	Unclassified
255	Fill value

The land cover Type 1: IGBP global vegetation classification scheme was chosen since it contains the land-use patterns dominating in the WANA region and, therefore, they could be used in the similarity analysis. The land cover Type 1 data are represented in a raster format with a pixel size of 500 m x 500 m; the raster clipped within the study area as shown in Map 3.



Data source: LP DAAC, USGS website: https://lpdaac.usgs.gov/products/MODIS_products_table/mcd12q1

Map 3: Land cover Type 1 classification of land use

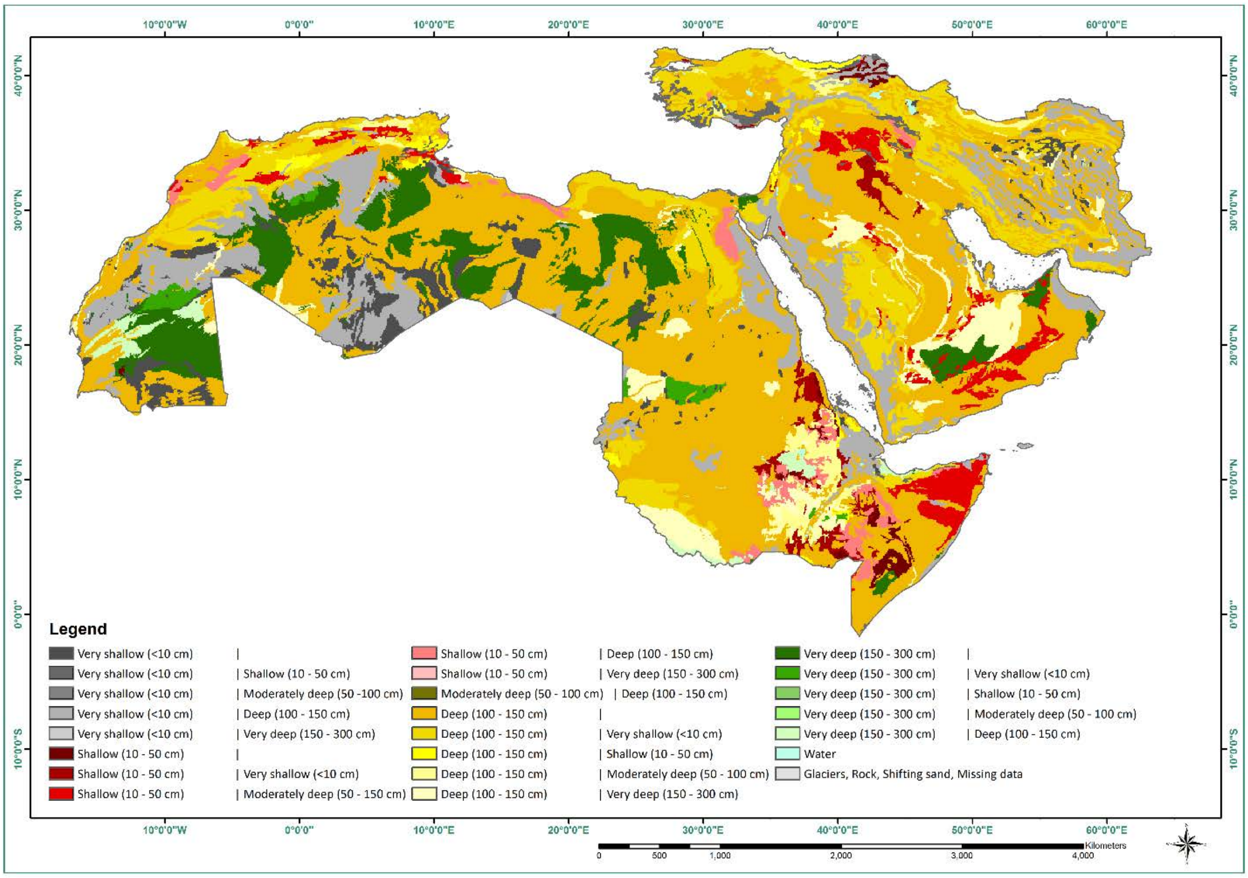
Soil depth data

The original data consist of a raster format 'tiff' with a pixel size of (0.08333333 inch by 0.08333333 inch); the raster is classified into 24 sections. These sections consist of two digits where the first digit indicates the dominant class and the second digit indicates the associated class. The same classes are used in the first and second digits, except that a zero as a second digit indicates that the class pointed by the first digit occurs in more than 80% of the pixel. All the 24 sections classified the soil depth into the main five classes as follows:
1: Very shallow (< 10 cm)
2: Shallow (10–50 cm)
3: Moderately deep (50–100 cm)
4: Deep (100–150 cm)
5: Very deep (150–300 cm)
97: Water
99: Missing data

The soil depth classes refer to:

- Soils are considered < 10cm deep if they occur on the map as rock, lithosols (I), glaciers, or as salt flats.
- Soils are considered to be between 10 and 50 cm deep if they are classified as rendzinas (E), rankers (U), or have a lithic phase. In addition, half of the area of soils with a petrocalcic, petrogypsic, petroferric, or duripan phase is considered to have an effective soil depth of between 10 and 50 cm.
- Soils are considered to have an effective soil depth of between 50 and 100 cm for the other half of the area (see 2. above) characterized by a petrocalcic, petrogypsic, petroferric, or duripan phase. In addition, other soils than those given above, occurring on steep slopes (> 30%) or having permafrost are considered for half of their area to have a soil depth of between 50 and 100 cm.
- All other soils are considered to have an effective soil depth of between 100 and 150 cm except nitosols (N), ferralsols (F), and histosols (O), when not occurring on slopes of more than 30%, and not having permafrost, which is assumed to be between 150 and 300 cm deep.

Preparing the WANA soil depth layer
For each raster section value, the dominant soil class and the associated soil class have been added and the resulting raster has been re-sampled and clipped to the project study area (Map 4).



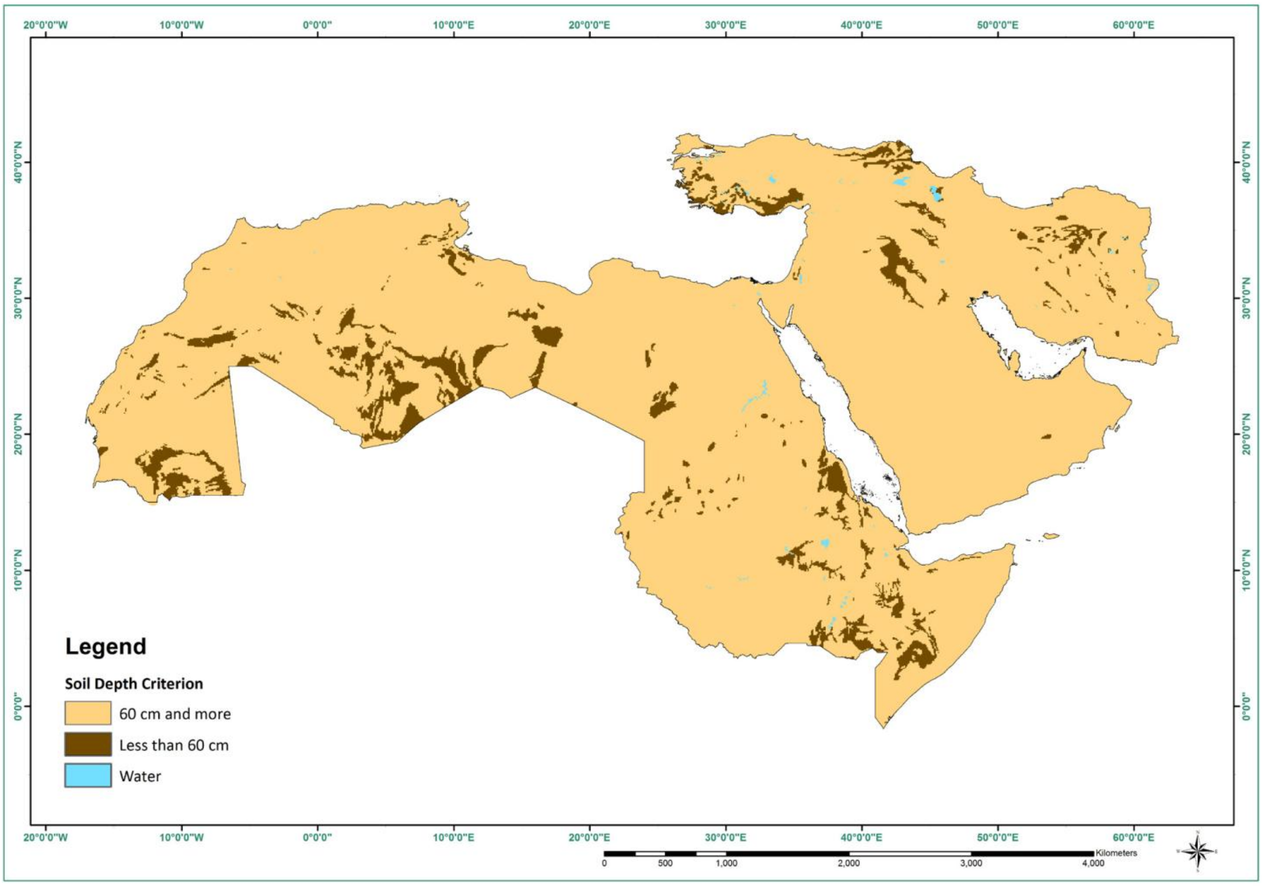
Data source: FAO- Effective soil depth (cm) map website: http://data.fao.org/map?entryId=c3bfc940-bdc3-11db-a0f6-000d939bc5d8
and WaterBase project website: http://www.waterbase.org/download_data.html

Map 4: Soil depth classification within WANA region

According to the agreed and adjusted soil depth criterion the soil depth raster is classified into two categories (Map 5: Soil depth criterion):

1. Soil depth ≥ 60cm
2. Soil Depth < 60 cm

Map 5: Soil depth criterion shows the classification of the soil depths according to the benchmark criterion.



Data source: FAO Effective soil depth (cm) map website: http://data.fao.org/map?entryId=c3bfc940-bdc3-11db-a0f6-000d939bc5d8 and WaterBase project website: Http://www.waterbase.org/download_data.html

Map 5: Soil depth criterion

Soil texture data

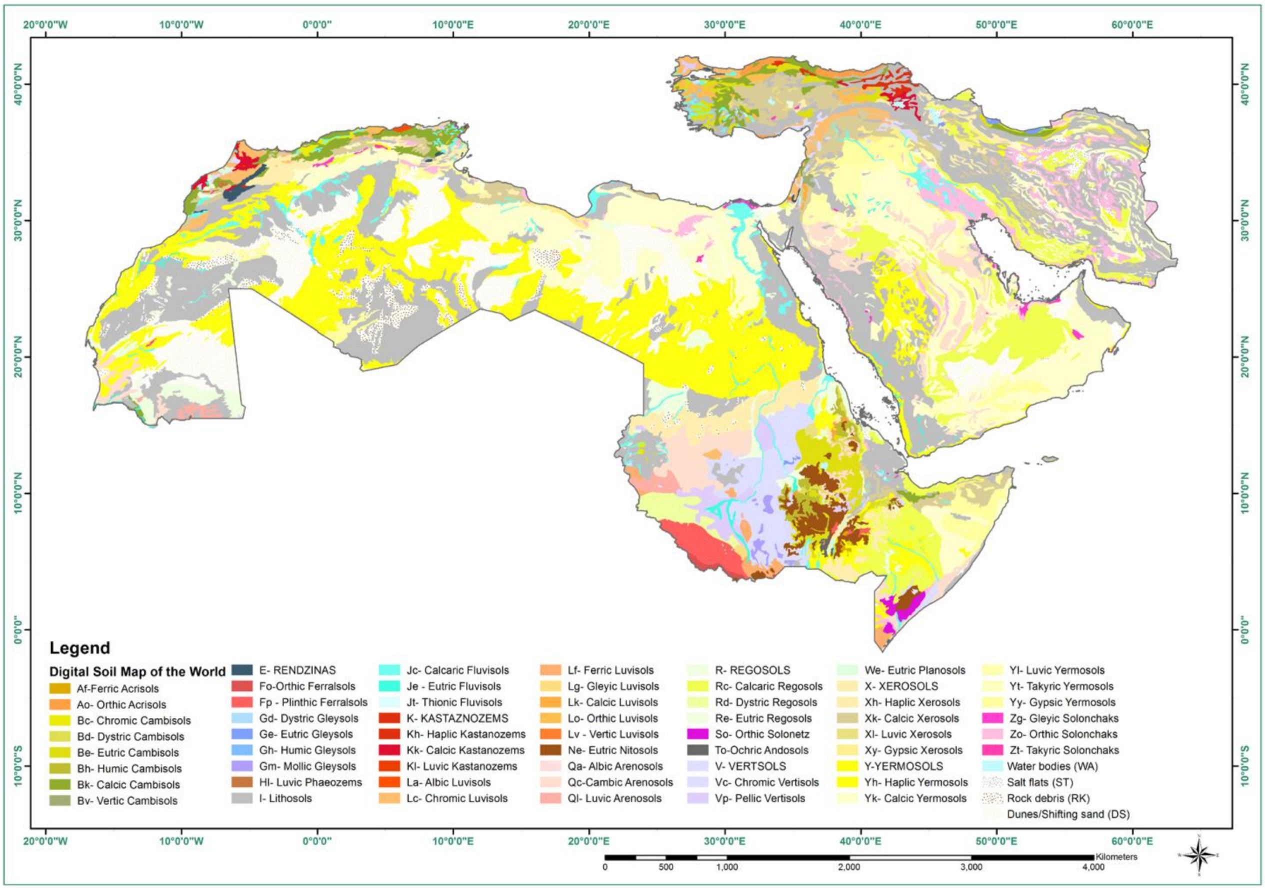
The data for soil texture was collected from the FAO digital Soil Map of the World version 3.6, completed January 2003.

The FAO has collected soil profile information from field projects. The soil profile information is contained in the volumes that accompany the Soil Map of the World (FAO-UNESCO, 1971-1981), that is published in Soil Taxonomy (Soil Survey Staff, 1972) and was released by World soil Information (ISRIC). In total, 1700 soil profiles were analyzed and grouped by the FAO Soil Unit and Topsoil Texture group.
A statistical (weighted) average was calculated for the topsoil (0–30 cm) and for the subsoil (30–100 cm) for the following chemical and physical parameters: sand%top, sand%sub, silt%top, silt%sub, clay%top, clay%sub, pH_2O-top, pH_2Osub, OC%top, OC%sub, N%top, N%sub, BS%top, BS%sub, CECtop, CECsub, CECclaytop, CECclaysub, $CaCO_3$%top, $CaCO_3$%-sub, BDtop, BDsub, C/Ntop, and C/Nsub.
Information on the soil mapping unit composition is contained in an Excel file and it includes 99 fields. The structure of this data file is as follows:

1. Soil mapping unit number
2. Soil mapping unit symbol (similar to the one on the paper map)
3. Phase number (between 1 and 12) followed by permafrost information (if applicable)
4. Dominant soil unit (FAO-UNESCO). Map 6
5. Percentage of dominant soil unit (soil unit 1)
6. Composition of soil unit 1 (% that belongs to texture-slope class 1a, 1b, 1c, 2a. 2b, 2c, 3a, 3b, 3c, and 4d)
7. First associated soil unit (legend symbol soil unit 2)
8. Percentage of first associated soil unit
9. Composition of soil unit 2 (% that belongs to texture-slope class 1a, 1b, 1c, 2a, 2b, 2c, 3a, 3b, 3c, and 4d)

88. Soil unit 8 (legend symbol)
89. Percentage of soil unit 8
90. Percentage of soil unit 8 that belongs to texture-slope class 1a, 1b, 1c, 2a, 2b, 2c, 3a, 3b, 3c, and 4d)

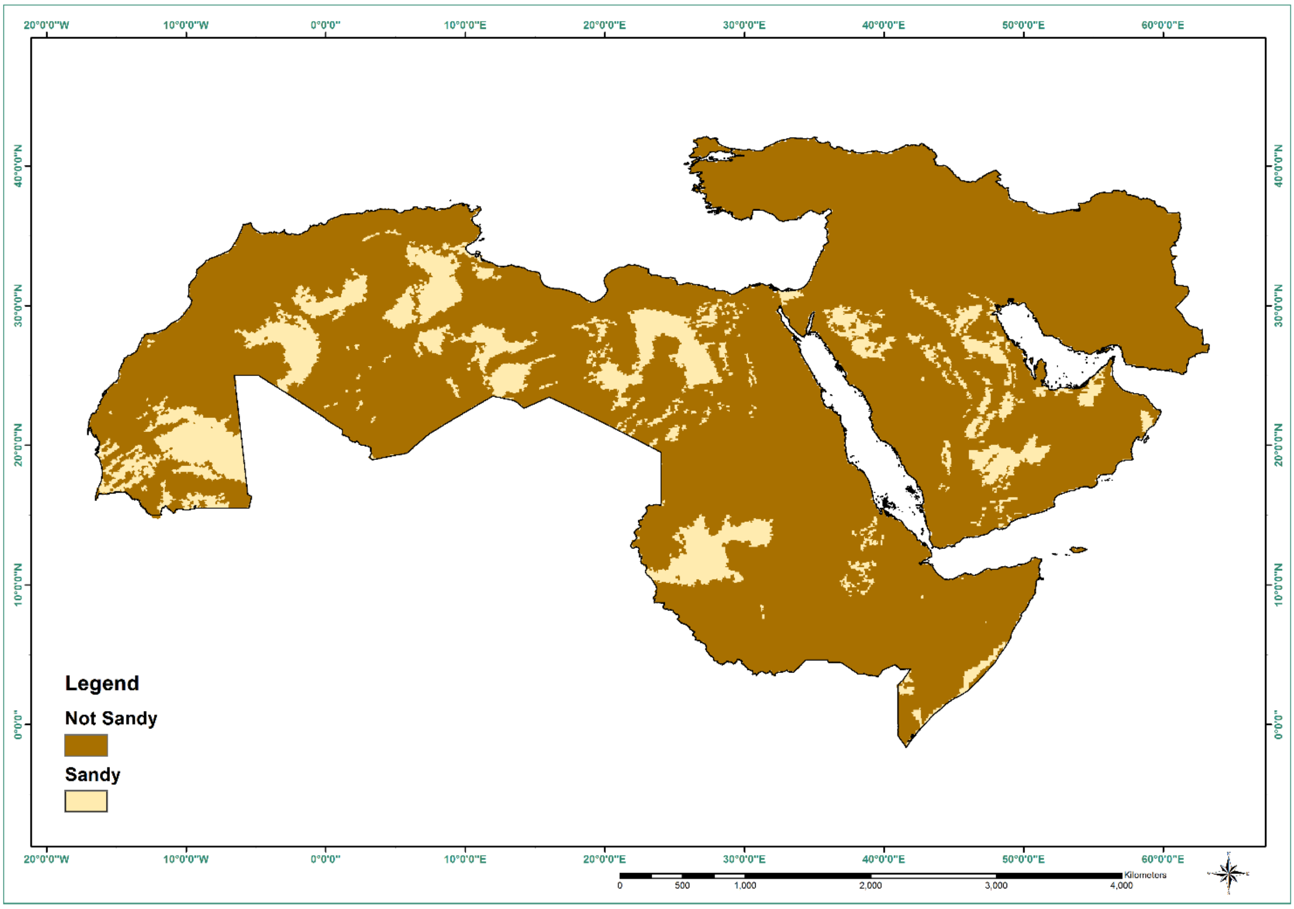
1, 2 and **3** stand, respectively, for **coarse, medium** and **fine textures** and **a, b, c** stand, respectively, for **flat (0–8% slope), undulating (8–30% slope),** and **hilly (> 30% slope)**. The dominant soil unit legend is shown in Map 6.



Data source: FAO– GeoNetwork, digital Soil Map of the World website:
http://www.fao.org/geonetwork/srv/en/metadatashow?id=14116

Map 6: Dominant soil unit (FAO-UNESCO)

To prepare the soil texture map for the similarity analysis the 'Con' function in the GIS toolbox was used to separate each soil texture in a different raster; a raster for each soil texture was created to show soils that are not sandy (sand less than 90%) as presented in Map 7. Soil texture.



Data source: Food and Agriculture Organization – GeoNetwork, Digital Soil Map of the World website: http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116

Map 7: Soil texture

Irrigation water resources data

In order to decide whether an area could be used for supplemental irrigation or not, information about the availability of water resources is needed. The global lakes and wetlands database (GLWD) is used to identify permanent water sources. This database has been developed and published since 2004 by Bernhard Lehner and Petra Döll in partnership with the Center for Environmental Systems Research (CESR), University of Kassel, Germany and the US office of the World Wildlife Fund (WWF-US). The database has been generated using and incorporating data derived from proprietary products of the Environmental Systems Research Institute, Inc. (ESRI), UNEP World Conservation Monitoring Centre (UNEP-WCMC), and others.

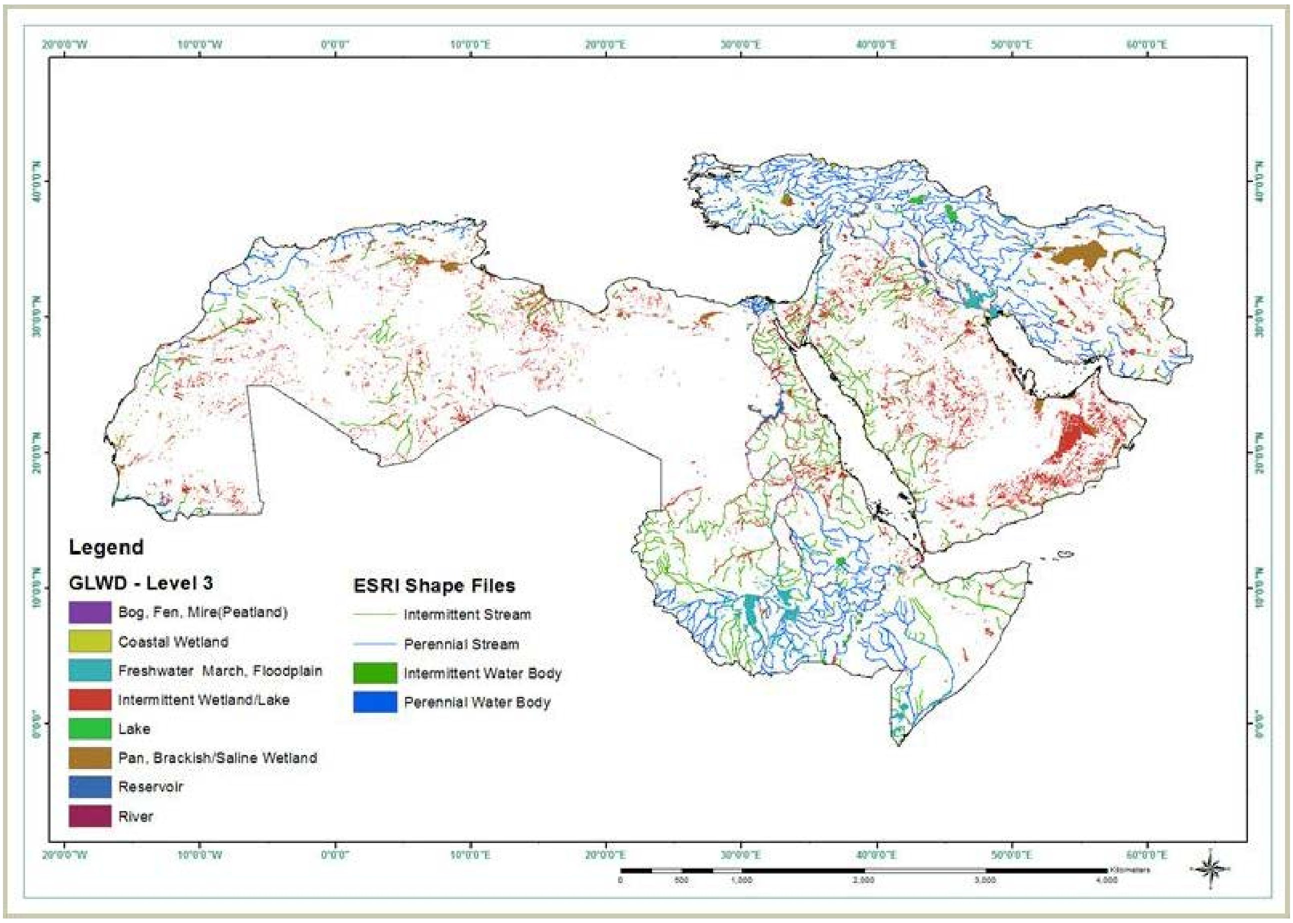
The data combination of the best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution) and the application of GIS functionality, enabled the generation of a database which focuses on three coordinated levels:

1. Level 1 (GLWD-1) comprises the shoreline polygons of the 3067 largest lakes (area = 50 km^2) and 654 largest reservoirs (storage capacity = 0.5 km^3) worldwide, and includes extensive attribute data
2. Level 2 (GLWD-2) comprises the shoreline polygons of permanent open water bodies with a surface area greater than 0.1 km^2 excluding the water bodies contained in GLWD-1. The approximately 250,000 polygons of GLWD-2 are attributed as lakes, reservoirs, and rivers
3. Level 3 (GLWD-3) comprises lakes, reser-

voirs, rivers, and different wetland types in the form of a global raster map at 30-second resolution. For GLWD-3, the polygons of GLWD-1 and GLWD-2 were combined with additional information on the maximum extents and types of wetlands.

World linear water and World water bodies are two layers available in the ArcGIS 10.1 package from ESRI. The World linear water (a line shapefile) provides all rivers and streams of the world and World water bodies (a polygon shapefile) provides the lakes, seas, oceans, and large rivers of the world. Both of the data sets classify the water lines and bodies into perennial and intermittent sources.

This data is being used with the Global Lakes and Wetland database to verify the locations of the permanent water sources as sources of irrigation water. Map 8 shows GLWD-3 and the ESRI shapefiles in WANA region.



Data Source: Global lakes and wetlands database and World linear water and World water bodies, websites: Http://worldwildlife.org/pages/global-lakes-and-wetlands-database, http://www.arcgis.com/home/item.html?id=e750071279bf450cbd510454a80f2e63, and http://www.arcgis.com/home/item.html?id=273980c20bc74f94ac96c7892ec15aff.

Map 8: Water sources In the WANA region

The dams' database, downloaded from the FAO AQUASTAT website as an Excel sheet, includes different information which was used for this purpose Table 6.

The database, in its present format, is neither complete nor can it be considered error-free. It corresponds to the best available information published as of 14 March 2011 and revised 20 June 2013. The references used for the database were:

i. International commission on large dams (ICOLD), 2007; the world register of dams
ii. National reports
iii. Information obtained from national experts through AQUASTAT national surveys
iv. An April 2010 version of global reservoir and dam (grand) database
v. The internet.

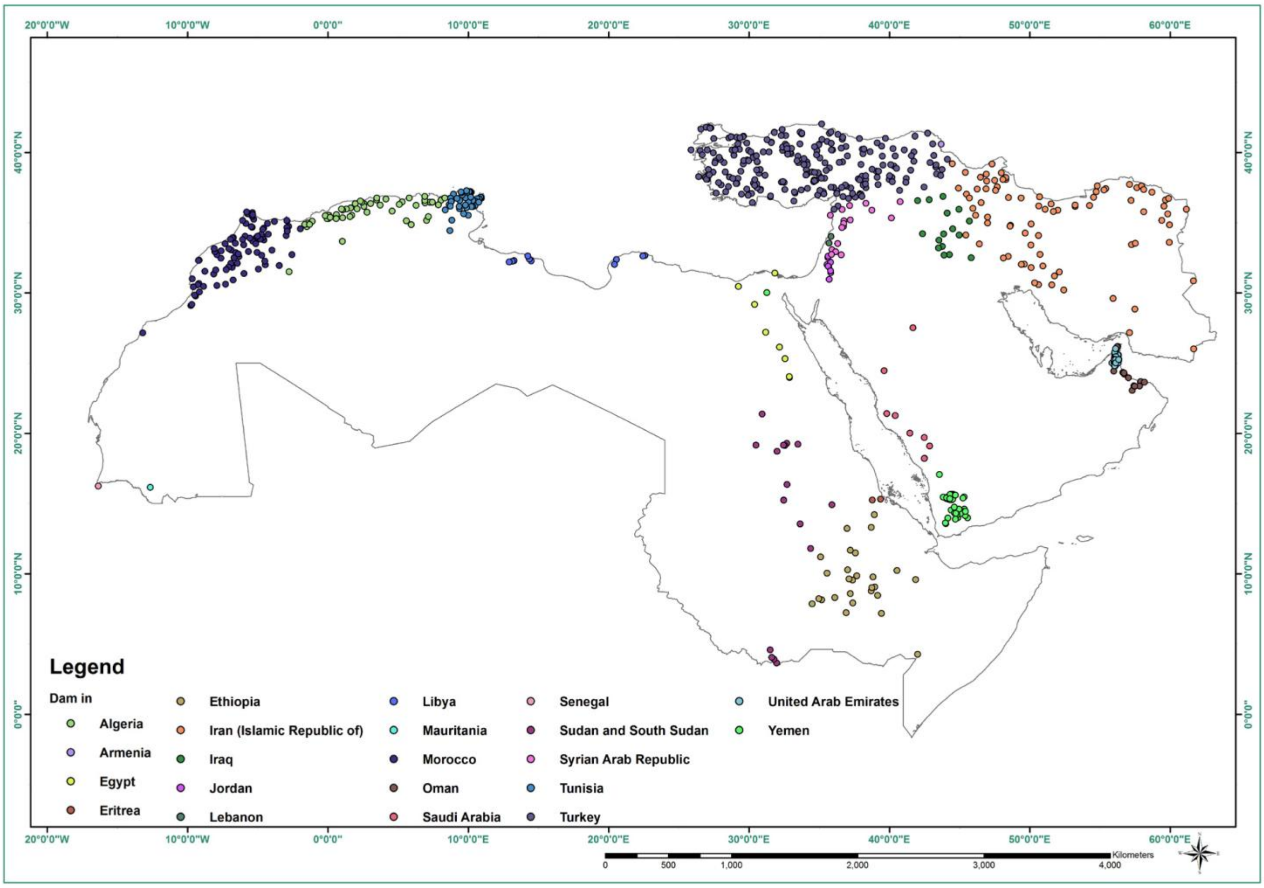
Table 6: Explanation of the fields of the dams' database in Excel

Column title	Explanation
Name of dam	The name of the dam
Country	The name of the country in which the dam is located
ISO alpha-3	Country codes used by the UN
Administrative unit	The name of the sub-national administrative unit in which the dam is located. Was often determined using the Genetic Algorithm Utility Library (GAUL) dataset
Nearest city	The name of the city closest to where the dam is located
River	The name of the river on which the dam is located
Major basin	The name of the major river basin in which the dam is located
Sub-basin	The name of the sub-basin in which the dam is located
Completed/operational since	Year in which the dam was completed, operational, or improved
Dam height	Height of the dam in meters. The precision given is two decimals (cm), although most of the available figures are given with a precision of 1 meter
Reservoir capacity	Capacity of reservoir in million (1,000,000) m^3 (this is equivalent to hectometer^3). It refers to the initial capacity, not taking into consideration the reduction in volume resulting from sedimentation
Sedimentation rate	Proportion of initial capacity lost to sedimentation (%). This information is updated to the latest known
Reservoir area	Surface area of the reservoir in km^2
Irrigation	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Water supply	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Flood control	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Hydroelectricity	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Navigation	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Recreation	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Pollution control	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Livestock rearing	An 'x' here denotes the dam is used for this purpose. Check the comment for potential additional details
Other	Purpose of the dam other than the eight above. Check the comment for potential additional details
Decimal degree latitude	Latitude coordinate of the dam, expressed in decimal degrees
Decimal degree longitude	Longitude coordinate of the dam, expressed in decimal degrees
National reference(s)	Number of references providing information on the dam, coming from a national source. The references are given in the notes and references of the regional file
Other reference(s)	Number of references providing information on the dam, coming from a global or general source (for example ICOLD). The references are given in the notes and references of the regional file
Notes	In this column specific comments of importance to the dam are given

The dams' database was downloaded for two regions:

1. Geo-referenced database on dams in the Middle East
2. Geo-referenced database on dams in Africa.

Databases for the two regions included 1562 dams in Africa and 1127 dams in the Middle East. Inside the databases, 416 dams do not have geographic coordinates, so the dams without coordinates were geocoded according to the closest city or administrative unit associated with each. The resulting shapefile has been clipped into the study area. Map 9 shows the distribution of dams within the WANA region.



Data source: FAO AQUASTAT global water information system websites:
http://www.fao.org/nr/water/aquastat/main/index.stm

Map 9: Distribution of dams within the WANA region

Digital elevation model (DEM)

The DEM was downloaded from the CGIAR CSI website. The CGIAR CSI geo-portal provides shuttle radar topography mission (SRTM) 90 m digital elevation data for the entire world. The SRTM digital elevation data, produced originally by NASA, is a major breakthrough in digital mapping and provides a major advance in the accessibility of high quality elevation data for large portions of the tropics and other areas of the developing world.

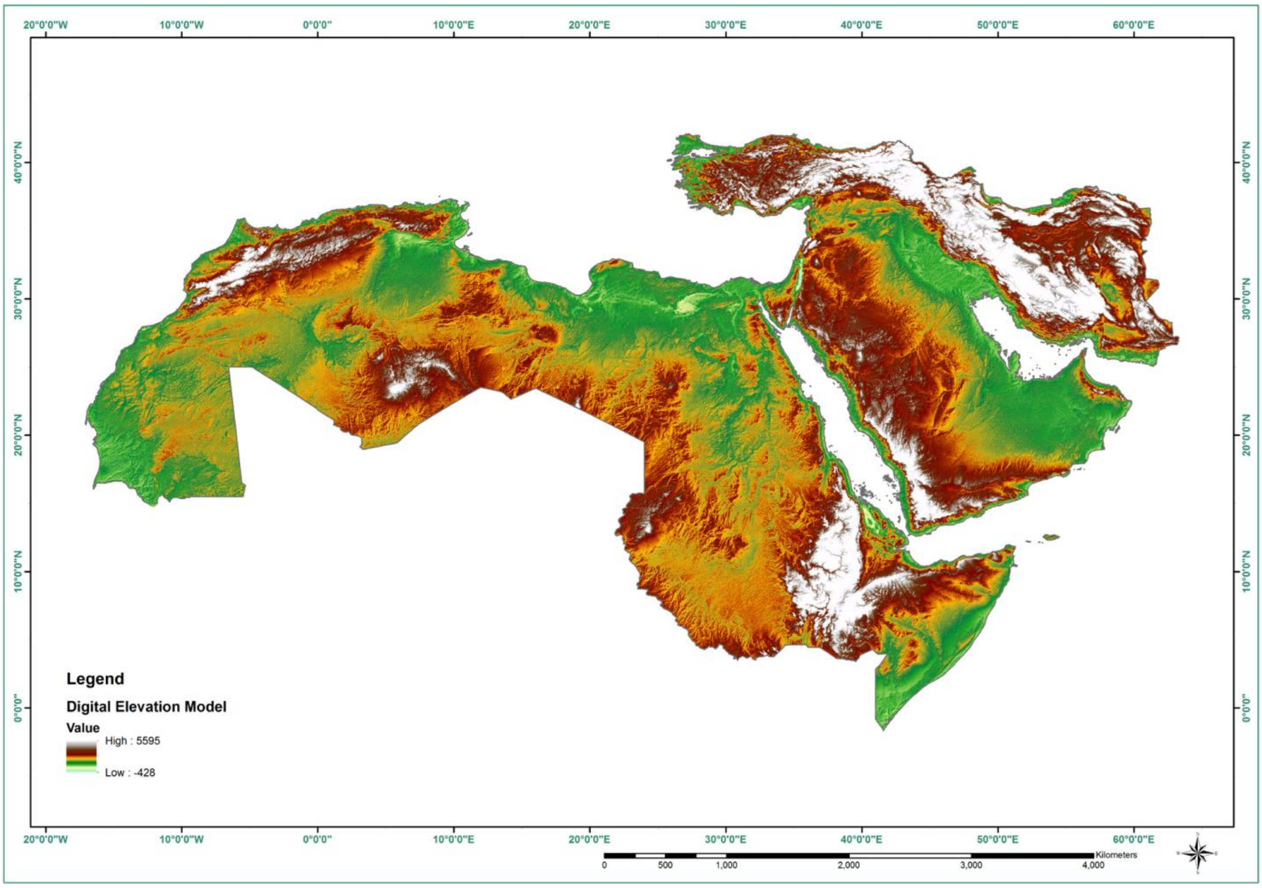
The SRTM digital elevation data provided has been processed to fill data voids and to facilitate ease of use by a wide group of potential users. This data is provided in an effort to promote the use of geospatial science and applications for sustainable development and resource conservation in the developing world.

The SRTM 90 m DEM's have a resolution of 90 m at the equator, and are provided in mosaicked 5° x 5° tiles for easy download and use. All are produced from a seamless dataset to allow easy mosaicing. These are available in both ArcInfo ASCII and GeoTiff format to facilitate their ease of use in a variety of image processing and GIS applications.

The NASA SRTM has provided DEM data for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National map seamless data distribution system, or the USGS ftp site. The SRTM data is available as 3 arc second (approximately 90 m resolution) DEMs. A 1 arc second data product was also produced, but it is not available for all countries. The vertical error of the DEM is reported to be less than 16 m. The data currently distributed by NASA/USGS (finished product) contains 'no-data' holes where water or heavy shadow prevented the quantification of elevation. These are generally small holes, which nevertheless render the data less useful, especially in the field of hydrological modeling.

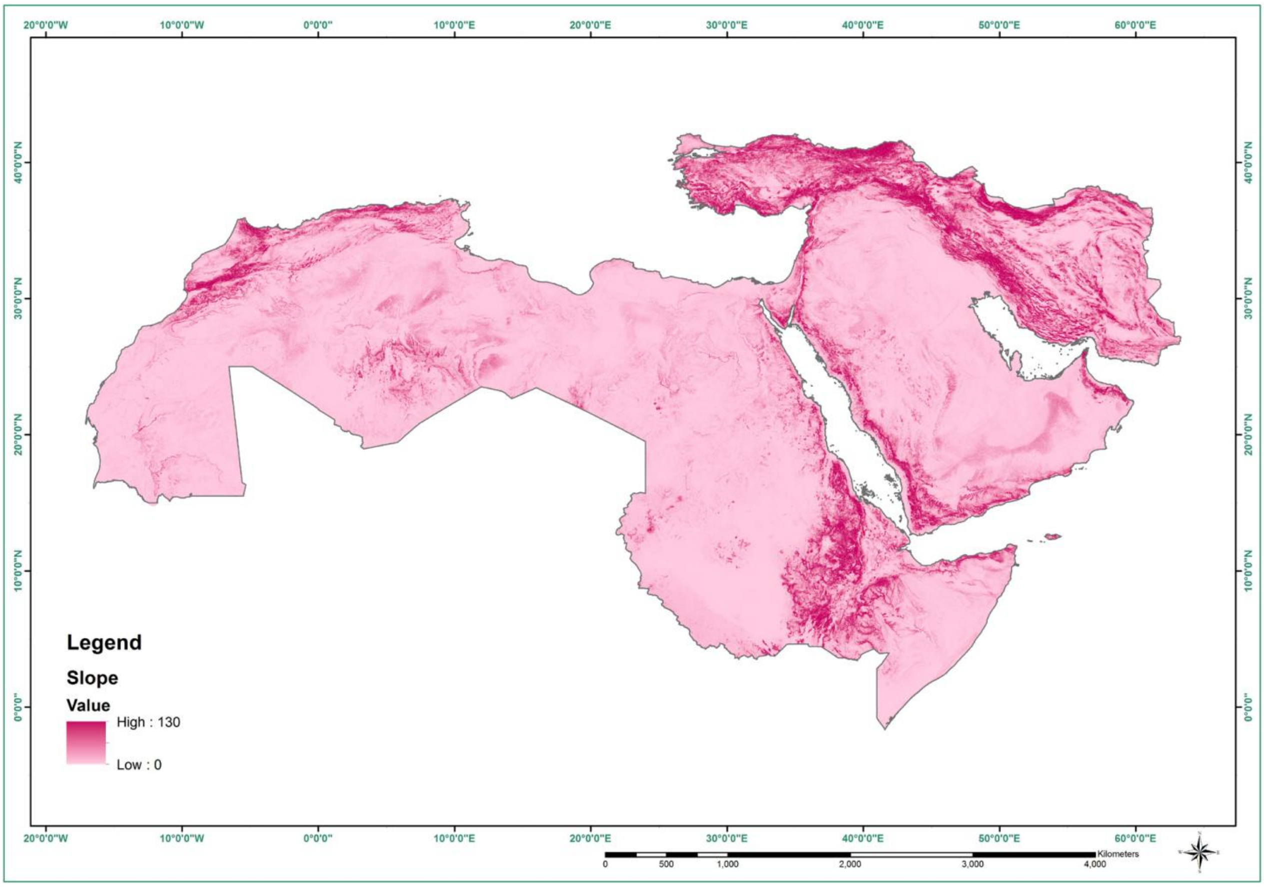
In order to have a DEM for the study area, the SRTM 90 m DEMs for 134 geographical sections were downloaded. All these sections were then mosaicked into one raster and this raster clipped to the study area as shown in Map 10.

To create a slope map for the WANA region, the original DEM (spatial reference GCS_WGS_1984) was re-projected to a geographic coordinate system (WGS 84/World Mercator) and re-sampled to a raster size of 500 m by 500 m, then the slope layer was created as a percentage, as shown in Map 11.



Data source: CGIAR CSI SRTM 90 m digital elevation data website: http://srtm.csi.cgiar.org/

Map 10: Digital Elevation Model 90 m



Data source: CGIAR-CSI SRTM 90 m digital elevation data website: http://srtm.csi.cgiar.org/

Map 11: Slope percent In the WANA region

Similarity analysis procedure and results

It was necessary to distinguish between areas similar to the water benchmark sites and potential sites, similar to the benchmark sites, where specific technologies, developed for each benchmark site, can be implemented. These analyses were conducted separately.

To perform the similarity analysis the 'Con' function was used to perform a conditional evaluation. This function allows the output value for each cell to be controlled based on whether the cell value evaluates to true or false for a specified conditional statement.

Similarity analysis for water benchmark sites

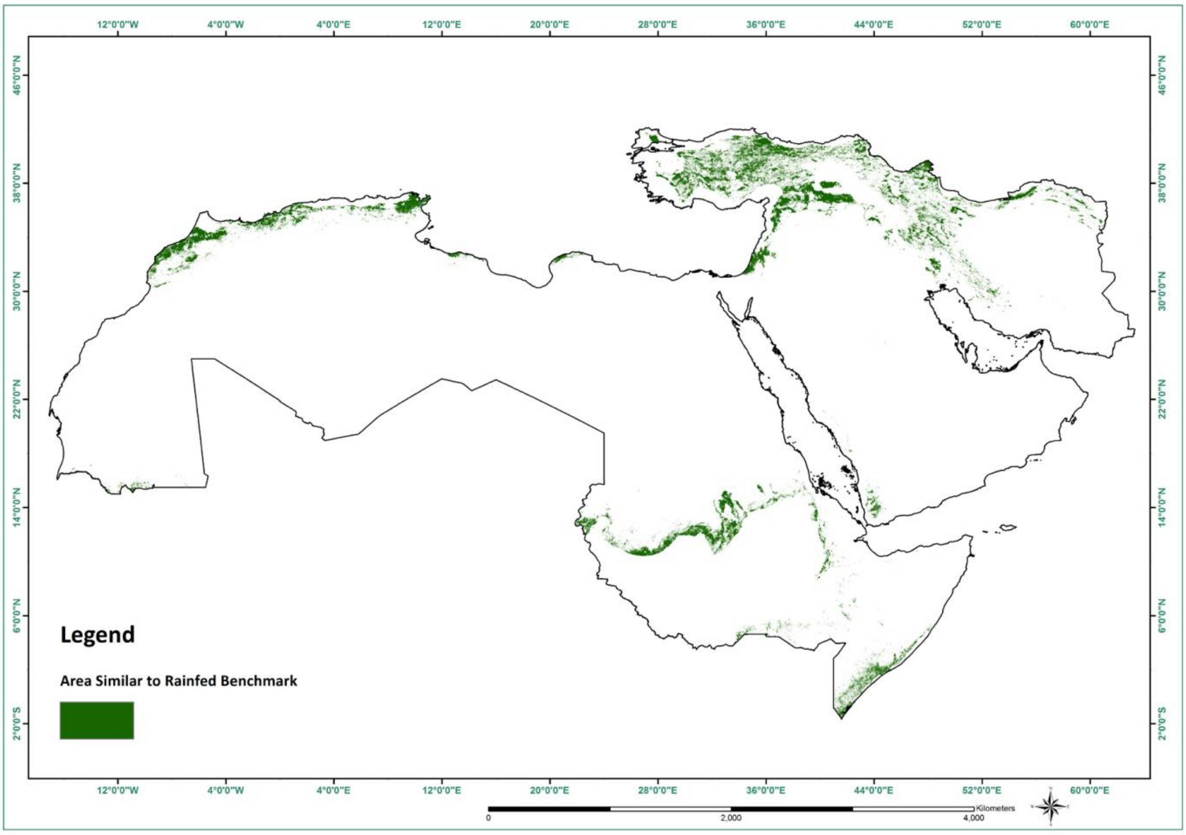
Areas similar to the water benchmark sites (rainfed, irrigated, and rangeland) were analyzed using the most important criteria. Maps 12, 13, and 14 present the results for the WANA region and Table 7 shows areas of similarity for each water benchmark location.

These maps show the spatial distribution of areas similar to those of the three benchmarks. An interesting feature is the distribution of appreciably similar areas at, and in the vicinity of, the locations of the each benchmark (rainfed areas near the Moroccan benchmark, irrigated areas near the Egyptian benchmark, and rangeland near the Jordan benchmark). This highlights the representativeness of these benchmarks to the agro-ecosystems that they are meant to characterize.

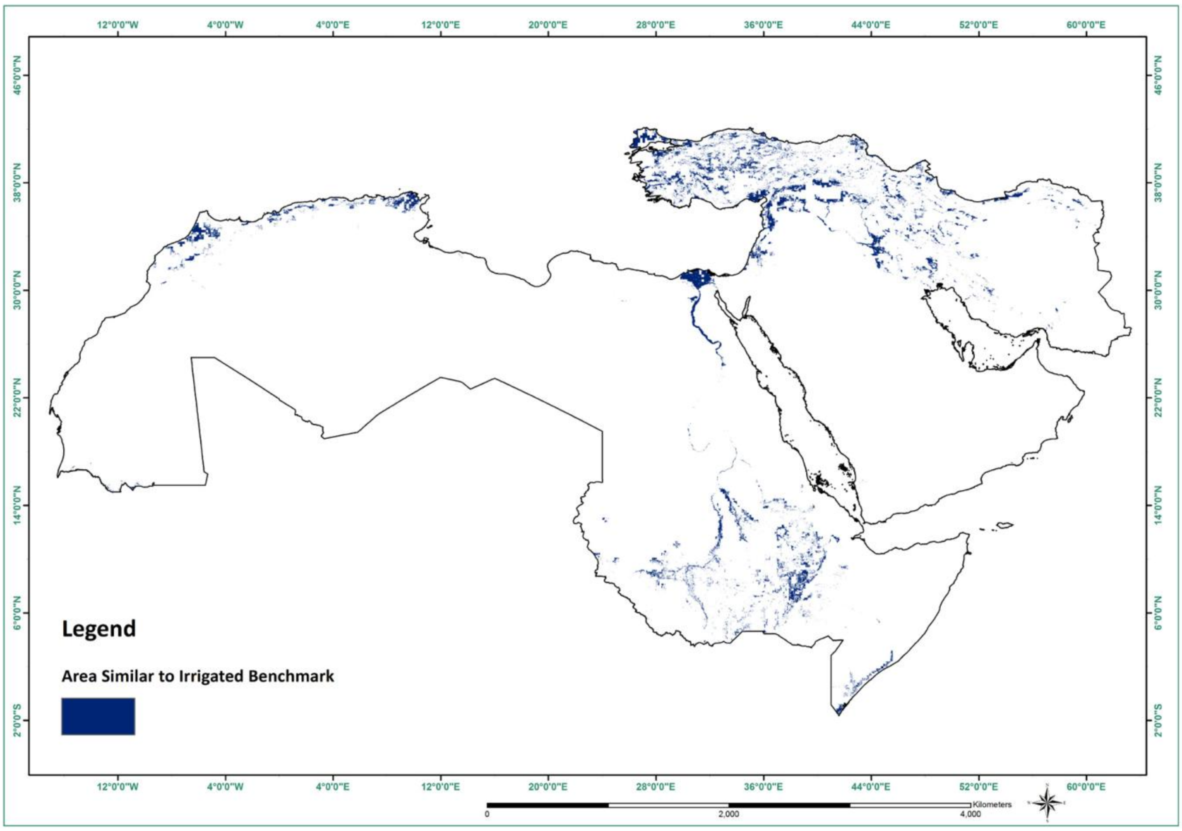
Table 7: Areas for each water benchmark location

Benchmark	Area (km^2)
Rainfed	349,046.7
Irrigated	249,328.1
Rangeland	6,893,160.3

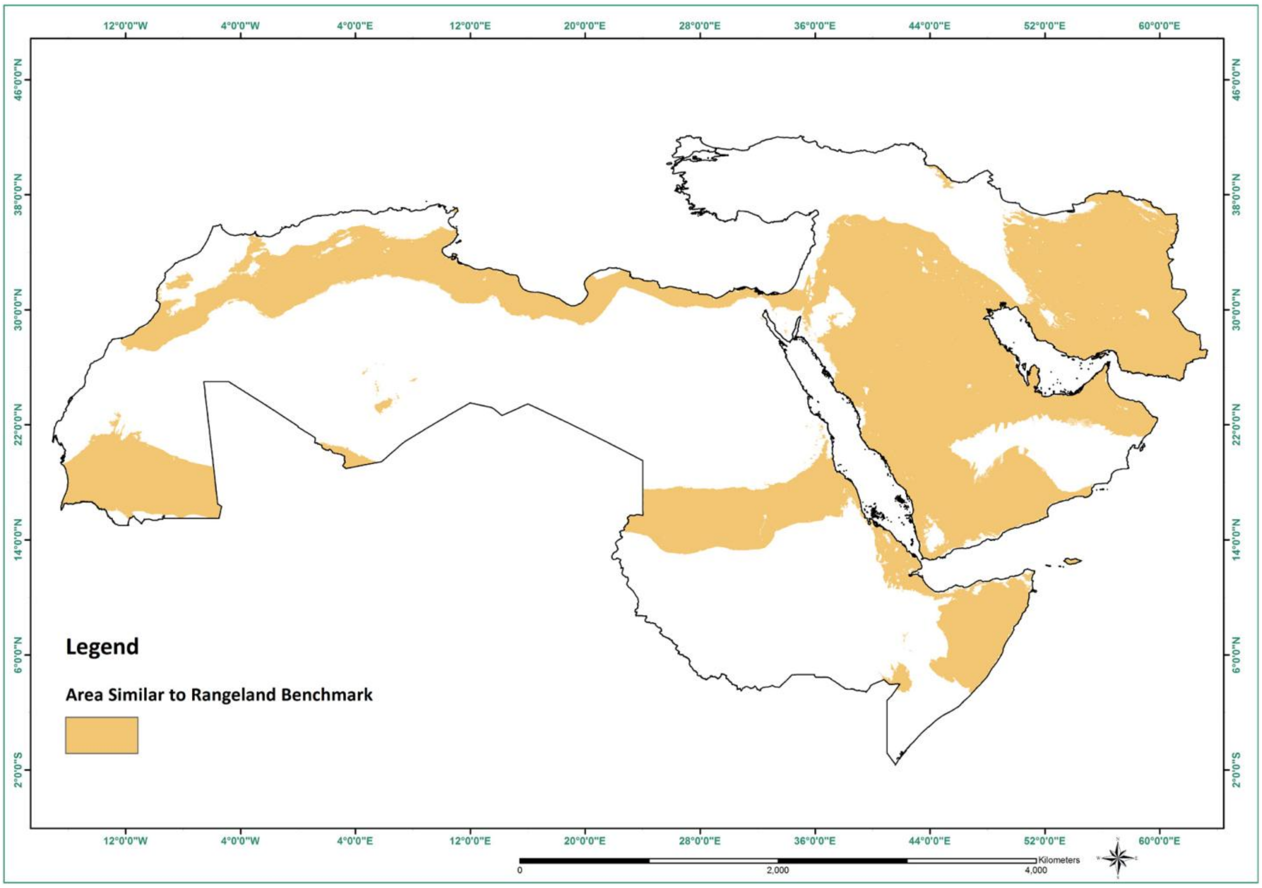
However, it also indicates that there are significant areas across the WANA region where the technologies developed for the three benchmark sites could be targeted for out-scaling. Each country can identify the extent and distribution of each benchmark and this helps in making informed decisions about out-scaling various practices based on the relative priorities of the different countries.



Map 12: Areas similar to the rainfed benchmark



Map 13: Areas similar to the irrigated benchmark



Map 14: Areas similar to the rangeland benchmark

Potential areas for specific technologies developed for each benchmark

Analysis for potential areas for supplemental irrigation within areas similar to the rainfed benchmark

Criteria applied

The criteria followed in identifying potential areas for supplemental irrigation within areas similar to the rainfed benchmark are present- ed in Table 8.

Table 8: Criteria used to define the supplemental irrigation areas

NO.	CRITERIA	CONDITION
1.	Rainfall	250–500 mm
2.	Water resources	Available for supplemental irrigation
3.	Land use	Crop lands
4.	Crops	Winter crop based system
5.	Slope	Up to 5%

To prepare the map, the data for each criteri- on was treated as follows:

Rainfall

A new rainfall raster, which included rainfall values of 250–500 mm, was created from the original one. The rainfall raster was prepared using the following equation:
Con ((“rainfall_500m” >= 250) & (“rain-fall_500m” <= 500),”rainfall_500m”)) = Rainfall

Land use

A land-use raster, that included the crop lands and winter crop based system classes, was created from the original one. The land-use raster was created using the following equation:
Con (("lu_t1_500m" == 12) | ("lu_t1_500m" == 14),"lu_t1_500m") = LU

Slope

The slope criterion included all areas with a slope of less than or equal to 5%. The slope raster was created using the following equation:
Con ("slope" <= 5,"slope") = Slope

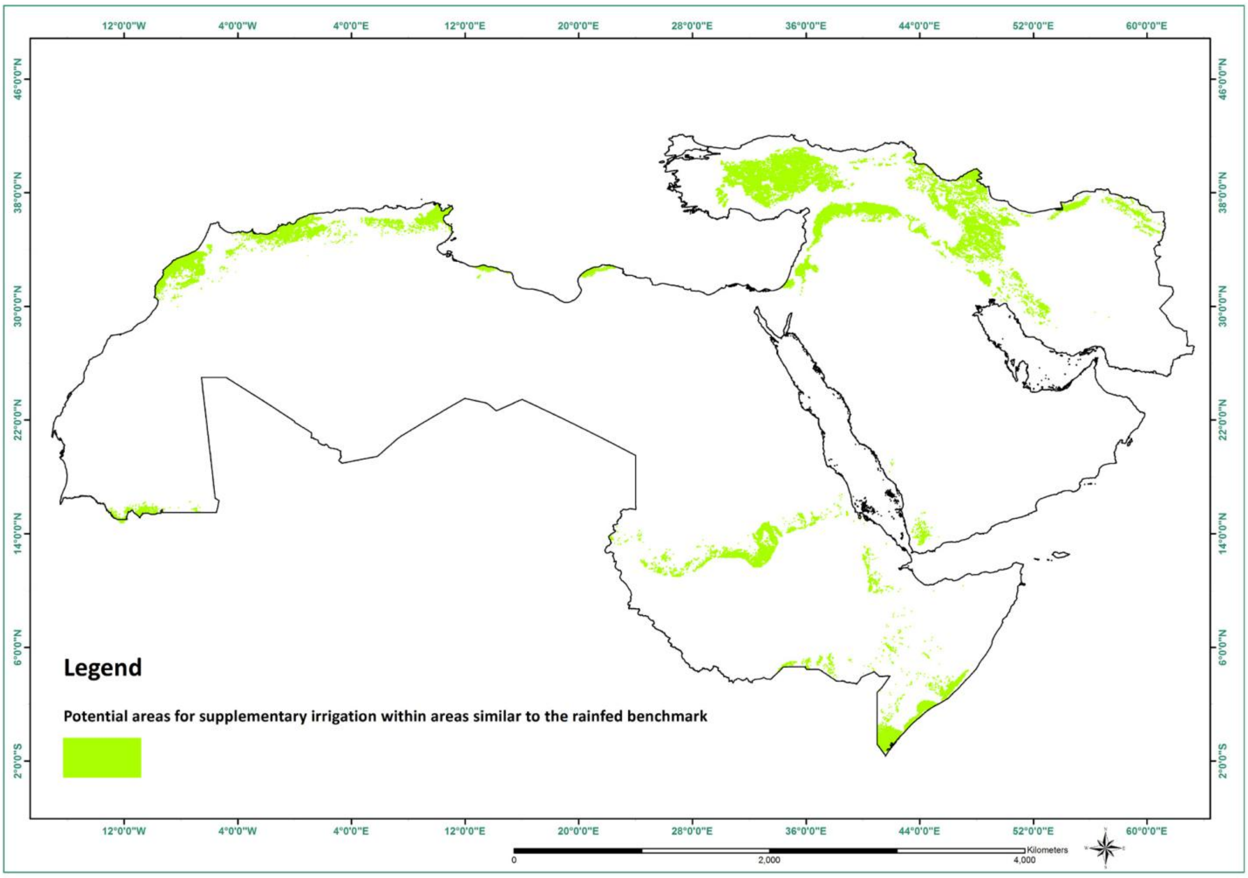
Results

The raster created by using the following equation: (“Rainfall” & “LU” & “Slope”), and the results are shown in Map 15.
These areas are less than those similar to the rainfed benchmark (Map 12) because these are more specific. They show areas where supplemental irrigation can be applied within the whole area that is similar to the rainfed benchmark. However, other practices could be implemented within those areas similar to the rainfed benchmark.

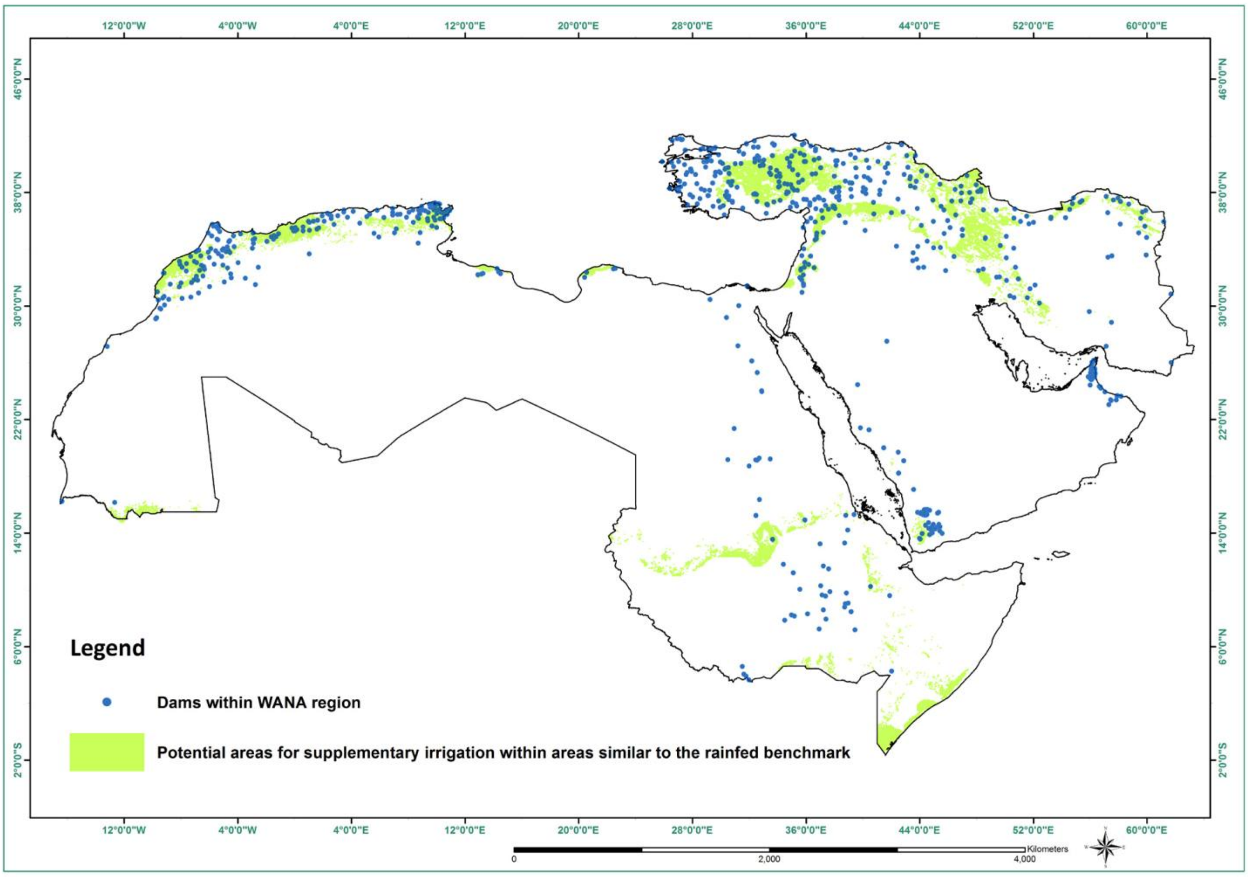
To identify more precisely those areas with a high potential for supplemental irrigation, the water resources were superimposed on the similarity map for the rainfed benchmark.

Areas close to irriga- tion water sources should be targeted by local governments for implementing supplemental irrigation.

The locations of dams in the WANA region that are close to those areas identified by the rainfed benchmark/supplementary irrigation results are shown in Map 16



Map 15: Potential areas for supplementary irrigation within areas similar to the rainfed benchmark.



Map 16: The closest water resources to potential sites for supplementary irrigation within areas simialr to the rainfed benchmark

Analysis for potential areas for raised-bed technology within areas similar to the irrigated benchmark

Criteria applied

The criteria followed in identifying potential areas for raised-bed technology within areas similar to the irrigated benchmark are present- ed in Table 9.

Table 9: Criteria used to define the raised-bed technology areas

No.	Criteria	Condition
1.	Rainfall	< 250 mm
2.	Water re- sources	Available for supplemen- tal irrigation
3.	Land use	Land that is cultivated
4.	Soil texture	Not sandy (≤ 90% sand)

To prepare the raised-bed technology areas map, the data for each criterion was pre- pared as follows.

Rainfall

A new rainfall raster, including rainfall values **<** 250 mm, was created from the original. The rainfall raster was prepared using the fol- lowing equation:

Con (“rainfall_500m” < 250),”rainfall_500m”) = Rainfall

Land use

A land-use raster that included the crop lands and winter crop based system classes was cre- ated from the original one. The land-use raster was created using the following equation:

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

Soil texture

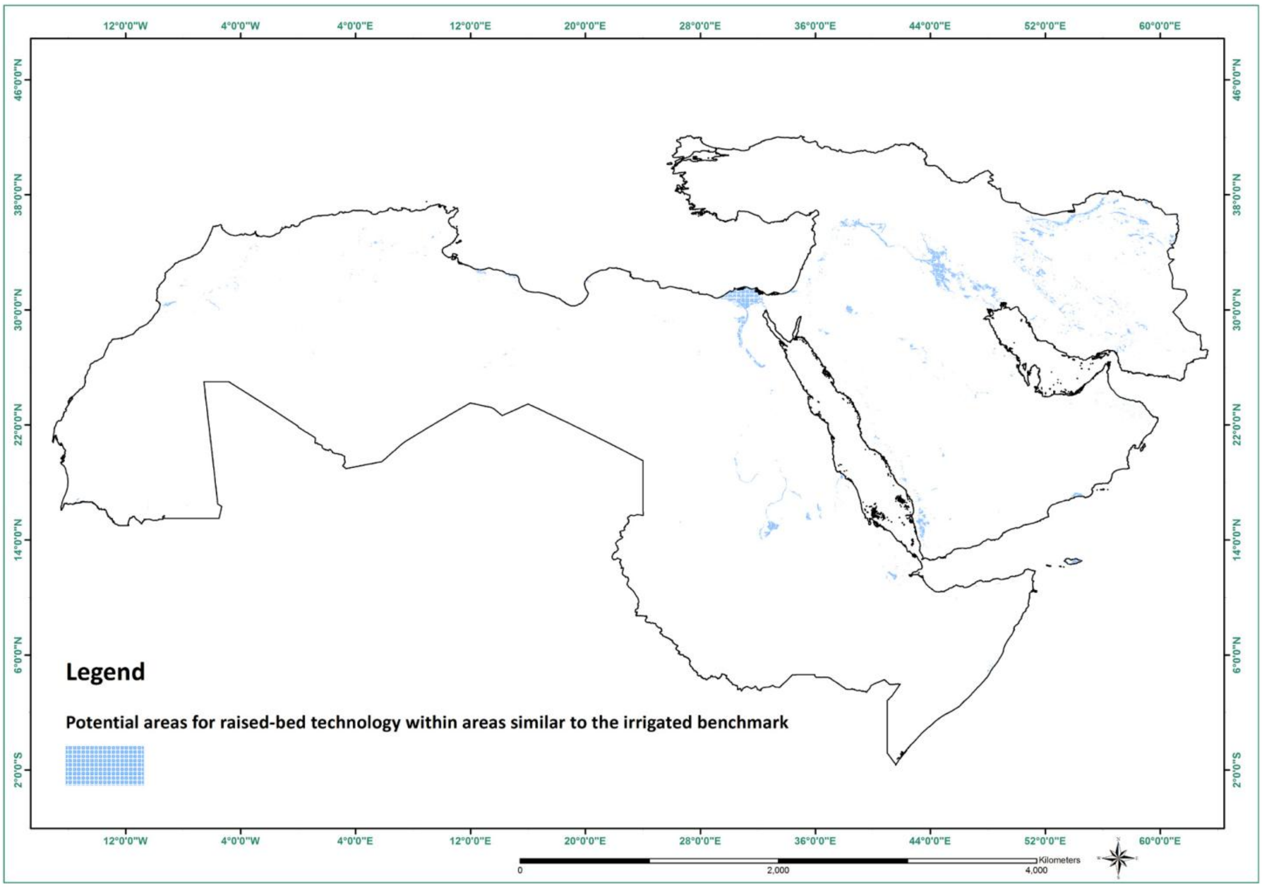
A soil texture of not sandy (≤ 90% sand) was used for the irrigated benchmark. The soil texture raster was created using the following equation:

Con (("texture” == not Sand),"texture”)) = Soil_Texture

Results

The raster created by using the following equation: “Rainfall” & “LU” & “Soil_Texture”, and the results are shown in Map 17.

These areas are less than those similar to the irrigated benchmark (Map 13) because these are more specific. They show areas where raise-bed technology can be applied within the whole area that is similar to the irrigated benchmark. However, other practices could be implemented within the areas similar to those of the irrigated benchmark.



Map 17: Potential areas for raised-bed technology within areas similar to the irrigated benchmark

Analysis for potential areas for Vallerani water harvesting within areas similar to the rangeland benchmark

Criteria applied
The criteria used to identify the potential areas for Vallerani water harvesting within areas similar to the pastoral benchmark are presented in Table 10.

To prepare the Vallerani water-harvesting areas map, the data for each criterion was prepared as follows.

Table 10: Criteria used to define the Vallerani water-harvesting areas

No.	Criteria	Condition
1.	Rainfall	100–300 mm
2.	Soil depth	60 cm or more
3.	Land use	< 30% vegetation cover
4.	Slope	Up to 20%
5.	Soil texture	Not sandy (< 90% sand)

Rainfall

A new rainfall raster that included rainfall values of 100–300 mm was created from the original. The rainfall raster was created using the following equation:
Con ((“rainfall_500m” >= 100) & (“rainfall_500m” <= 300),”rainfall_500m”) = Rainfall

Soil depth

A new raster, representing the lands with a soil depth of 60 cm and more, was created from the original (Map 5). To extract the required soil depth the ‘not equal’ function was used (!=) to omit depths of less than 60 cm. Table 11 shows the depth criteria classifications.

Table 11: Soil depth criteria

Value	Depth (according to effective soil depth (cm) map – FAO)	Depth criteria	Status
13	Very shallow (< 10 cm) to moderately deep (50–100 cm)	60 cm and more	Included
14	Very shallow (< 10 cm) to deep (100–150 cm)	60 cm and more	Included
15	Very shallow (< 10 cm) to very deep (150–300 cm)	60 cm and more	Included
23	Shallow (10–50 cm) to moderately deep (50–150 cm)	60 cm and more	Included
24	Shallow (10–50 cm) to deep (100–150 cm)	60 cm and more	Included
40	Deep (100–150 cm)	60 cm and more	Included
41	Deep (100–150 cm) to very shallow (< 10 cm)	60 cm and more	Included
42	Deep (100–150 cm) to shallow (10–50 cm)	60 cm and more	Included
43	Deep (100–150 cm) to moderately deep (50–100 cm)	60 cm and more	Included
45	Deep (100–150 cm) to very deep (150–300 cm)	60 cm and more	Included
50	Very deep (150–300 cm)	60 cm and more	Included
51	Very deep (150–300 cm) to very shallow (< 10 cm)	60 cm and more	Included
54	Very deep (150– 300 cm) to deep (100–150 cm)	60 cm and more	Included
10	Very shallow (< 10 cm)	Less than 60 cm	Excluded
12	Very shallow (< 10 cm)to shallow (10–50 cm)	Less than 60 cm	Excluded
20	Shallow (10–50 cm)	Less than 60 cm	Excluded
21	Shallow (10–50 cm) to very shallow (< 10 cm)	Less than 60 cm	Excluded
97	Water	Water	Excluded

The raster was created using the following equation. In this equation areas with a soil depth of less than 60 cm have been omitted.

Con((“depth1_wana.tif” != 10) & (“depth1_wana.tif” != 12) & (“depth1_wana.tif” != 20) & (“depth1_wana.tif” != 21) & (“depth1_wana.tif” != 97),”depth1_wana.tif”) = Soil_Depth

Land use

A new land-use raster that included areas with less than 30% vegetation cover was creat- ed from the original. Map 18 shows the land cover Type 1 classes (7: Open shrublands, 12: Cropland, 14: Cropland/natural vegetation mosaic, and 16: Barren or sparsely vegetated). These classes are used to represent the rainfed criteria.

The raster was created using the following equation:
Con((“lu_t1_500m” == 7) | (“lu_t1_500m” == 12) | (“lu_t1_500m” == 14) | (“lu_t1_500m” == 16),”lu_t1_500m”) = LU

Slope

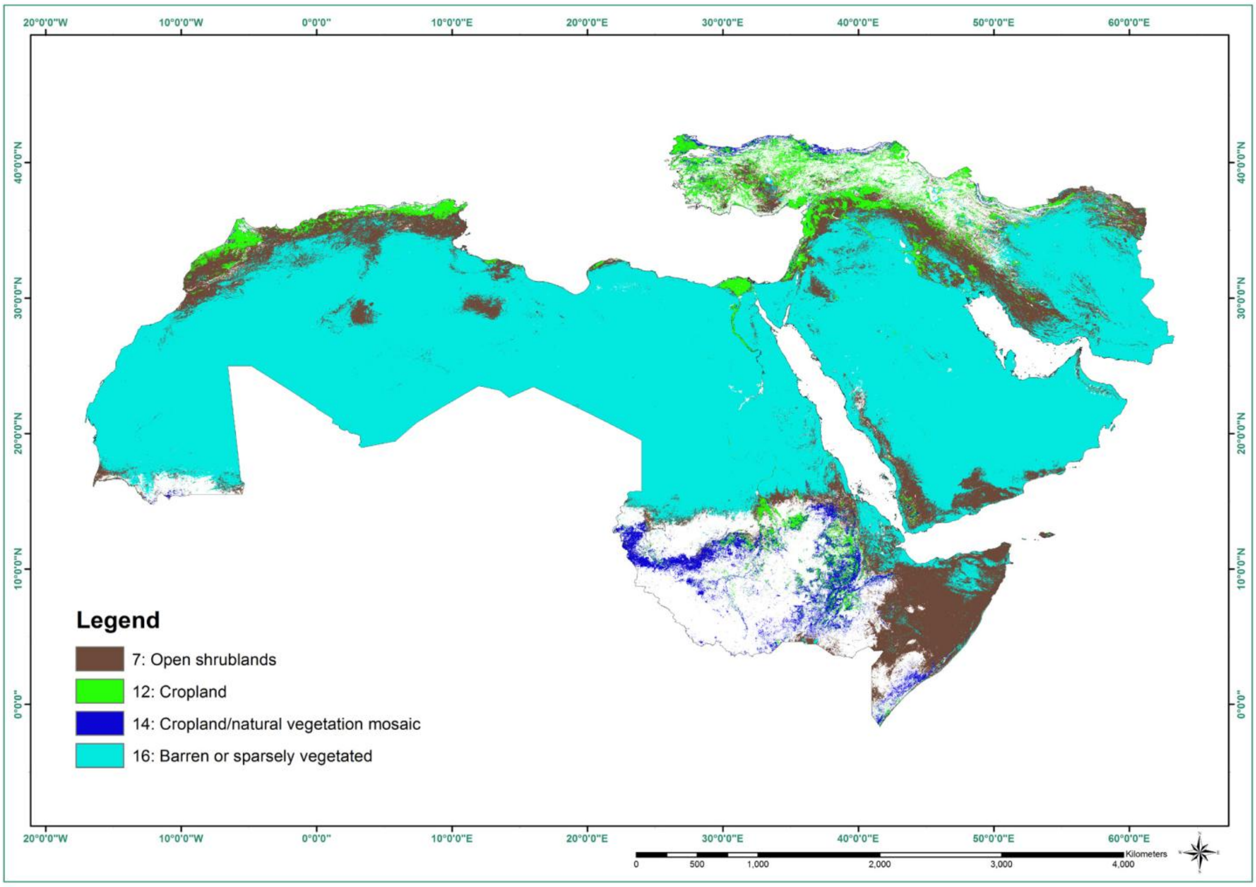
The slope criterion needed to identify areas, similar to those of the rangeland benchmark, with slope less than or equal to 20%. The slope was created using the following equation:
Con(“slope” <= 20,”slope”) = Slope

Soil texture

A soil texture criterion of not sandy was used for the rangeland benchmark. The soil texture raster was created using the following equation:
Con ((“texture” == not Sand),”texture”)) = Soil_Texture

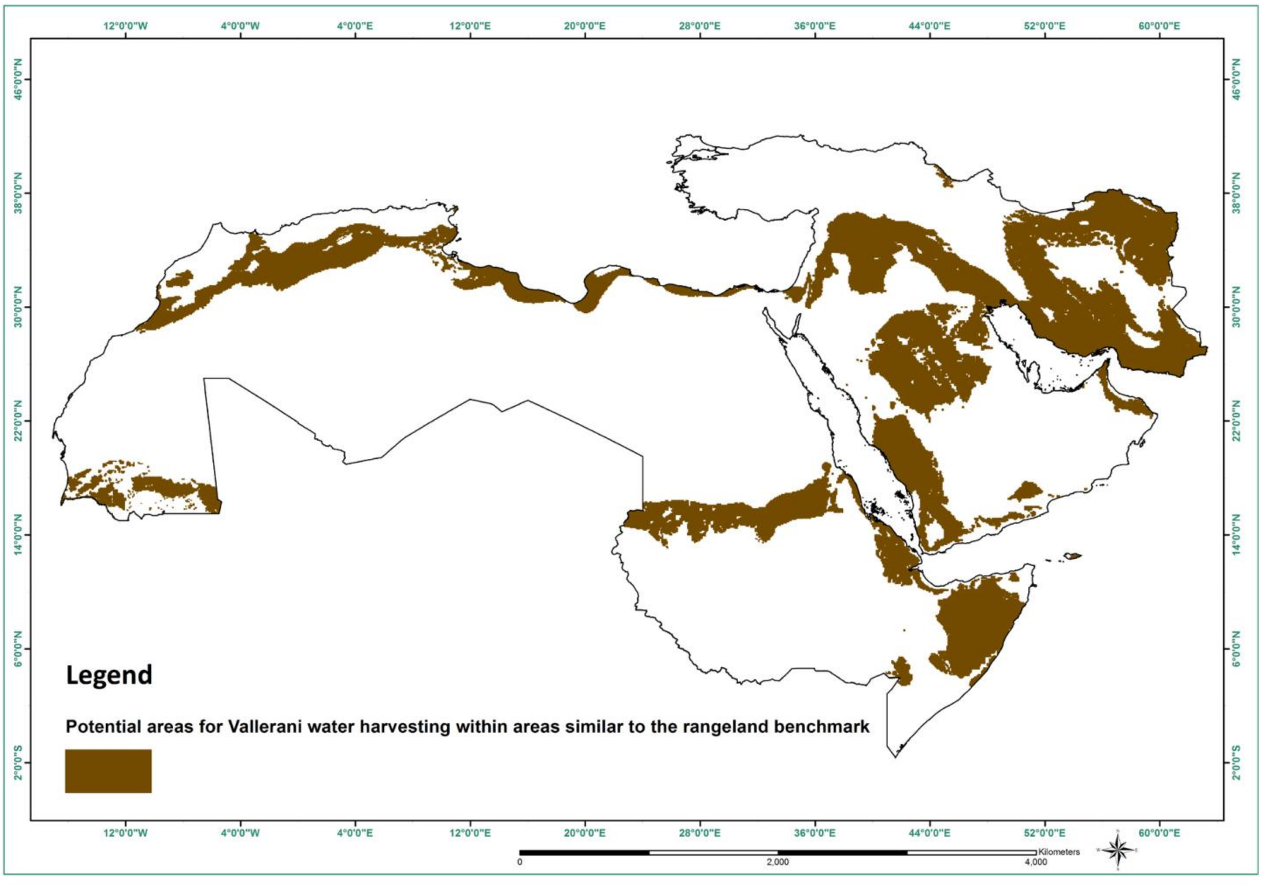
Results

The raster created by using the following equation: “Rainfall” & “Soil_Depth” & “LU” & “Slope” & “Soil_Texture”, and the results are shown in Map 19.
These areas are less than those similar to the rangeland benchmark (Map 14) because these are more specific. They show areas where the Vallerani water-harvesting intervention can be applied within the whole area that is similar to the rangeland benchmark. However, other practices could be implemented within the areas similar to the rangeland benchmark.



Data source: LP DAAC, USGS website: https://lpdaac.usgs.gov/products/MODIS_products_table/mcd12q1

Map 18: Rangeland benchmark -land use



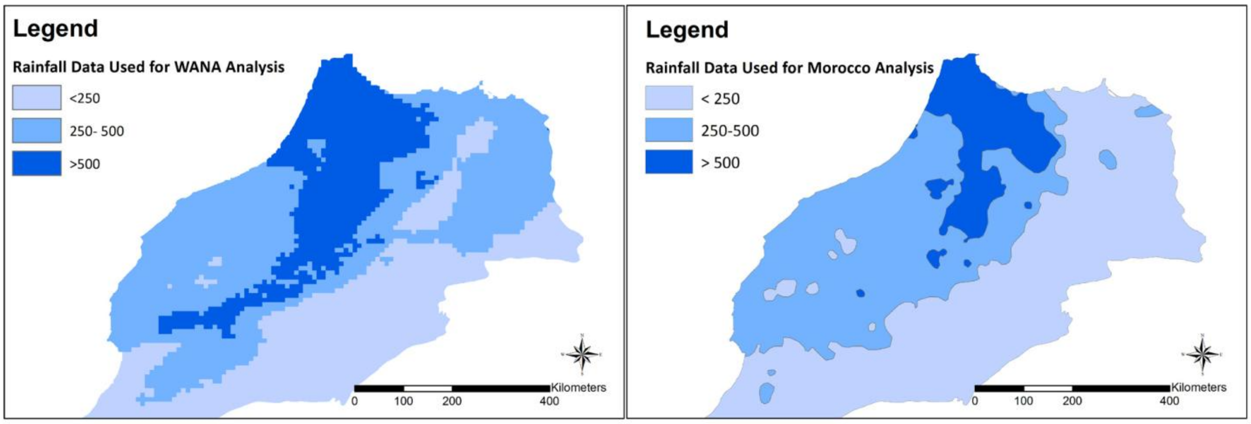
Map 19: Potential areas for Vallerani water harvesting within areas similar to the rangeland benchmark

Verification of the similarity analysis results

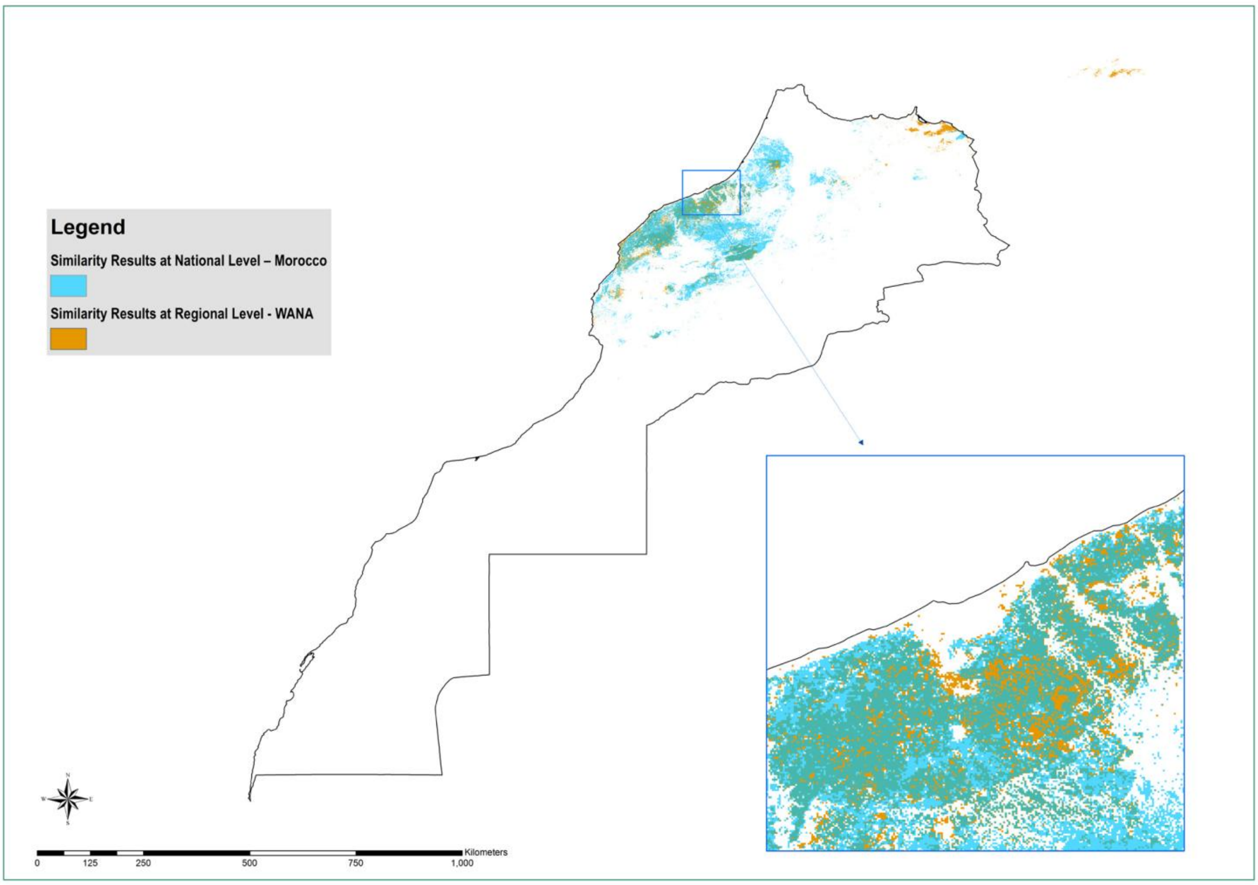
The similarity analysis results were verified using two methods:

A. Running the similarity maps at the national level using the same criteria, but with more detailed data available in the countries provided by the national agricultural research systems (NARS)

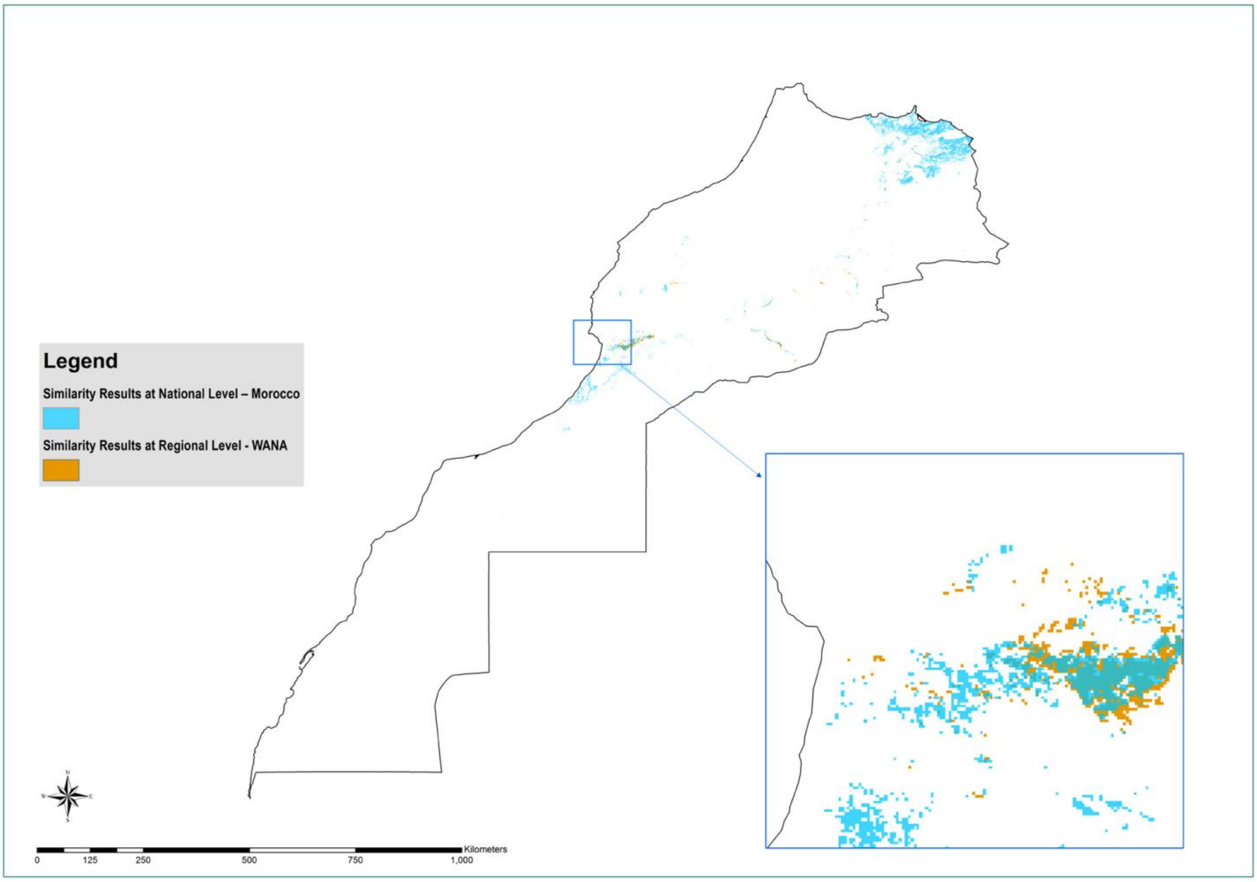
Generally, there is an acceptable agreement between the two results, although the data used for the WANA region is much coarser than those used at the national level. Some differences were identified between the two results and were used to adjust the similarity results for the WANA region. The following maps show the difference in the data resolution (Map 20) between the data at the WANA and national levels and the results of both similarity analyses. (Maps from 21, 22, and 23).



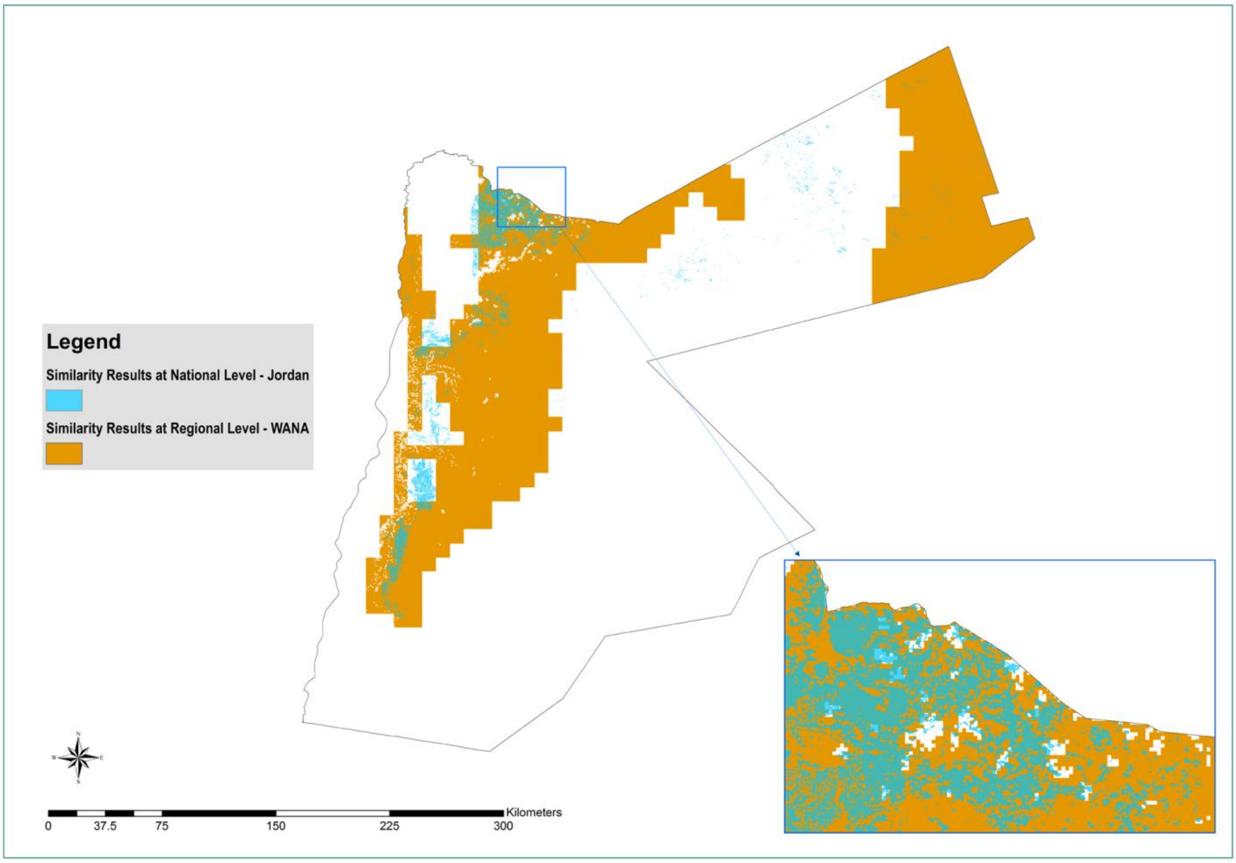
Map 20: Rainfall data resolution difference using WANA and national level data



Map 21: Supplemental irrigation results using national and local level data – Morroco



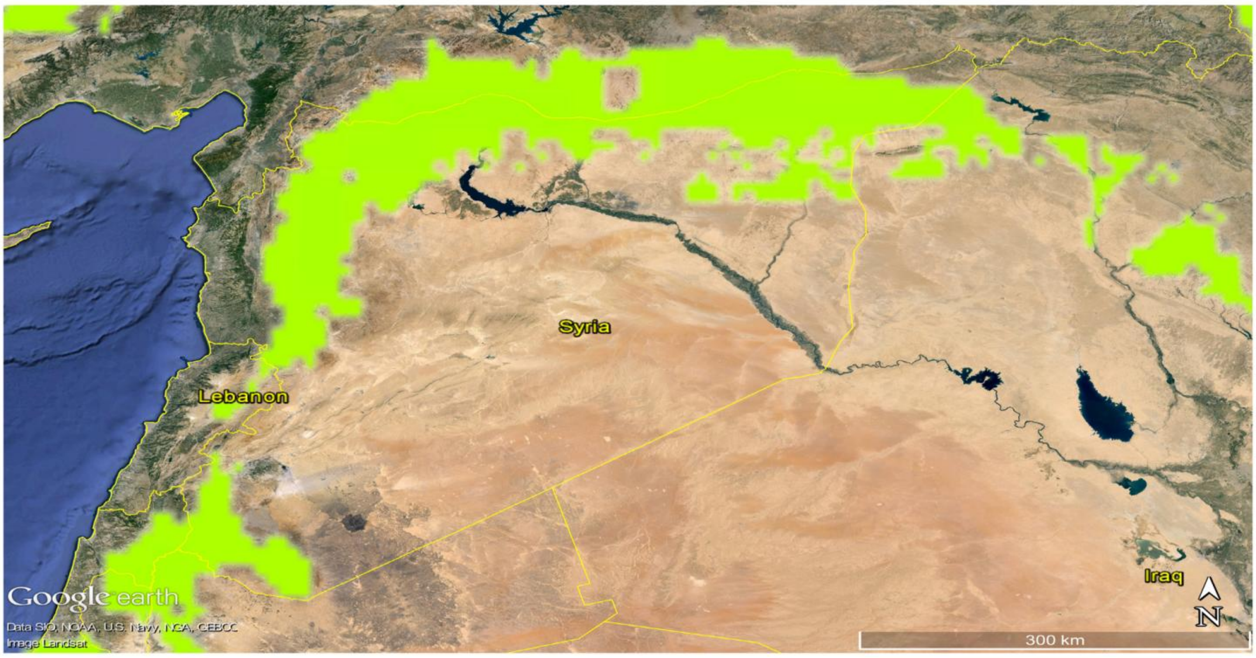
Map 22: Raised-bed technology results using national and local level data – Morocco



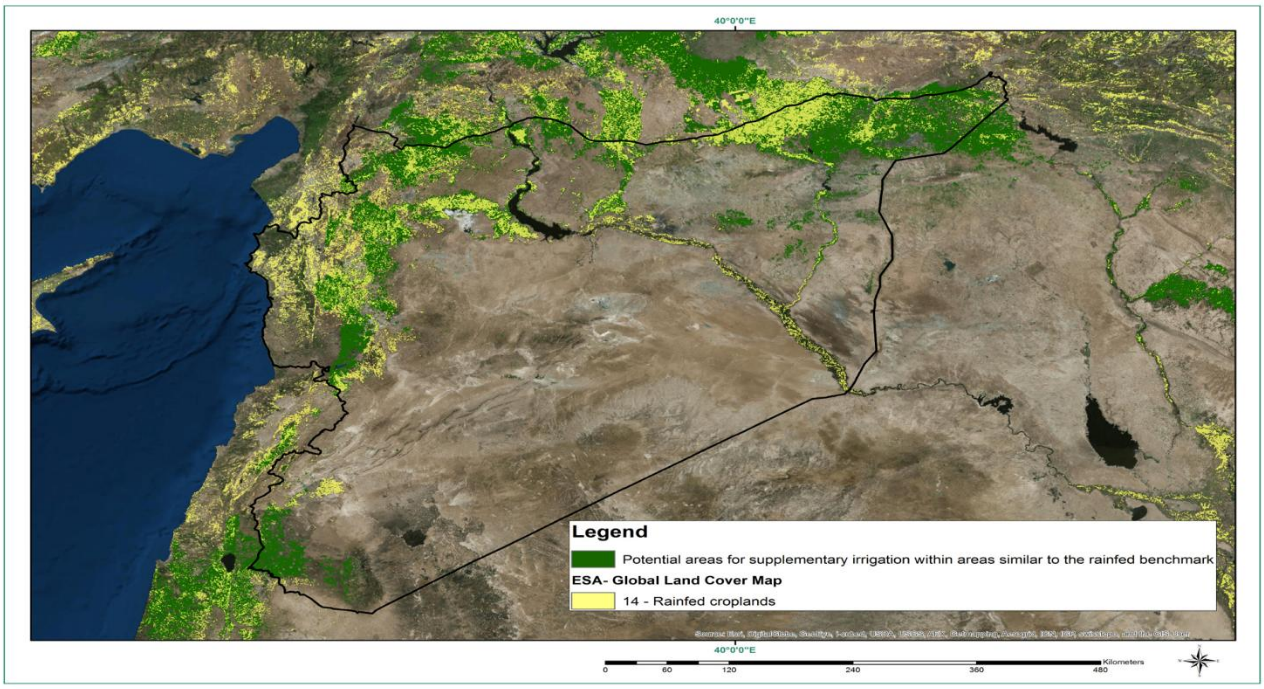
Map 23: Vallerani water harvesting results using national and local level data – Jordan

B. Using Google Earth pro: by converting the final similarity maps from raster to shapefiles and displaying the shapefiles over Google Earth

According to the findings from the rainfed similarity work, Map 24 indicates the distribution of the rainfed areas in Syria. The similar areas for supplementary irrigation were compared with the European Space Agency data – Global Land Cover data base (2009). This data is in a raster format with a 300 m resolution and includes land cover classification, one of which is '14 – Rainfed croplands'. This layer is displayed over the similarity results (Map 25) and it can be seen that the results are reasonably comparable.

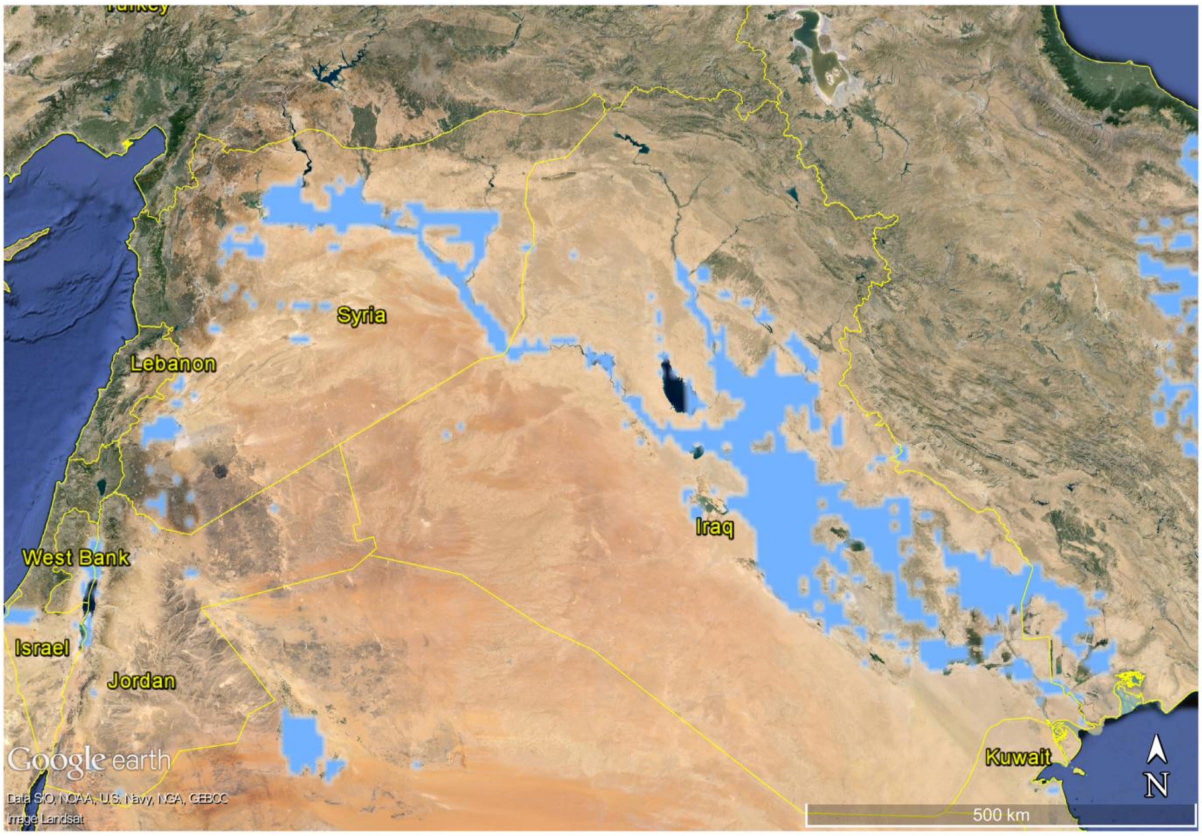


Map 24: Rainfed areas in the West Bank, Jordan, and Syria



Map 25: Distribution of agricultural lands in Syria

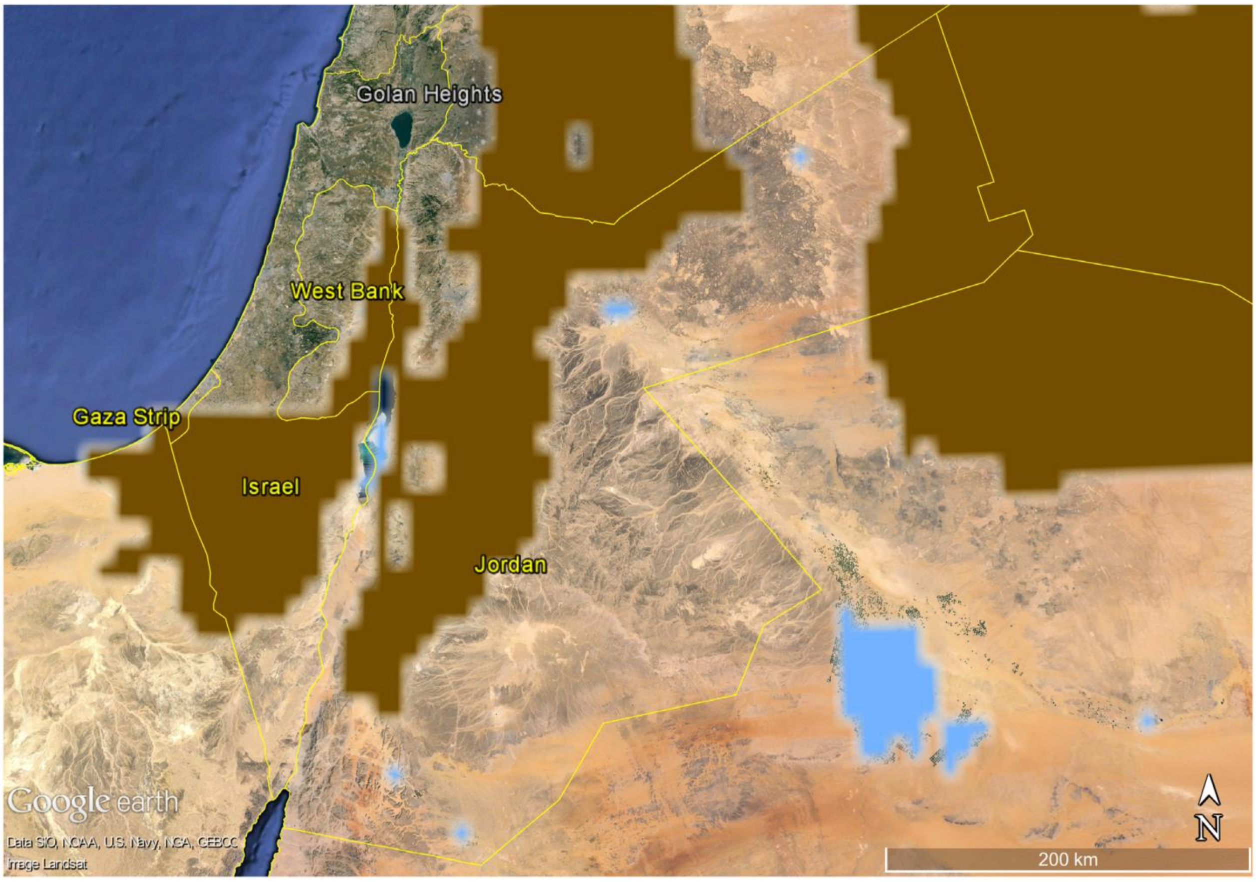
According to the similarity results and findings for the irrigated areas, raised-bed technology, it can be seen that the irrigated areas are located around major rivers, such as the Euphrates River in Syria and Iraq, and Nile River in Egypt (see Maps 26 and 27).



Map 26: Irrigated aeras in Syria and Iraq

Map 27: Irrigated areas in Egypt

According to the rangeland similarity results, the findings show quite good results for this area of classification in the WANA region. Map 28 shows the rangeland area in Jordan.



Map 28: Rangeland in Jordan

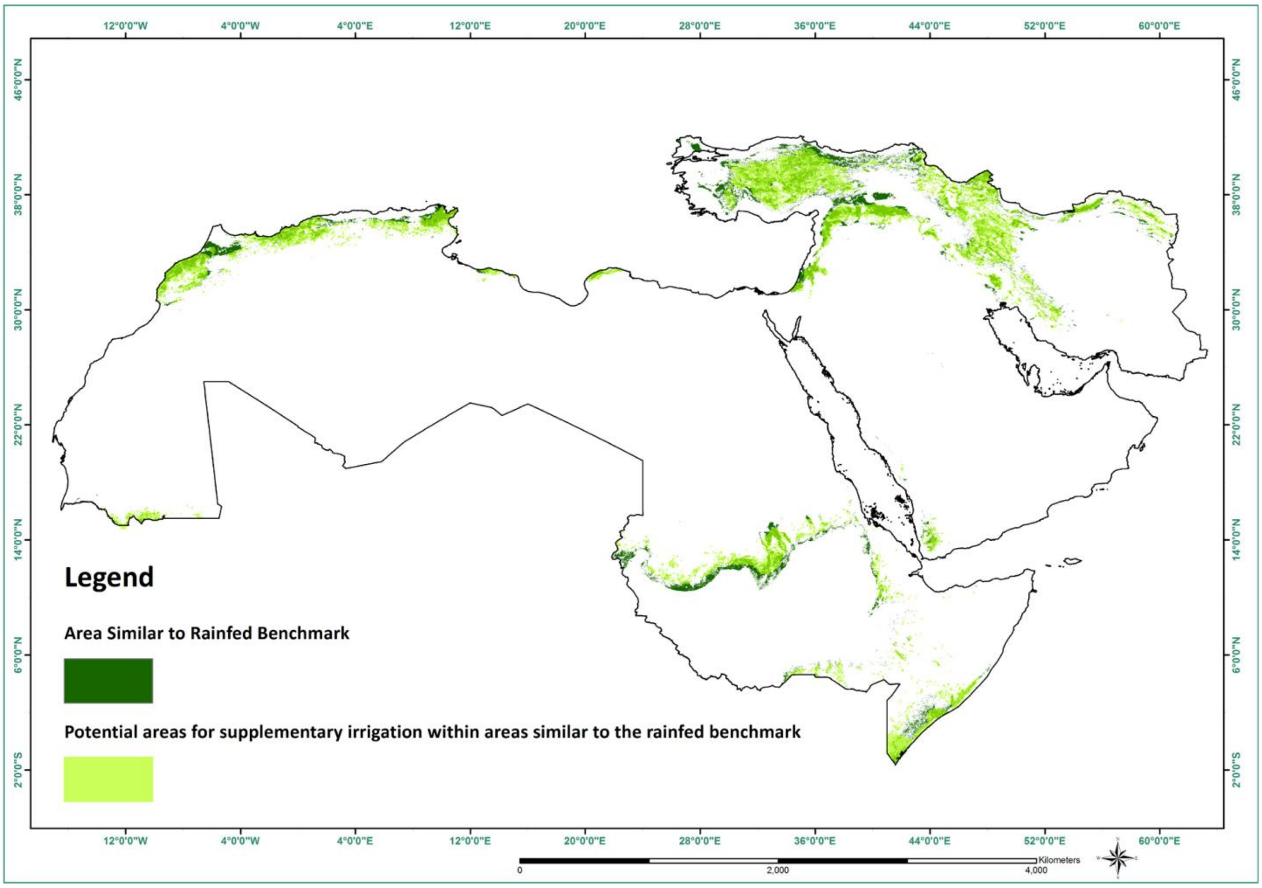
Comparison between the similarity analysis for benchmark sites and the technologies adopted

Table 12 shows the similar areas for each benchmark and for each technology adopted, and Maps 29, 30, and 31 show the results of the similarity analysis in the WANA region for benchmark sites and specific technologies.

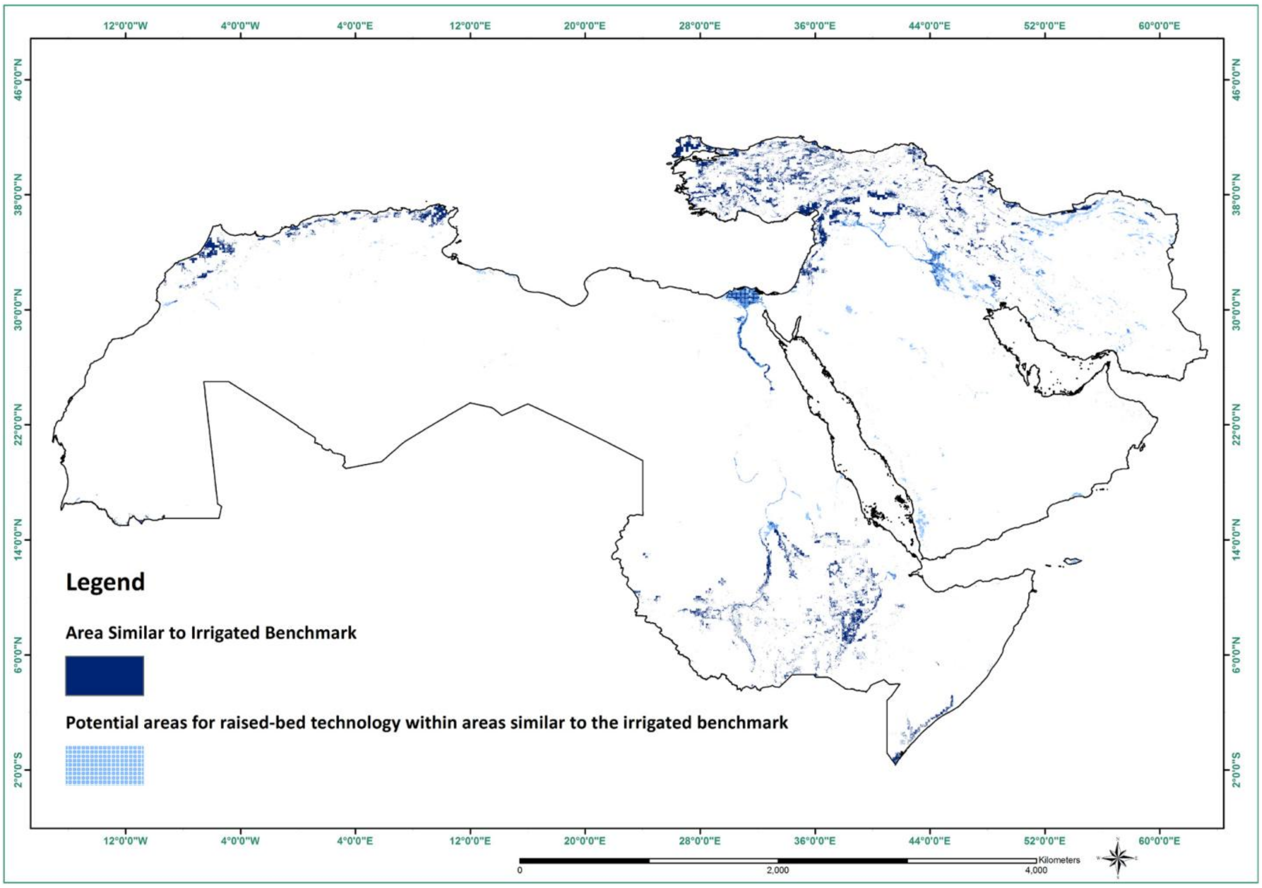
The results indicated significant areas that are similar to the three benchmarks. It also shows significant areas where specific technologies within each benchmark can be promoted. These vary from country to country and could be used to build specific information dissemination and out-scaling campaigns for each one.

Table 12: Similarity areas of the benchmark sites and the potential areas within the benchmark sites

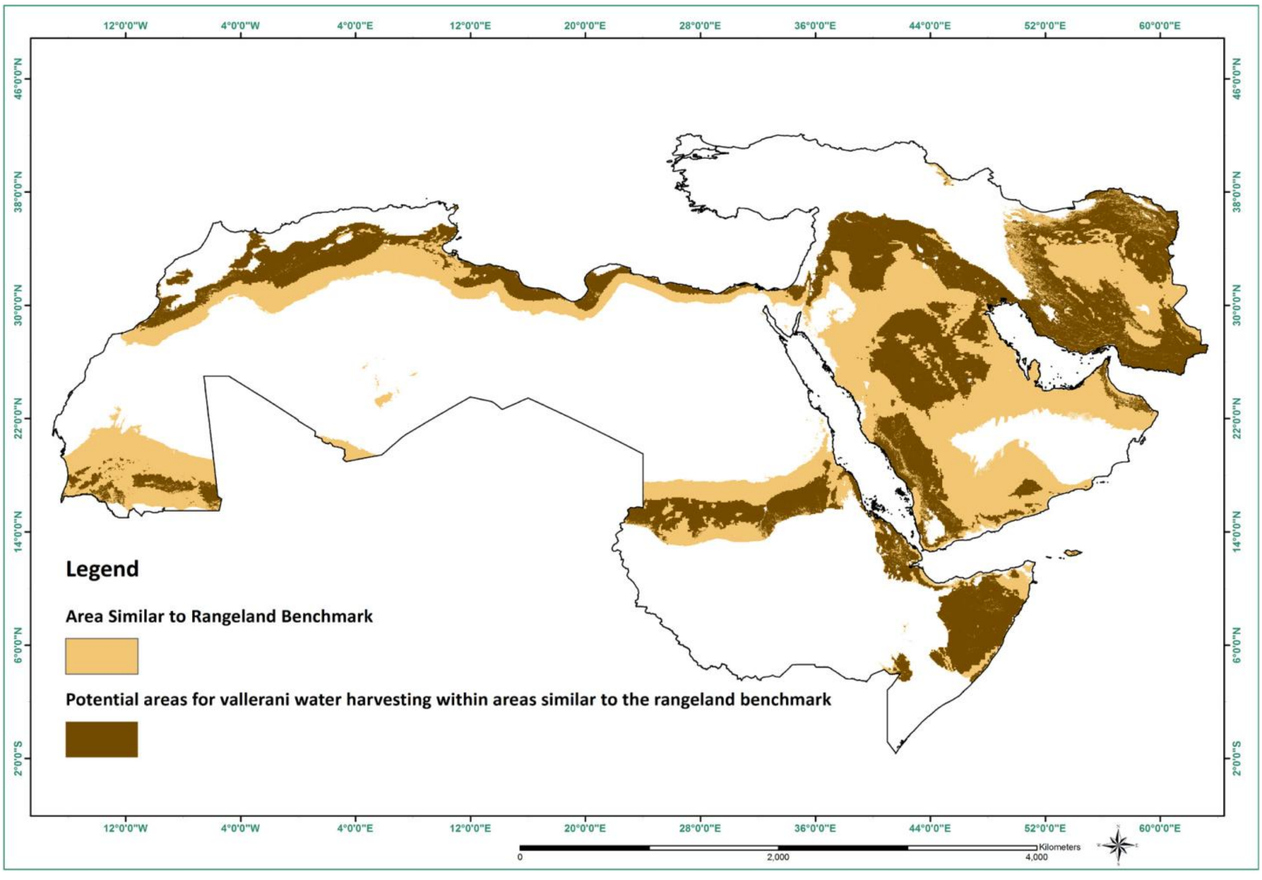
		Area (km²)
Rainfed	Benchmark	349,046.7
	Supplementary irrigation	147,447.9
Irrigated	Benchmark	249,328.1
	Raised-bed technology	754,11.2
Rangeland	Benchmark	6,893,160.3
	Vallerani water harvesting	3,240,797.2



Map 29: Areas similar to the rainfed benchmark and potential areas for supplementary irrigation



Map 30: Areas similar to the irrigated benchmark and potential areas for raised-bed technology



Map 31: Areas similar to the rangeland benchmark and potential areas for Vallerani water harvest-ing

Benchmarks suitability analysis

Suitability analysis for the WANA region

The suitability analysis was undertaken for the whole WANA region to identify the extent of the suitability for each technology for each of the three benchmarks. However, because of the extent of the study area and the availability of high resolution data, the suitability analysis conducted in the WANA region used criteria modified from those used at the national level (which will be explained later):

Table 13: Suitability for raised-bed packages in the irrigated agroecosystems

Land quality/characteristic	S1	S2	S3	NS	Data sources
Soil depth (rooting depth) (cm)	≥ 100	≥ 50	≥ 10	< 10	**FAO, Effective soil depth (cm) map** http://data.fao.org/map?entryId=c3b-fc940-bdc3-11db-a0f6-000d939bc5d8
Soil texture class	Clay, silty clay, clay loam, and silty clay loam	Clay, silty clay, clay loam, and silty clay loam. Silt, silty loam, loam	Clay, silty clay, clay loam, and silty clay loam. Silt, silty loam, loam. Sandy clay, sandy clay loam, sandy loam, loamy sand	sand	**FAO, GeoNetwork, digital Soil Map of the World** http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116
Stone content(5–10 cm diameter)	≤ 5	> 5 and ≤ 10	> 10 and ≤ 20	> 20	**HWSD Version 1.2** http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
$CaCO_3$ (clay and silt size)	≤ 2	> 2 and ≤ 5	> 5 and ≤15	> 15	**HWSD, Version 1.2** http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
Soil salinity mmhos/cm (dS/m = mmhos/cm)	< 2	2–4	4–8	> 8	**HWSD Version 1.2** http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/
Slope (%)	≤ 1	1–2	2–5	> 5	**CGIAR-CSI - SRTM 90 m digital elevation data** http://srtm.csi.cgiar.org/
Crop type class	Annual crops	Annual crops	Annual crops	Anything else	**LP DAAC, USGS** Https://lpdaac.usgs.gov/products/MODIS_products_table/mcd12q1

Table 14: Suitability for supplemental irrigation packages in the rainfed agroecosystems

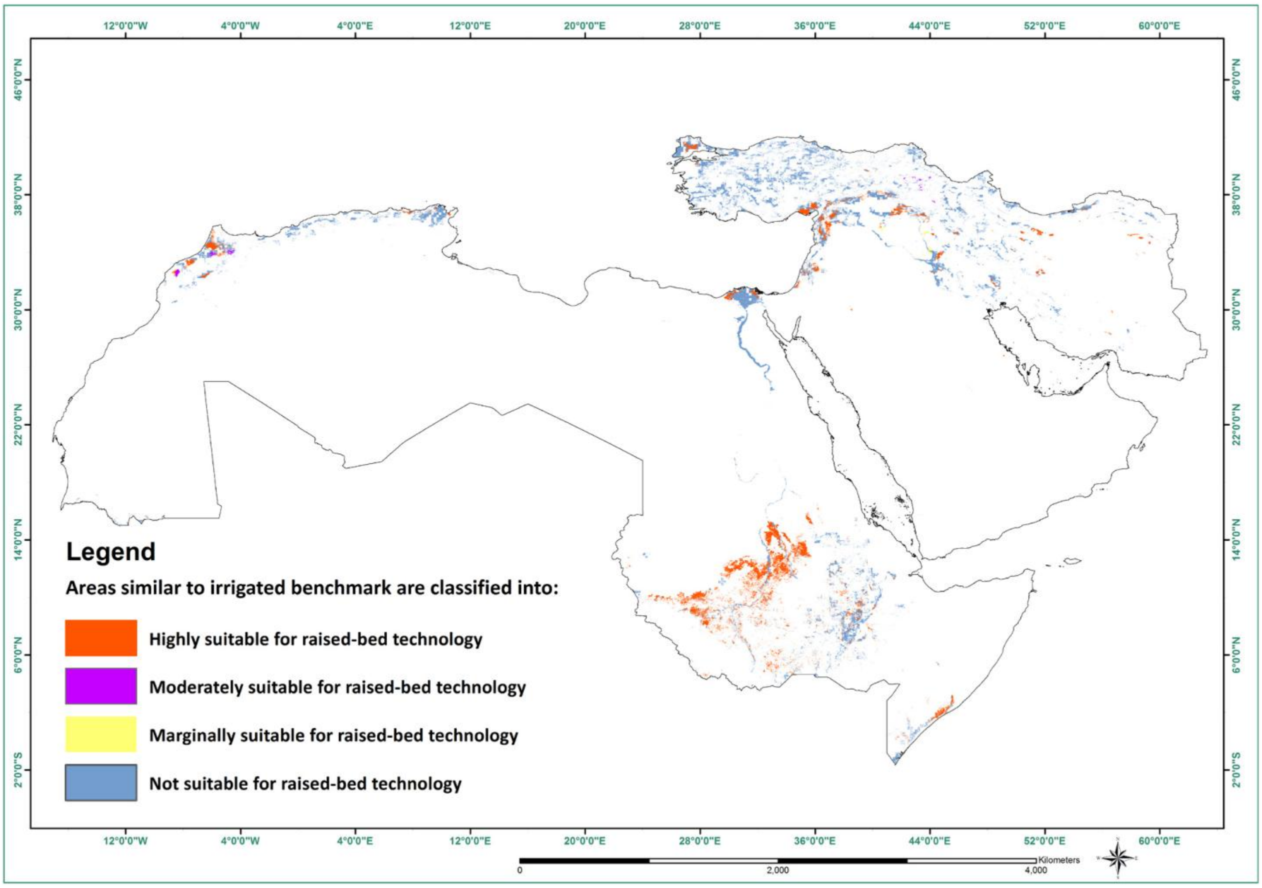
Land quality/characteristic	S1	S2	S3	NS	
Rainfall (mm)	> 250 and ≤ 350	> 350 and ≤ 400	> 400 and ≤ 500	> 500 and < 250	**WorldClim – a set of global climate layers (climate grids)** http://www.worldclim.org/
Soil depth (cm)	≥ 100	≥ 50	≥ 10	< 10	**FAO,- Effective soil depth (cm) map** http://data.fao.org/map?entryId=c3b-fc940-bdc3-11db-a0f6-000d939bc5d8
Soil water holding capacity (available water content) (mm/m)	≥ 150	≥ 100	≥ 75	< 75	**HWSD Version 1.2** http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/

Table 15: Suitability for Vallerani micro-catchment water harvesting in the rangelands agroeco systems

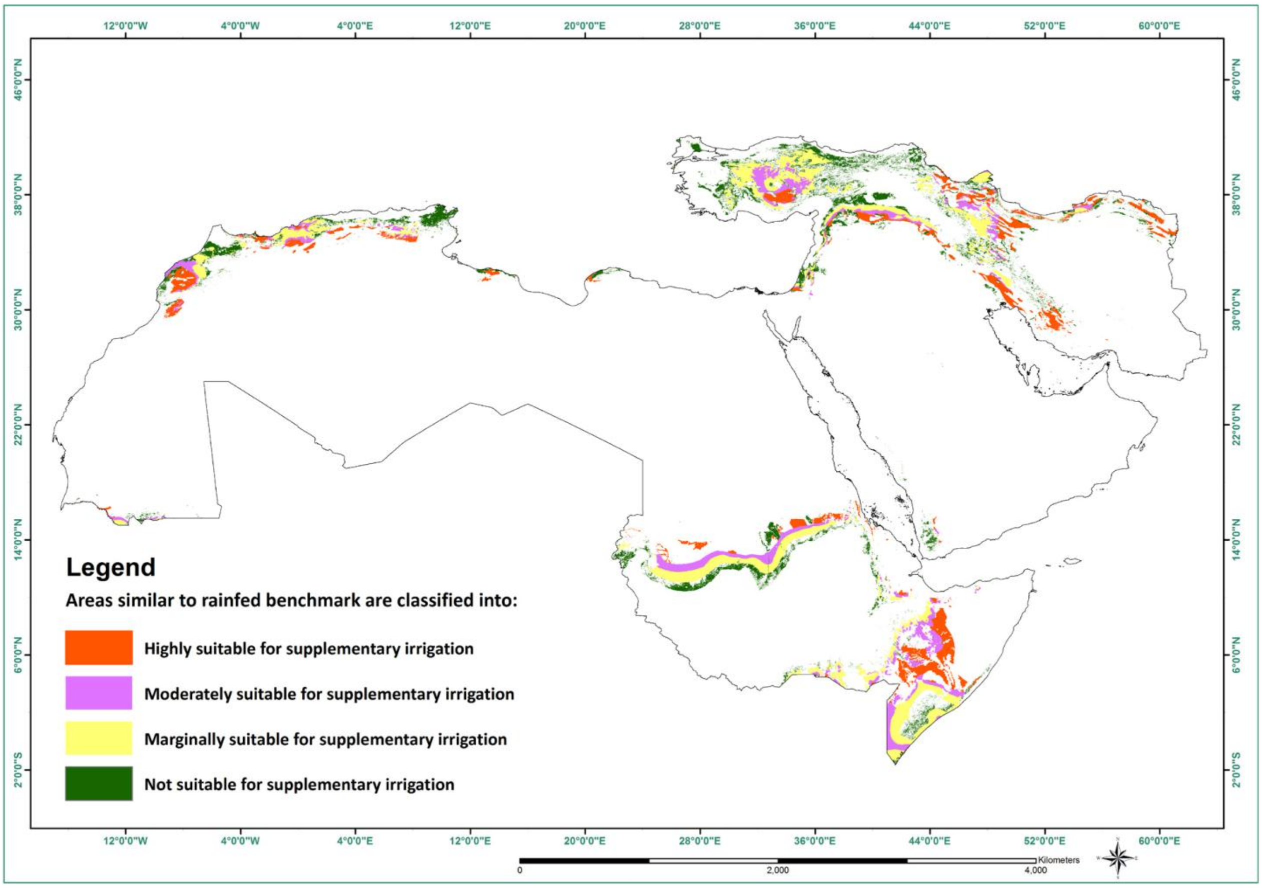
Land quality/characteristic	S1	S2	S3	NS	
Soil depth (cm)	≥ 100	≥ 50	≥ 10	< 10	**FAO, Effective soil depth (cm) map** http://data.fao.org/map?entryId=c3b-fc940-bdc3-11db-a0f6-000d939bc5d8
Soil texture	Silty loam, loam, silty clay, silty clay loam	Silty loam, loam, silty clay, silty clay loam, clay, clay loam, silt	Silty loam, loam, silty clay, silty clay loam, clay, clay loam, silt, sandy clay, sandy clay loam, sandy loam, loamy sand		**FAO GeoNetwork, digital Soil Map of the World** http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116
Rainfall (mm)	200–300	100–200	100–200	< 100 or > 300	**WorldClim – a set of global climate layers (climate grids)** http://www.worldclim.org/
Slope (%)	≥ 2 – < 4	> 2 – < 8	> 2 – < 12	< 2 or > 12	**CGIAR-CSI – SRTM 90 m digital elevation data** http://srtm.csi.cgiar.org/
Vegetation (natural)	< 15	≤ 20	≤ 30	> 30	**LP DAAC, USGS** Https://lpdaac.usgs.gov/products/MODIS_products_table/mcd12q1

After applying the criteria presented in the suitability tables, the areas suitable for the three benchmarks are presented in Maps 32, 33, and 34.

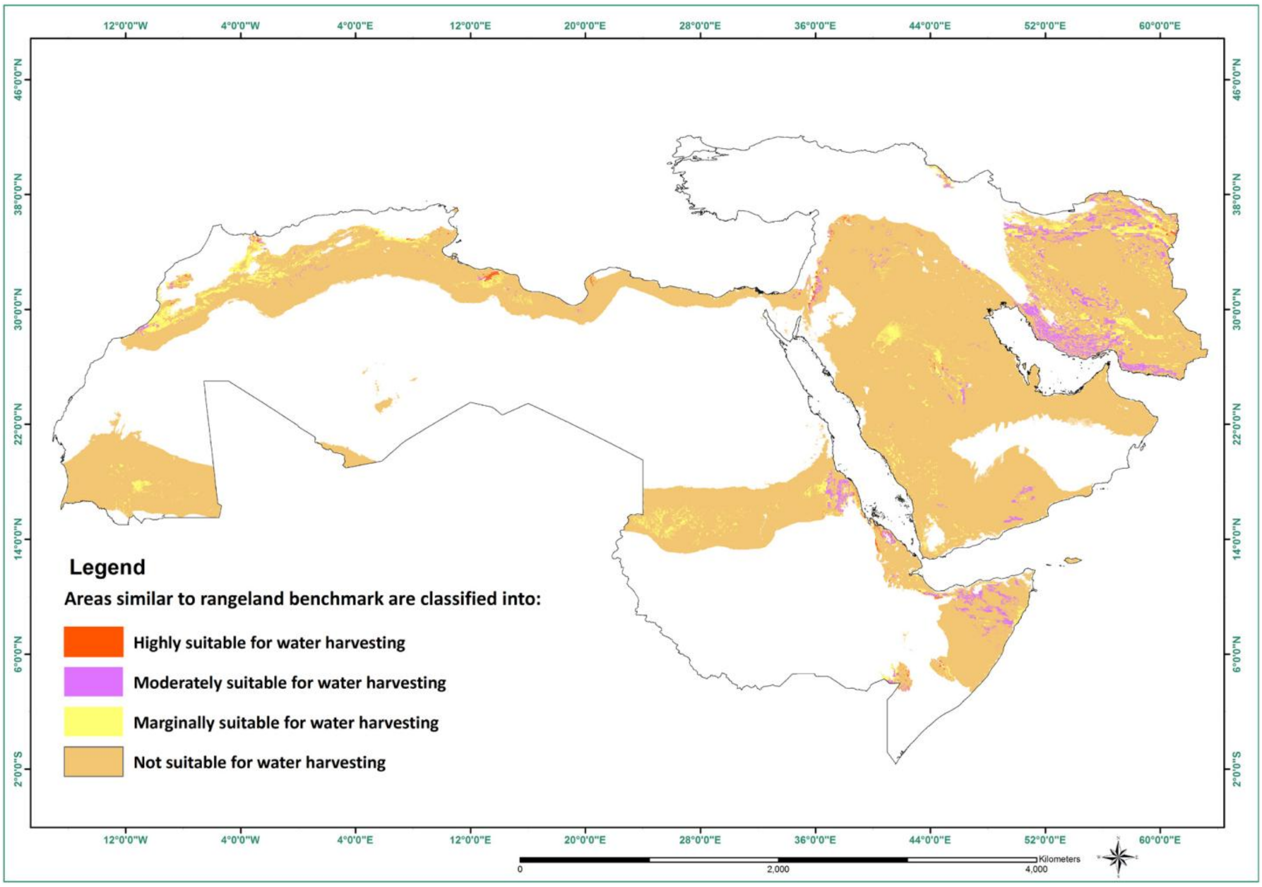
It seems that producing suitability maps with acceptable accuracy at this scale is challenging. These maps should be used with caution, especially for the irrigated benchmark. For example, the Nile Delta in Egypt was classified as unsuitable for raised-bed agriculture whereas suitability analysis at the national level showed that most of the area is highly and moderately suitable. Therefore, it is not recommended that suitability maps produced at the regional level (WANA region) be used for making local level decisions and land-use allocations unless these are verified using more detailed data, preferably at the national level.



Map 32: Area suitable for the raised-bed packages.



Map 33: Area suitable for supplemental irrigation packages



Map 34: Area suitable for water harvesting practices

Suitability analysis at the national level

The suitability analysis was undertaken for the following countries: Egypt (land suitability for irrigated agriculture), Morocco (land suitability in the rainfed areas), and Jordan (land suitability for rangelands). The differences and similarities in the suitability analyses in these case studies in terms of the criteria used and the approach followed are discussed. This represents an important starting point for developing criteria for the suitability analyses for the three benchmarks.

A hands-on training in land suitability analysis, with an example of land suitability for water harvesting in rangelands and another example of land suitability for rainfed agriculture in the mountainous areas, were undertaken by the trainees with guidance from NCARE and ICARDA staff. This prepared the trainees from the various countries to undertake the required analyses in their home countries and, most importantly, to standardize the procedure of land suitability analysis.

To standardize the whole process of land suitability, the suitability criteria were unified. The current suitability criteria were discussed and new criteria were formulated. The new criteria were suggested and modified by a multi-disciplinary team representing all the countries involved. The new criteria consider the requirements for each benchmark under the assumption that the most promising technology will be implemented.

In the case of the irrigated benchmark, raised-bed technology was considered as the most promising technology for promotion and out-scaling. It assumes that the area where this technology will be applied is already under irrigation and the requirements to implement this technology were identified following a thorough discussion by the multi-disciplinary team Table 16. These criteria primarily consider the specific requirements that apply to the raised-bed technology and other requirements for successful crop growth and production are not considered here.

For the rainfed benchmark, the requirements for out-scaling the supplemental irrigation package were identified Table 17. The implementation of these criteria assumes that the area is already cultivated and these criteria are those that apply to supplemental irrigation.

For the rangeland benchmark, the Vallerani water-harvesting system was identified for out-scaling and the suitability criteria were identified Table 18. These criteria consider the requirements to implement the Vallerani water-harvesting system as well as establish shrub cultivation. This is because in most areas, establishing the water-harvesting system is associated with planting shrubs of drought tolerant species.

Table 16: Land suitability for the irrigated benchmark, raised-bed technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Soil depth (rooting depth)	cm	≥ 100	60–100	30–60	< 30
Soil texture	class	Clay, silty clay, clay loam and silty clay loam	Silt, silty loam, loam	Sandy clay, sandy clay loam, sandy loam, loamy sand	Sand
Stone content(5–10cm diameter) (surface and surface horizon; machine)	%	< 5	5–10	10–20	> 20
$CaCO_3$ (clay and silt size)	%	< 2	2–5	5–15	> 15
Soil salinity	mmhos/cm	< 2	2–4	4–8	> 8
Topography – slope	%	≤ 1	1–2	2–5	> 5
Crop type	class	Annual crops	Annual crops	Annual crops	Trees

Table 17: Land suitability for the rainfed benchmark, supplementary irrigation technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Climate					
Rainfall	mm	250–350	350–400	400–500	> 500
Water resources	mm	+150	+100	+50	
Soil					
Soil depth	cm	≥ 100	60–100	30–60	< 30
Soil water holding capacity	mm/m	≥ 150	110–150	75–110	< 75
Water quality/salinity	mmhos/cm	‹ 1	1–2	2–3	> 3
Crop type	class	Wheat	Wheat	Wheat	Others

Table 18: Land suitability for the rangeland benchmark water-harvesting technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Soil depth	cm	≥ 100	80–100	60–80	< 60
Soil texture	class	silty loam, loam, silty clay, silty clay loam	Clay, clay loam, Silt	Sandy clay, sandy clay loam, sandy loam, loamy sand	sand
Rainfall	mm	200–300	100–200	100–200	< 100 or > 300
Slope	%	2–4	4–8	8–12	< 2 or > 12
Vegetation (natural)	%	< 15	15–20	20–30	> 30
Stoniness (surface)	%	< 15	15–20	20–30	> 30

Suitability analysis for the pasture (rangeland) benchmark water-harvesting technology in Jordan

Report by: Safa Mazahreh,-NCARE-Jordan

Introduction

The purpose of this study is to present the data collection, processing, and approaches followed to produce the suitability maps for the rangeland benchmark Vallerani water-harvesting technology in Jordan based on the criteria suggested by the experts. These criteria were revised and modified according to the discussions of a workshop of the participating multi-disciplinary team of experts from eight countries in the WANA region. The suitability analysis was conducted in a GIS environment using many processes to overlay different thematic maps. According to the criteria, thematic suitability maps were produced to represent individual criterion suitability maps. In our case, six suitability maps were prepared in addition to the final suitability map. The final suitability map was scored to the worst suitability class for each polygon. Different suitability maps were produced to indicate the areas suitable for the rangeland benchmark Vallerani water harvesting technology. Three approaches were applied in the suitability analysis and mapping. This report explains the approaches and the process of producing suitability maps.

Criteria used

Table 19 shows the criteria that were applied to draw the suitability maps for the rangeland benchmark Vallerani water-harvesting technology in Jordan.

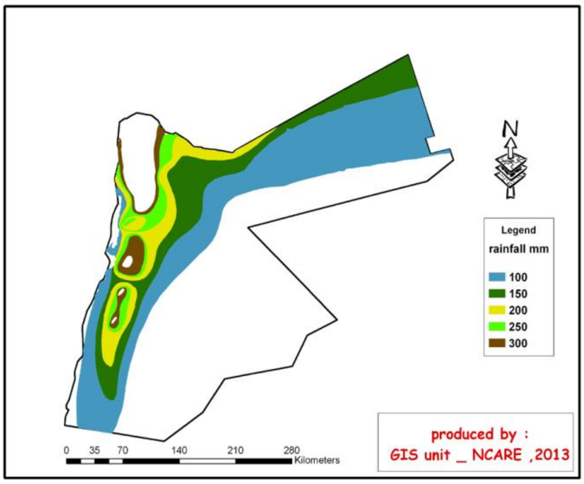
Table 19: Criteria for land suitability for the rangeland benchmark Vallerani water-harvesting technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Soil depth	cm	≥ 100	80-100	60-80	< 60
Soil texture	class	Silty loam, loam, silty clay, silty clay loam	Clay, clay loam, silt	Sandy clay, sandy clay loam, sandy loam, loamy sand	Sand
Rainfall	mm	200–300	100–200	100–200	< 100 or > 300
Slope	%	2–4	4–8	8–12	< 2 or > 12
Vegetation (natural)	%	< 15	15–20	20–30	> 30
Stoniness (surface)	%	< 15	15–20	20–30	> 30

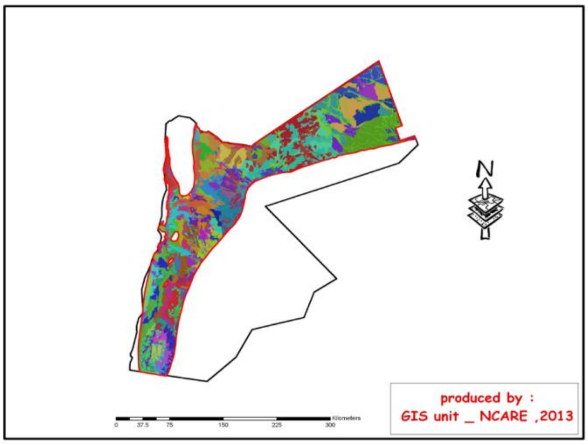
Methodology

Data used

The maps used in the suitability analysis are based on a vector format. The basic map used to define the boundary of all layers was the rainfall isohyets map for 100–300 mm of rainfall. All layers were clipped with the basic boundary map to reduce the time of process- ing and analysis.
Common layers for all approaches were: slope map (Map 35) derived from DEM and rainfall isohyets (Map 36). These maps were classified according to the criteria used. These maps were rated and scored into suitability classes based on the suitability criteria.

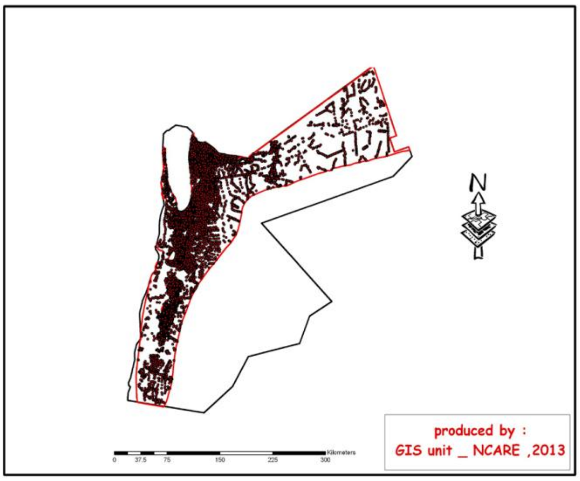


Map 35: Slope map classified based on suitability criteria



Map 36: Rainfall isohyets map for Jordan

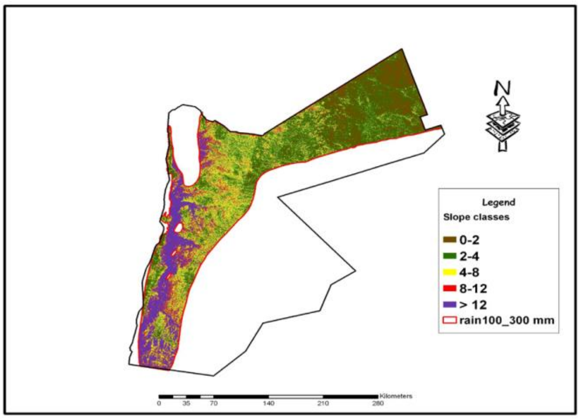
Data related to soil depth, stoneiness, texture, and vegetation criteria were extracted from field observations in the study area. About 26,890 observations (Map 37), with a lot of information important for the suitability analysis provided by the Ministry of Agriculture (MoA), were used and analyzed (MoA 1995).



Map 37: Field observations distributed in the rainfall zone 100–300 mm

Approach one:

The soil map (Map 38) and field observations were the basic layers used to rate the soil depth, stoniness, texture, and vegetation criteria on the basis of the soil mapping units.
For each soil mapping unit:



Map 38: Soil map with 128 mapping units

- Soil depth was estimated as the average of existing observations
- Stoniness was identified as the mode of ‘suface cover type’ related to field observations and the percentage was estimated as the average of that mode. Criteria were applied, as shown in the table, for the surface cover types – rock, boulders, and stones – while other types of surface cover were rated as ‘S1’ for an estimated percentage ≤ 15 % otherwise they were rated as ‘NS’

- Texture was rated according to the mode values that existed in each soil mapping unit. Two sources were used – texture class if present, otherwise 'particle size' – and then classified according to the criteria into suitability classes
- Vegetation type and percentage were identified using 'land-use cover' and 'ground cover %' linked to field observations. Any class with a zero value was ignored and observations having classes 23, 24, 25, 26, and 34 were reclassified as natural vegetation with class '999' Then the mode values were estimated for each mapping unit and the percentage was calculated for that mode and rated according to the criteria. Other land cover classes (modes) were rated as 'S1' for a related percentage of less than 15% otherwise they were classified as 'NS'.

Note: 'very little soil' mapping units do not have any observations to be characterized, therefore, they were classified as not available 'NA'.

As a result, the soil map contains fields of average depth, stoniness mode and percentage, texture mode, and vegetation type mode and percentage, and the suitability classes for all criteria.
An intersect process was applied to the three layers (slope, rainfall, and soil) that represent the criteria, resulting in a very complicated map that was scored finally to the worst suitability class for each polygon.

Approach two:
The field observations layer was the basic one for running the suitability analysis. In this approach, intepolation using the Thiessen process[1] was applied to the field observations layer. The result was a complicated map with 26,798 polygons (after clipping with the boundary layer rainfall isohyet 100–300 mm). The large number of polygons is explained by each field observation being located in one polygon (area). This process assures that all polygons in the study area have data related to the criteria. Then all polygons were rated and scored according to the criteria into suitability classes. Any missing or unexplained data were compensated for from the mode and percentage criteria related to the soil mapping units produced in Approach one.

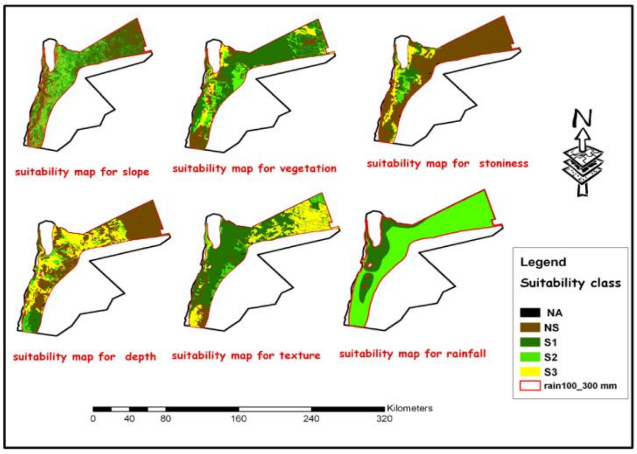
An intersect process was applied to the three layers (slope, rainfall, and Thiessen) that represented the criteria, resulting in a very complicated map that was scored finally to the worst suitability class for each polygon.

Approach three:
In this approach, a soil depth layer was created with an interpolation process following the Kriging method[2], using the field observatins layer (26,890 points), reclassified according to the criteria, and then rated into suitability classes. Stoniness with classes 2 (rocks), 3 boulders), and 4 (stones) were selected from field observations (16,601 points) and exported into a new layer with their percentages. Then interpolation (Kriging method) of the percentage of stoniness was applied, reclassified according to the criteria classes, and rated accordingly.
Vegetation types of classes 23, 24, 25, 26, and 34 were selected (12,645 points), with their related percentages, using the field observation layer. The same process (interpolation) was applied to the vegetation percentage. Then the output layer was organized into classes according to the vegetation criteria and rated intosuitabilityclasses. Soil texture suitability classes, produced from the Thiessen layer that was created in Approach two, were used.

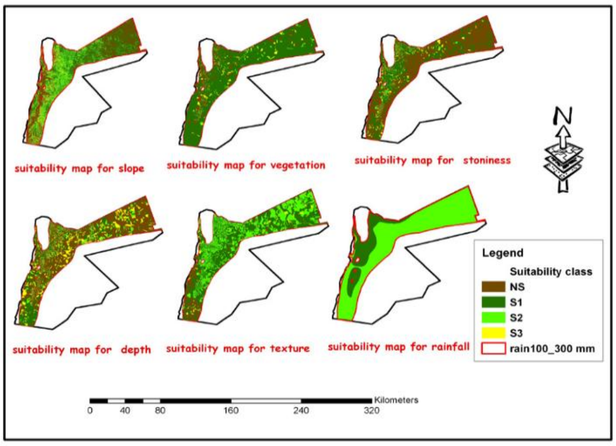
[1] The Thiessen process is a procedure to generate Thiessen polygons which are polygons generated from a set of sample points. Each Thiessen polygon defines an area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points. Thiessen polygons are named for the American meteorologist Alfred H. Thiessen (1872–1931). Source: ESRI. ESRI understanding our world. Support. GIS dictionary. Thiessen polygons. Available at: http://support.esri.com/en/knowledgebase/GISDictionary/term/Thiessen%20polygons. Accessed: 28 January 2014.

[2] Kriging: an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points. Kriging is unique among the interpolation methods in that it provides an easy method for characterizing the variance, or the precision, of predictions. Kriging is based on regionalized variable theory, which assumes that the spatial variation in the data being modeled is homogeneous across the surface. That is, the same pattern of variation can be observed at all locations on the surface. Kriging was named for the South African mining engineer Danie G. Krige (1919). Source: ESRI. ESRI understanding our world. Support. GIS dictionary. Kriging. Available at:. http://support.esri.com/en/knowledgebase/GISDictionary/term/kriging. Accessed 28 January2014

Intersecting the six layers (slope, rainfall, Thiessen-texture, soil depth, vegetation, and stoniness), which represent the suitability criteria, resulted in a very complicated map that was scored finally to the worst suitability class for each polygon.



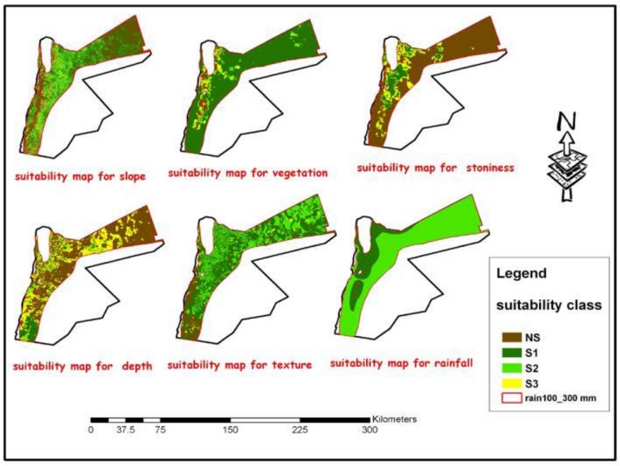
Map 39: Individual land suitability for the rangeland benchmark Vallerani technology in Jordan, Approach one.



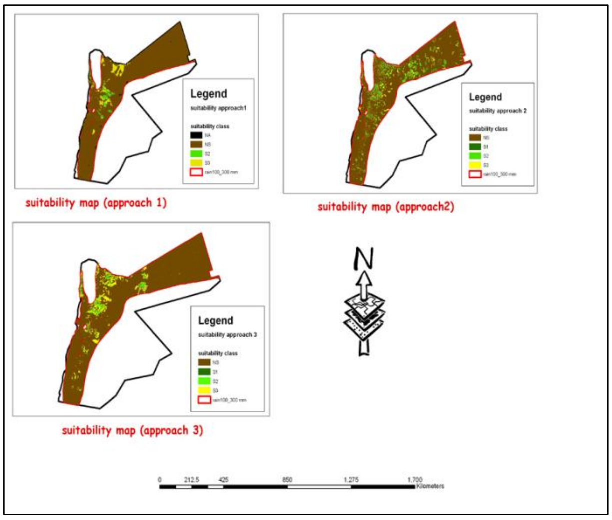
Map 40: Individual land suitability for the rangeland benchmark Vallerani technology in Jordan, Approach two

Results and outputs

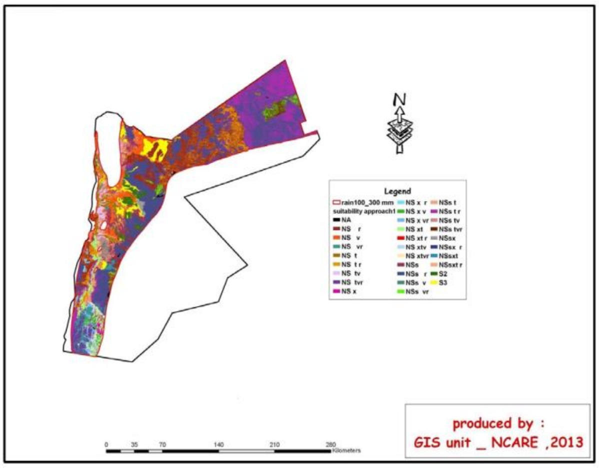
Six individual suitability maps were produced to represent the six criteira for the three approaches, as shown in Map 39, 40, and 41. Based on the different approaches, the final general suitability maps were produced as shown in Map 42, while the detailed suitability maps with the limitations for all aproaches are shown in Map 43, 44, and 45. The limitations for land suitability classes are explained in Table 20.



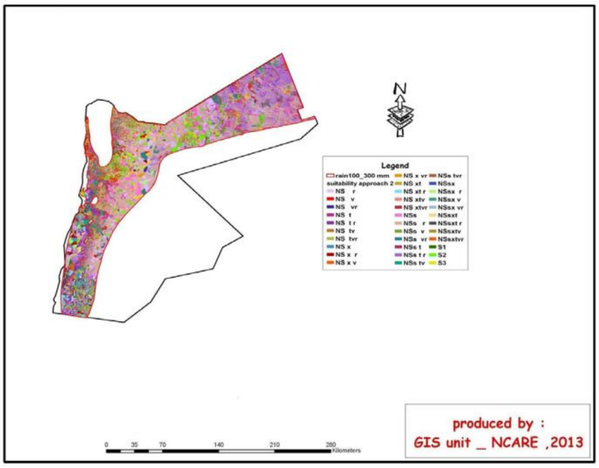
Map 41: Individual land suitability for the rangeland benchmark Vallerani technology in Jordan Approach three.



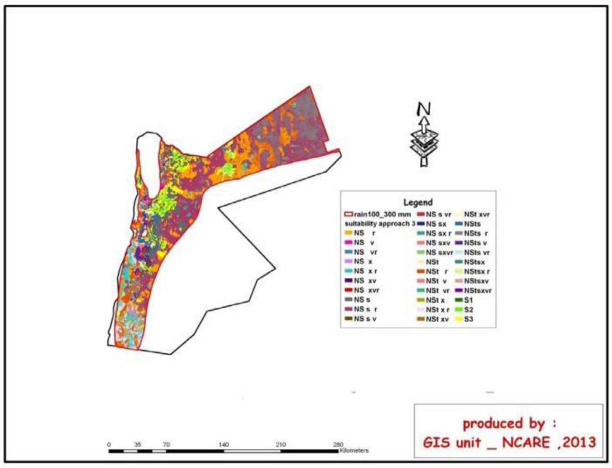
Map 42: General land suitability for the rangeland benchmark Vallerani technology in Jordan, for the three approaches.



Map 43: Detailed land suitability with limitations for the rangeland benchmark Vallerani technology in Jordan, Approach one



Map 44: Detailed land suitability with limitations for the rangeland benchmark Vallerani technology in Jordan, Approach two



Map 45: Detailed land suitability with limitations for the rangeland benchmark Vallerani technology in Jordan, Approach three

Areas and area percentages were analyzed to represent the general suitability classes for the three approaches, as shown in Tables 21, 22, and 23, while Tables 24, 25, and 26 show the area analyses for the suitablity classes with the limitations for all approaches. The index for the limitations is shown in Table 20.

Table 20: Index of limitations

Limitation criteria	Abbreviation index
Soildepth	s
Stoniness	r
vegetation	v
texture	x
Topography–slope	t

Table 21: Area analysis for the general suitability classes, Approach one

Suitability class	Area (km²)	Area (%)
NA	93.3	0.2
NS	41,015.3	93.7
S2	790.7	1.8
S3	1,851.7	4.2
Total area	43,751.0	100.0

Table 22: Area analysis for the general suitability classes, Approach two

Suitability class	Area (km²)	Area (%)
NS	38,818.0	88.7
S1	111.6	0.3
S2	2,829.3	6.5
S3	2,001.3	4.6
Total area	43,760.2	100.0

Table 23: Area analysis for the general suitability classes, Approach three

Suitability class	Area (km²)	Area (%)
NS	39,994.2	91.6
S1	50.7	0.1
S2	1,040.9	2.4
S3	2,555.5	5.9
Total area	43,641.2	100.0

Table 24: Area analysis for the suitability classes with limitations, Approach one

Suitability class with limitation		Area (km²)	Area (%)
NA		93.3	0.2
NS	r	6,559.8	15.0
NS	v	1,954.4	4.5
NS	v, r	833.7	1.9
NS	t	1,058.7	2.4
NS	t, r	2,620.5	6.0
NS	t, v	844.5	1.9
NS	t, v, r	960.2	2.2
NS	x	357.8	0.8
NS	x, r	153.2	0.4
NS	x, v	269.3	0.6
NS	x, v, r	452.8	1.0
NS	x, t	964.9	2.2
NS	x, t, r	56.7	0.1
NS	x, t, v	80.1	0.2
NS	x, t, v, r	318.4	0.7
NS	s	15,60.5	3.6
NS	s, r	11,801.6	27.0
NS	s, v	222.6	0.5
NS	s, v, r	566.8	1.3
NS	s, t	1,355.5	3.1
NS	s, t, r	6,798.5	15.5
NS	s, t, v	331.2	0.8
NS	s, t, v, r	580.7	1.3
NS	s, x	171.9	0.4
NS	s, x, r	100.4	0.2
NS	s, x, t	2.1	0.0
NS	s, x, t, r	38.6	0.1
S2		790.7	1.8
S3		1,851.7	4.2
Total area		43,751.0	100.0

Table 25: Area analysis for the suitability classes with limitations, Approach two

Suitability class with limitations		Area (km²)	Area (%)
NS	r	4,060.9	9.3
NS	v	1,019.5	2.3
NS	v, r	252.8	0.6
NS	t	2,220.5	5.1
NS	t, r	2,135.8	4.9
NS	t, v	706.3	1.6
NS	t, v, r	183.8	0.4
NS	x	800.8	1.8
NS	x, r	742.7	1.7
NS	x, v	28.3	0.1
NS	x, v, r	60.6	0.1
NS	x, t	605.9	1.4
NS	x, t, r	710.4	1.6
NS	x, t, v	12.0	0.0
NS	x, t, v, r	20.3	0.0
NS	s	3,566.7	8.2
NS	s, r	10,128.9	23.1
NS	s, v	625.0	1.4
NS	s, v, r	776.0	1.8
NS	s, t	1,636.9	3.7
NS	s, t, r	6,011.3	13.7
NS	s, t, v	630.2	1.4
NS	s, t, v, r	550.6	1.3
NS	s, x	63.5	0.1
NS	s, x, r	607.7	1.4
NS	s, x, v	37.8	0.1
NS	s, x, v, r	12.0	0.0
NS	s, x, t	90.7	0.2
NS	s, x, t, r	499.5	1.1
NS	s, x, t, v	17.6	0.0
NS	s, x, t, v, r	2.8	0.0
S1		111.6	0.3
S2		2,829.3	6.5
S3		2,001.3	4.6
Total area		43,760.2	100.0

Table 26: Area analysis for the suitability classes with limitations, Approach three

Suitability class and limitations		Area (km^2)	Area (%)
NS	r	6,300.5	14.4
NS	v	234.9	0.5
NS	v, r	56.6	0.1
NS	x	254.5	0.6
NS	x, r	1,588.5	3.6
NS	x, v	0.4	0.0
NS	x, v, r	1.1	0.0
NS	s	3,030.0	6.9
NS	s, r	11,506.6	26.4
NS	s, v	414.0	0.9
NS	s, v, r	112.6	0.3
NS	s, x	23.2	0.1
NS	s, x, r	482.4	1.1
NS	s, x, v	0.7	0.0
NS	s, x, v, r	0.5	0.0
NS	t	1,118.9	2.6
NS	t, r	3,517.7	8.1
NS	t, v	298.7	0.7
NS	t, v, r	104.2	0.2
NS	t, x	138.6	0.3
NS	t, x, r	1,451.3	3.3
NS	t, x, v	1.8	0.0
NS	t, x, v, r	1.5	0.0
NS	t, s	1,101.9	2.5
NS	t, s, r	7,032.8	16.1
NS	t, s, v	698.3	1.6
NS	t, s, v, r	157.0	0.4
NS	t, s, x	52.3	0.1
NS	t, s, x, r	304.8	0.7
NS	t, s, x, v	4.2	0.0
NS	t, s, x, v, r	3.7	0.0
S1		50.7	0.1
S2		1,040.9	2.4
S3		2,555.5	5.9
Total area		43,641.2	100.0

Table 27: Area analysis for suitability classes in all approaches

	Area (%)		
Suitability class	Approach one	Approach two	Approach three
S1		0.3	0.1
S2	1.8	6.5	2.4
S3	4.2	4.6	5.9
NS	93.7	88.7	91.6
NA	0.2		
Total	100	100	100

Results for the area percentages for all approaches are summarized in Table 27.
The results show that more than 80% of the total area is classified as 'NS' – Not suitable – for all approaches. While the 'highly suitable S1' class is not identified in Approach one it is found in the other two approaches. Suitable areas – classes S1 and S2 – are the largest in Approach two (6.8%) as compared with the other approaches (1.8, 2.5%). The table also shows that the suitability class S3 is almost the same in all approaches.
An analysis of the suitabillity classes with limitations is not easy between the three approaches, but an example that shows and compares the 'NS' class with individual limitations for all approaches is shown in Table 28.

Table 28: Comparison of the percentage area for the 'NS' class with individual limitations between the different approaches

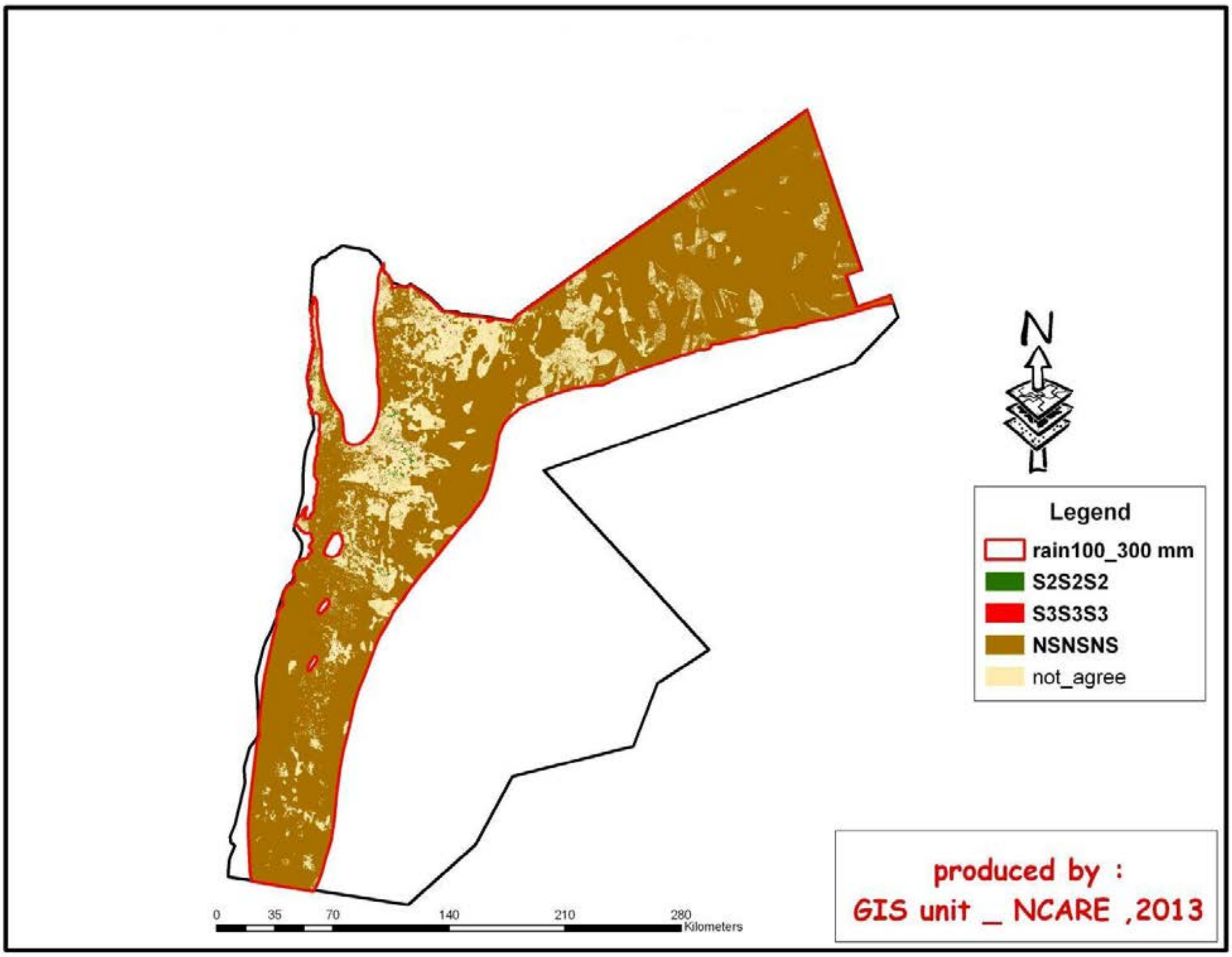
Suitability class with limitations		**Area (%)**		
		Approach one	**Approach two**	**Approach three**
NS	**r**	15	9.3	14.4
NS	**v**	4.5	2.3	0.5
NS	**t**	2.4	5.1	2.6
NS	**x**	0.8	1.8	0.6
NS	**s**	3.6	8.2	6.9

Table 29 shows the perecent agreement of the suitability combinations between the three approaches. For the NS class, 81% of the total area is classified to 'not suitable' in the three approaches. For the S2 and S3 classes, 0.2% of the total area is classified as 'moderately suitable' and 'marginally suitable' in the three approaches. As a result, 81.3% agreement was found between the suitability classes for the three approaches. The remaining area, which was estimated to be 18.7%, has different combinations of land suitability classes in the three approaches.

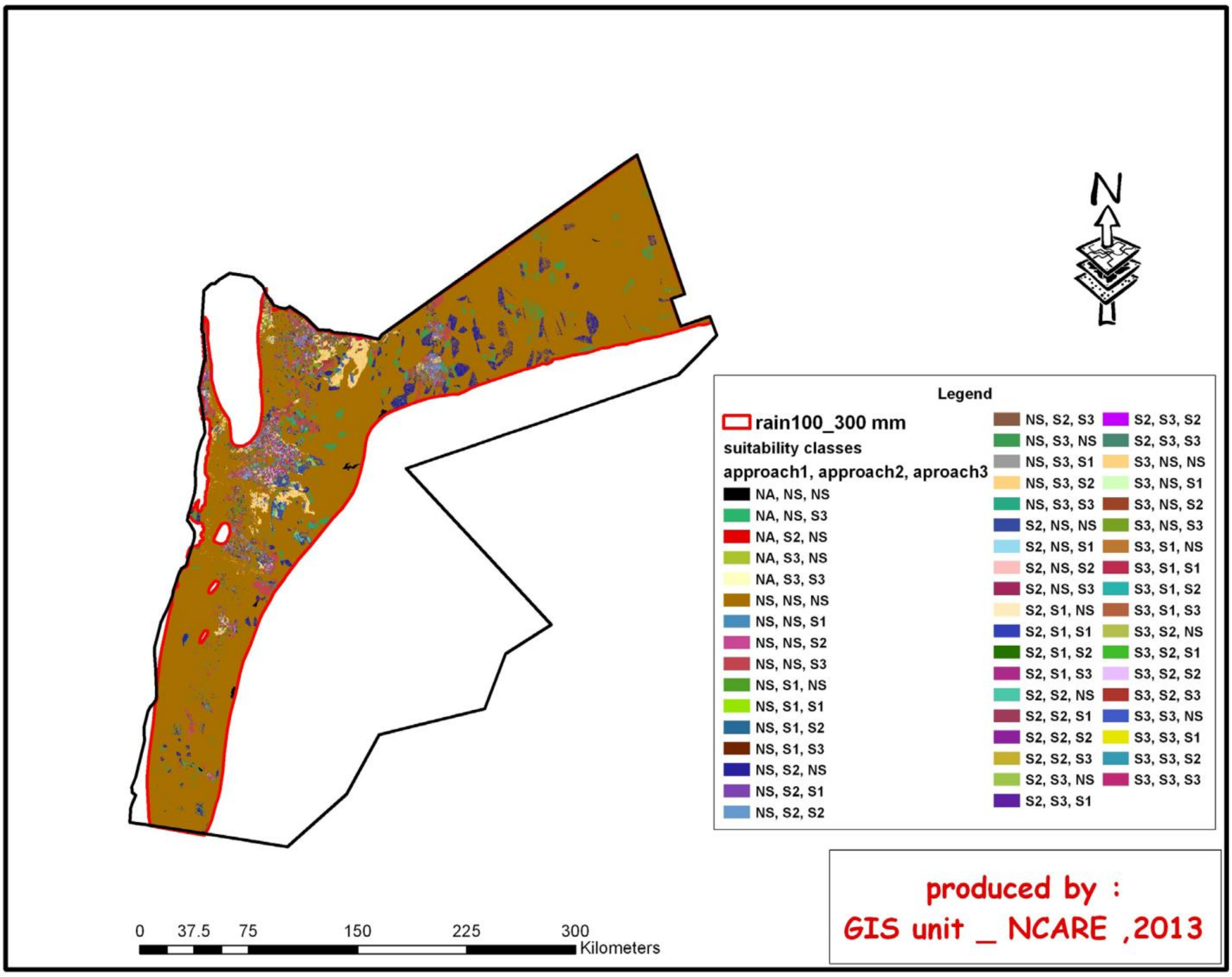
Map 46 shows the areas where the three approaches agree on the suitability classes and those areas where there is no agreement and which have different combinations of land suitability classes. The combinations of land suitability classes are shown in Map 47

Table 29: Agreement on percentage suitability between the three approaches

Suitability for all approaches(one, two, and three)	Agreement (%)
NS, NS, NS	**80.9**
S2, S2, S2	**0.2**
S3, S3, S3	**0.2**
Total agreement	**81.3**



Map 46: Suitability map for the rangeland benchmark Vallerani water-harvesting technology that shows the areas where the three approaches agree on the suitability classes and where they do not



Map 47: Suitability map that shows the land-use areas where the three approaches agree on the different combinations of suitability classes and areas where they do not

Land suitability for the rainfed benchmark: Tadla irrigated perimeter

Report by: Tarik Benabdelouahab, INRA,-Morocco

Introduction

The main purpose of this work is to present the results of the suitability analysis. The maps prepared present the suitability classes based on the suggested expert criteria for the rainfed agro-ecosystems developed under the benchmark project.
The suitability map was established by intersecting data on climate, soil (soil depth and soil water holding capacity), water quality, and the crop cover throughout the region of interest. For the whole study area, the annual amount of rainfall varies between 250 and 350 mm, corresponding to the S1 class according to the criteria Table 30 defined for the benchmark site.

For this study, given the presence of hydro-agricultural infrastructure and the exploitation of groundwater, we assume that water is available and it is considered as a non-limiting factor.

Data preparation

Available water content (AWC)

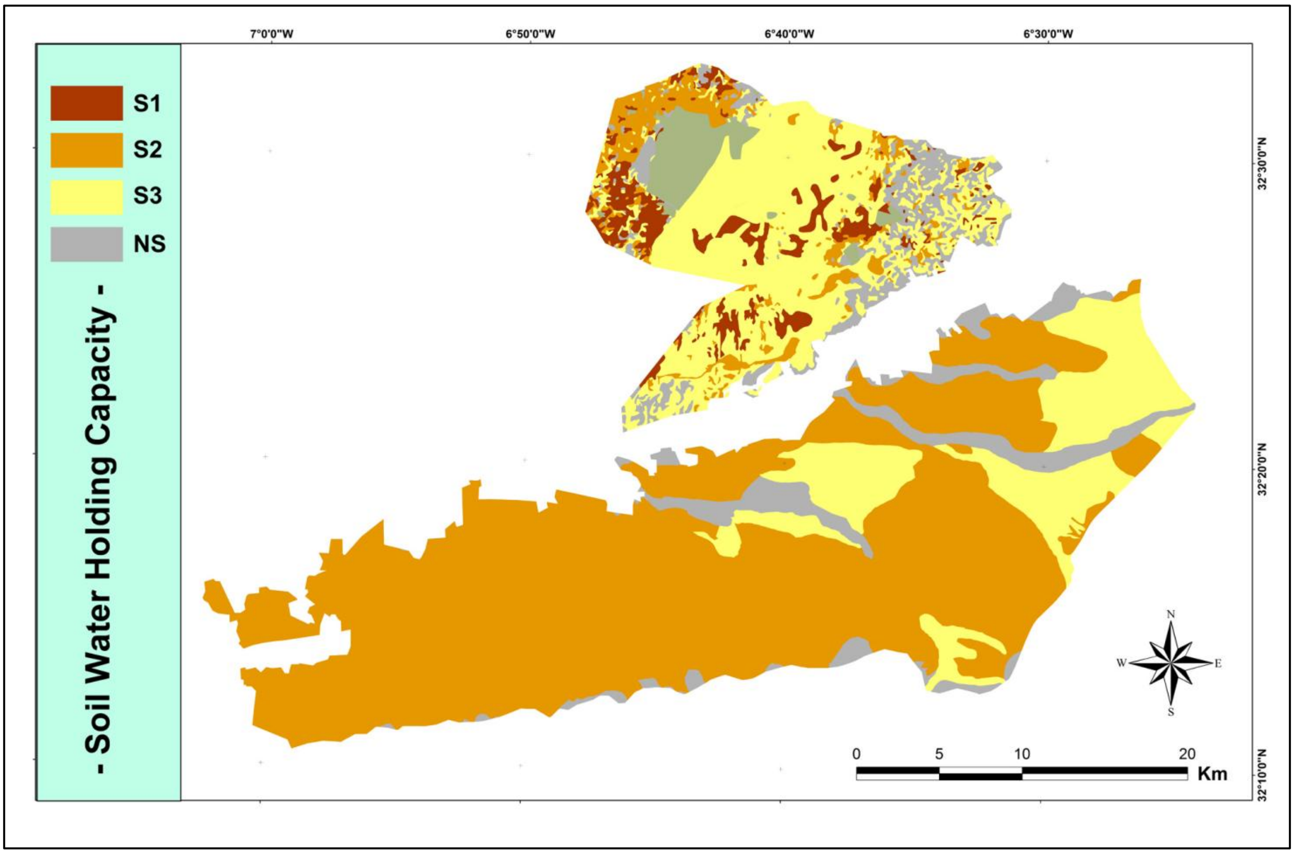
The calculation of the AWC requires a knowledge of the field capacity (FC) and wilting point values.

To determine the FC and permanent wilting point (PWP) values, we used the equation developed by Merzouk et al. (1987), which is based on the textural characteristics of the soil. We used the mean values of the physical and chemical parameters for each soil type in the region (texture, bulk density, and soil depth) cited in the soil report (Massoni et al. 1967).

- Calculation of FC: is taken as the existing water content held in the soil after 48 hours of drainage - The equation used is: FC (mm) = 43.638 - 0.31 * (% sand)
- Calculation of PWP: corresponds to the soil moisture level from which the plant cannot take water - The equation used is: PWP (mm) = - 0.83 + 0.77 * (% clay) - 0.0054 * (% clay) ^{2}
- Calculation of the capacity to store water (AWC) - The equation used: AWC (mm) = (FC - PWP) * Depth * Bulk density.

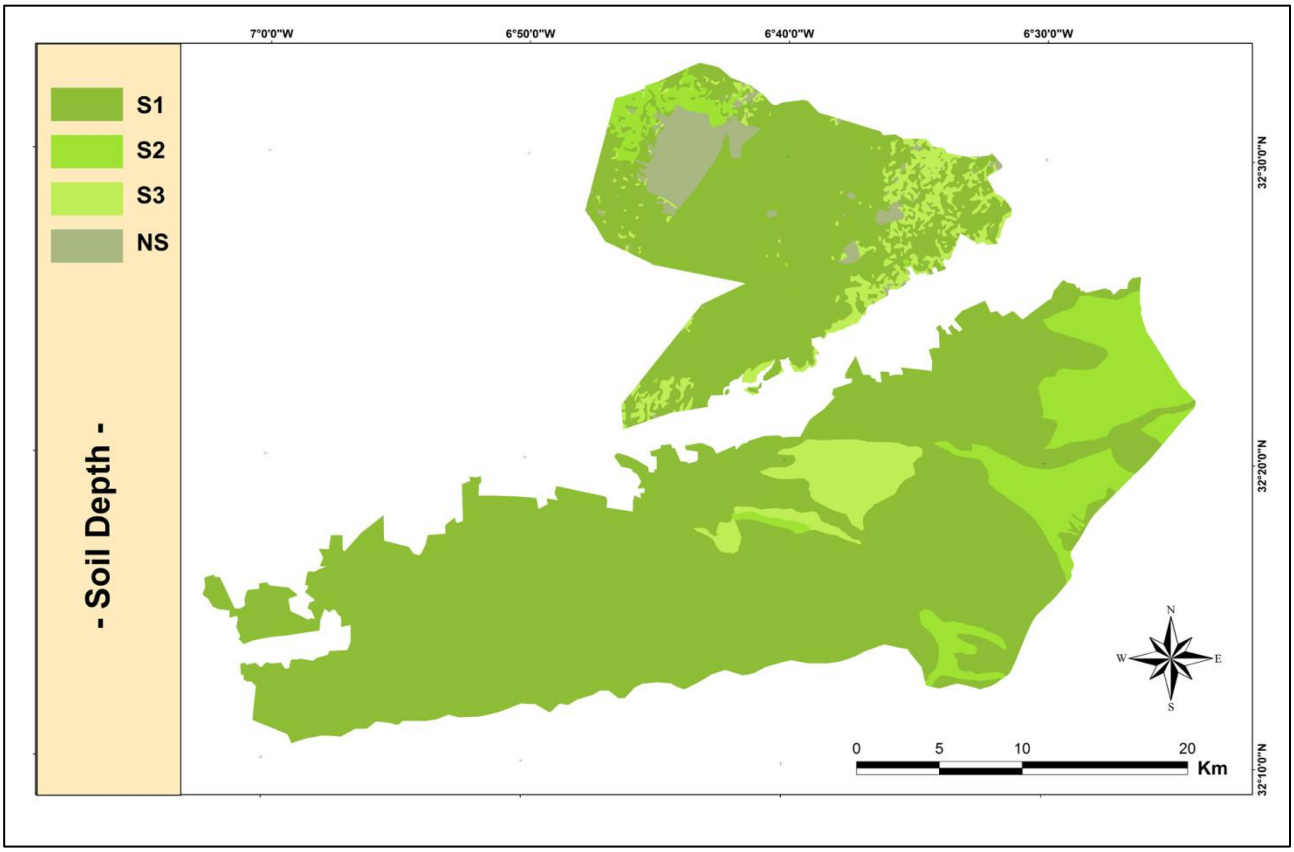
Table 30: Criteria used in the suitability analysis for rainfed benchmark supplementary irrigation technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Climate					
Rainfall	mm	250–350	350–400	400–500	>500 or <250
Water resources	mm	+150	+100	+50	-
Soil					
Soil depth	cm	≥ 100	60–100	30–60	< 30
Soil water holding capacity	mm/m	≥ 150	110–150	75–110	< 75
Water quality/salinity	mmhos/cm	‹ 1	1–2	2–3	> 3
Crop type	class	Wheat	Wheat	Wheat	Others



Map 48: Map of AWC for the irrigated perimeter of Tadla

Soil depth



Map 49: Map of soil depth within the irrigated perimeter of Tadla

Ground water

From 50 analyses of groundwater conducted by the Office Regional de Mise en Valeur Agricole of Tadla (ORMVAT) across the irrigated perimeter, we conducted a spatial interpolation (inverse distance weighting) to produce Map 50.

Suitability classes

To automatically assign a suitability class to each polygon according to the criteria developed we used the following program developed in Visual Basic for Applications (VBA).

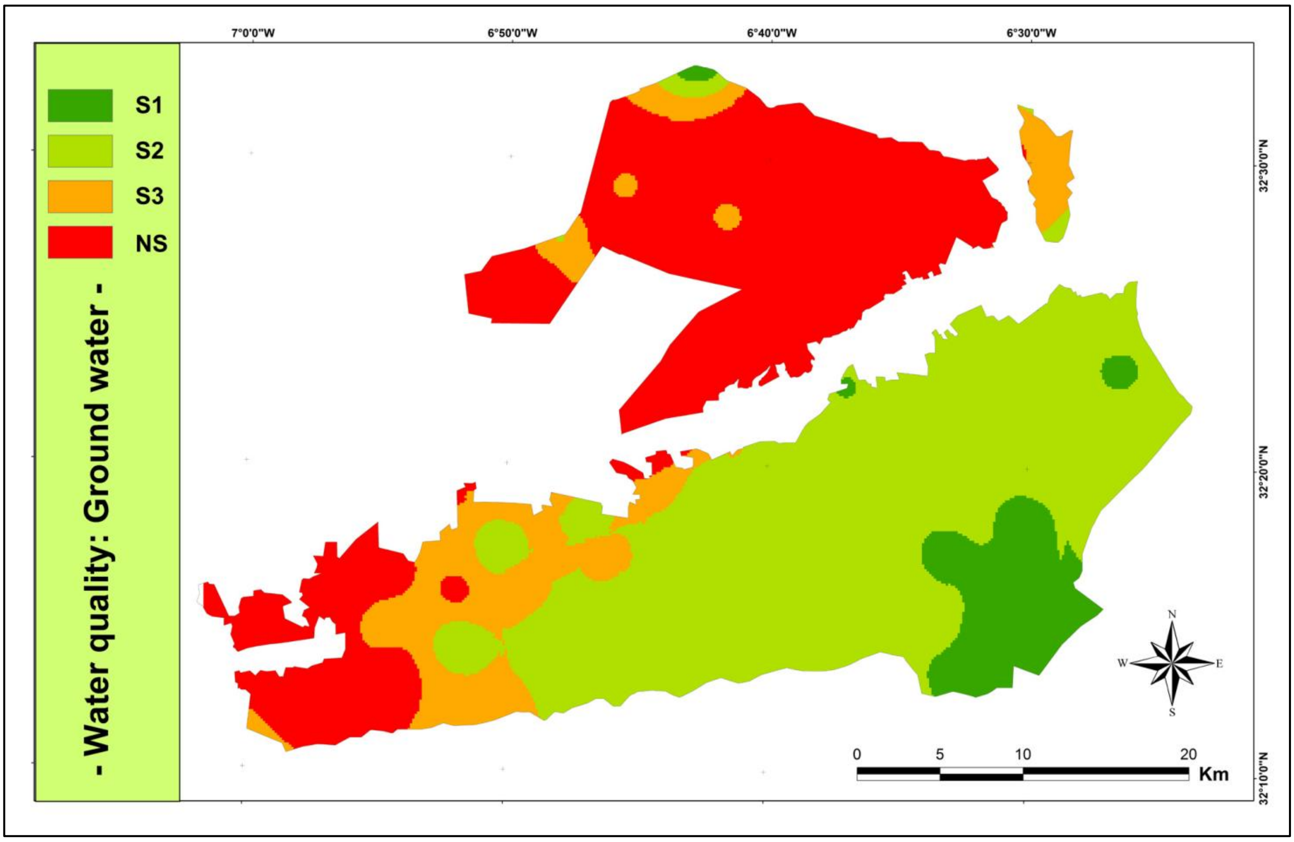
If [Criteria1] ="NS" OR [Criteria 2] ="NS" OR [Criteria 3] ="NS" OR [Criteria 4] ="NS" **THEN** [Suitability_Final] ="NS"

elseif [Criteria1] ="S3" OR [Criteria 2] ="S3" OR [Criteria 3] ="S3" OR [Criteria 4] ="S3" **THEN** [Suitability_Final] ="S3"

elseif [Criteria1] ="S2" OR [Criteria 2] ="S2" OR [Criteria 3] ="S2" OR [Criteria 4] ="S2" **THEN** [Suitability_Final] ="S2"

elseif [Criteria1] ="S1" AND [Criteria 2] ="S1" AND [Criteria 3] ="S1" AND [Criteria 4] ="S1" **THEN** [Suitability_Final] ="S1"

End if



Map 50: Map of the quality of groundwater resources for the irrigated perimeter of Tadla

Suitability map

Within the perimeter of Tadla, there are multiple ground and surface water resources for irrigation – the dams of Bin El Ouidane, Oued El Abid, Kasbat Zidania, and Oued Oum Er Rbia. It is important to note that groundwater is characterized by high salinity in Beni Amir (on the north side).

Suitability map using surface water

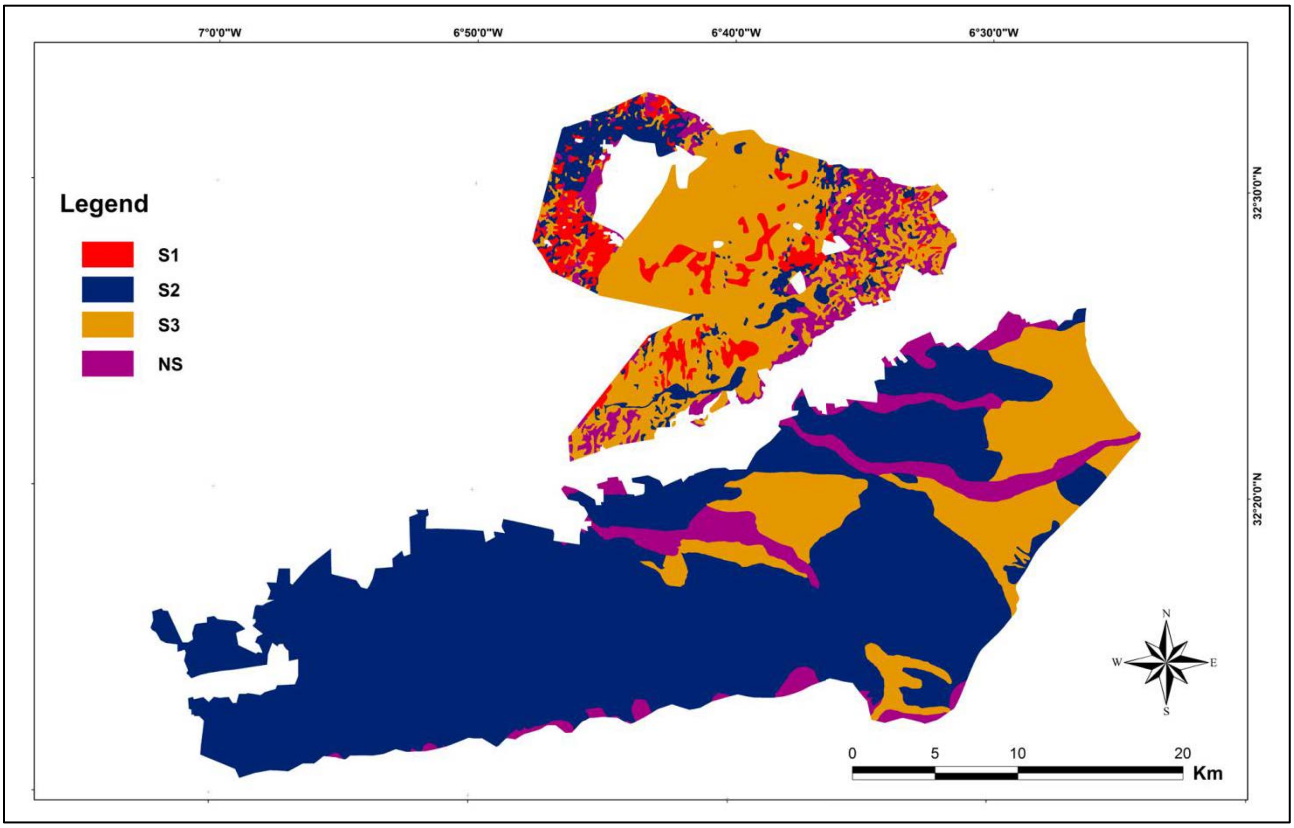
Map 51 shows the suitability of the land areas Beni Amir and Beni Moussa for the application of the supplemental irrigation technique. We conclude that much of Beni Moussa and part of Beni Amir are represented in the 'S2' class of suitability. An area of approximately 62,771 ha (62.7%) is suitable for the development of the supplemental irrigation technique. The areas unsuitable for the use or development of this technique constitute 9.57%.

Suitability map using surface water and ground water

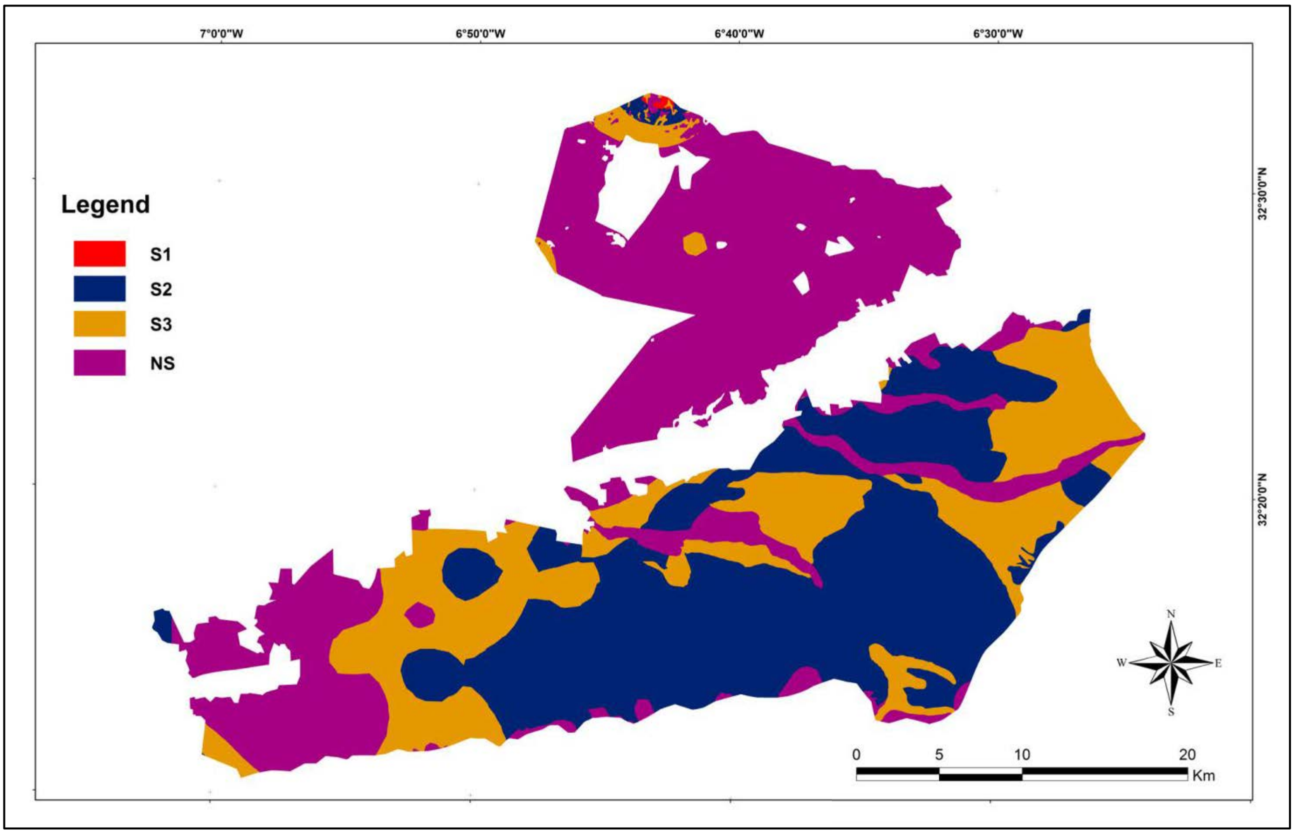
Map 52 shows the suitability of the land areas Beni Amir and Beni Moussa for the application of the supplemental irrigation technique using both surface water and ground water.

Table 31: Proportions (%) of the land area in the Tadla irrigation perimerter suitable for supplemental irrigation technology

Suitability class	Area (%)
S1	3.42
S2	59.34
S3	27.67
NS	9.57



Map 51: The suitability of the land areas Beni Amir and Beni Moussa for the application of the supplemental irrigation technology



Map 52: The suitability of the land areas Beni Amir and Beni Moussa for the application of the supplemental irrigation technology using both surface and ground water

Table 32: Proportions (%) of the land area in the Tadla irrigation perimerter suitable for supplemental irrigation technology using surface and ground water

Suitability classes	Area (%)
S1	0.058
S2	36.73
S3	23.13
NS	40.082

We note that in 40% of the area it is unsuitable to apply supplemental irrigation using ground water. This is because of the high salinity and high nitrate content of this resource.

Suitability analysis for the irrigated benchmark raised-bed technology

Report by: Samar Attaher, ARC, Egypt

Introduction

The following report presents the methods for and the results of developing a land suitability analysis for applying raised-bed technology in Egypt. Research has shown that water-saving irrigation techniques on raised-bed systems dramatically reduced water consumption without any appreciable loss in crop yields. Using a raised-bed system, the number of furrows was half that of conventional fields in the Nile Delta and consumed 20% less water. Labor costs for preparing the land, irrigating, and controlling weeds also dropped by 30%, and fertilizer application dropped by 25%. The net return of crop yield per unit of water was 20% higher than that from conventional furrow irrigation (First annual report of the benchmark project – Phase II).

It was assumed that the area where this suitability analysis will be applied is already under irrigation and the requirements listed in Table 33 are those required to implement the raised-bed technology successfully. Other requirements for successful crop growth and production are not considered here.

Table 33: Land suitability for irrigated benchmark raised-bed technology

Land quality/characteristic	Unit	S1	S2	S3	NS
Soil depth (rooting depth)	cm	≥ 100	60–100	30–60	< 30
Soil texture	class	Clay, silty clay, clay loam and silty clay loam	Silt, silty loam, loam	Sandy clay, sandy clay loam, sandy loam, loamy sand	sand
Stone content (5–10cm diameter) (surface and surface horizon; machine)	%	< 5	5–10	10–20	> 20
$CaCO_3$ (clay and silt size)	%	< 2	2–5	5–15	> 15
Soil salinity	mmhos/cm	< 2	2–4	4–8	> 8
Topography - slope	%	≤ 1	1–2	2–5	> 5
Crop type	class	Annual crops	Annual crops	Annual crops	Trees

The methodology used is the agreed simple method reported in 'Manual for suitability mapping using GIS – an example of rainfed agriculture for the Irak village watershed, Jordan', with some modifications. Table 34 lists the main resources used in the analysis.

Table 34: Main data sources used in the analysis

GIS resources	What it represents	Type	Source
WANA_soil_data	Represent the soil properties of the Middle East and North Africa (MENA) region. The fields used: Soil texture Soil depth classes	Raster	WaterBase project - United Nations University hosted by UNU-INWEH http://waterbase.org/download_data.html
Salinity	Present the salinity limits classification of the agricultural lands. The classification has four categories of salinity limits	Vector	Spatial distribution of soil salinity level (National Authority of Remote Sensing- NARS 1998)
Eg-spatial-agg	Aggregated land-use map, including agricultural land-use types (rainfed crops, rainfed trees, irrigated crops, and irrigated trees)	Vector	Egypt – spatially aggregated multipurpose land cover database (FAO, Africa cover) http://www.fao.org/geonetwork/srv/en/metadata.show?id=38180&currTab=simple
SRTM_NE_250m_TIF	Slope (%)		SRTM 250 m digital elevation data http://srtm.csi.cgiar.org/
Egypt_boundary	The political boundaries of Egypt	Vector	National Authority for Remote Sensing

General remarks on methodology

- The approach followed in the land suitability process using GIS, is by overlaying secondary data from soil, topography, and precipitation
- Suitability analysis steps:
  1. Derive slope classes map from DEM
  2. Extract the required soil data from soil map (texture and depth)
  3. Extract agricultural land-use data from the land-use map
  4. Classify the data on the main resources (five layers) to the suitability categories, based on the criteria in Table 33
  5. Overlay-intersect the layers
     A. Soil depth
     B. Soil type
     C. Salinity
     D. Slope class
     E. Crop type/land cover
  6. Aggregate and normalize the suitability categories into one map
- Develop a slope map from DEM
  - The final filtered values of the slope were reclassified into the following 14 classes:
    1= 0.01–1
    2= 1.01–2
    3=2.01–3
    4= 3.01–4
    5= 4.01–5
    6= 5.01–6
    7= 6.01–8
    8= 8.01–10
    9= 10.01–20
    10= 20.01–30
    11=30.01–40
    12=40.01–60
    13=60.01–80
    14=80.01–95.27
  - The slope classified raster map was converted to a vector map and the slope classes defined, according to the categories of classes and the suitability criteria, into two fields – 'Slope_Clas' [text] and 'Slope_Suit' [text].
- Soil texture:
  - The data for Egyptian soil was clipped from the WANA_soil_data reference to the Egypt_boundary layer
  - The raster soil map was converted to a vector map and the soil suitability classes defined, based on soil texture, in the added field 'Texture_Su'.
- Soil depth:
  - Soil depth guidelines:
    Depth: the effective depth of soil for plant growth is the vertical distance into the soil from the surface to a layer that essentially stops the downward growth of plant roots. The barrier layer may be rock, sand, gravel, heavy clay, or a cemented layer (e.g. caliche). Terms that are used to express effective depth of soil are:

Table 35: Soil depth descriptions

Depth class	Description	Depth (cm)–	Suitability categories
Very shallow	Soil surface is less than 10 inches from a layer that retards root development	< 25	NS
Shallow	Soil surface is 10 to 20 inches from a layer that retards root development	25–50	S3
Moderately deep	Soil surface is 20 to 36 inches from a layer that retards root development	50–92	S2
Deep	Soil surface is 36 to 60 inches from a layer that retards root development	92–153	S1
Very deep	Soil surface is 60 inches or more from a layer that retards root development	> 153	S1

- Soil salinity:
    - The salinity map was a paper map from NARS, presenting a salinity limits classification of the agricultural lands. The description of the four salinity categories is illustrated in Table 36

Table 36: Description of the salinity problem

Code	Description of the salinity problem	Salinity limits
1	No salinity problems	Less than 4 mmhos/cm
2	Moderate salinity problems	4–8 mmhos/cm
3	High salinity problems	8–16 mmhos/cm
4	Very high salinity problems	> 16 mmhos/cm

Source: NARS 1998. National Authority for Remote Sensing, Egypt

    - The map was scanned, digitized, and edited for topology errors. This process is time consuming
    - A 'Salinity_Su' field is added to define the suitability categories. From Tables 33 and 36, the first salinity limits category (< 4 mmhos/cm) covered the 'S1' and 'S2' suitability levels, and is labeled 'S1S2'
- Agricultural land-use classes from 'Eg-spatial-agg':
    - From the 'LC' field the agricultural land 'AG' is selected
    - Based on the different types of 'AG' listed in the 'Type' field, four types of agricultural land are defined in the added field 'Type_N', as C: irrigated crops, CR: rainfed crops, T: irrigated trees, TR: rainfed trees
    - 'Crop_Suit' is added, and the irrigated crops 'C' is labeled as 'S', whereas irrigated trees, 'T' is labeled as 'NS'
- National data for the following parameters is not available:
    - Stone content (5–10 cm diameter) (surface and subsurface horizon; machine)
    - $CaCO_3$ (clay and silt size)
- The final overlaid layers.

Table 37: Land suitability for irrigated benchmark raised-bed technology (modified)

Land quality/ characteristic	Unit	S1	S2	S3	NS	Layer
Soil depth (rooting depth)	cm	≥ 100	60–100	30–60	< 30	Soil_d_egy
Soil texture	class	Clay, silty clay, clay loam and silty clay loam	Silt, silty loam, loam	Sandy clay, sandy clay loam, sandy loam, loamy sand	Sand	Soil_data_ Egypt
Soil salinity	mmhos/ cm	< 2	2–4	4–8	> 8	Salinity_Intersect
Topography -slope	%	≤ 1	1–2	2–5	> 5	Slope_classes
Crop type	class	Annual crops	Annual crops	Annual crops	Trees	Eg_spatial_agg

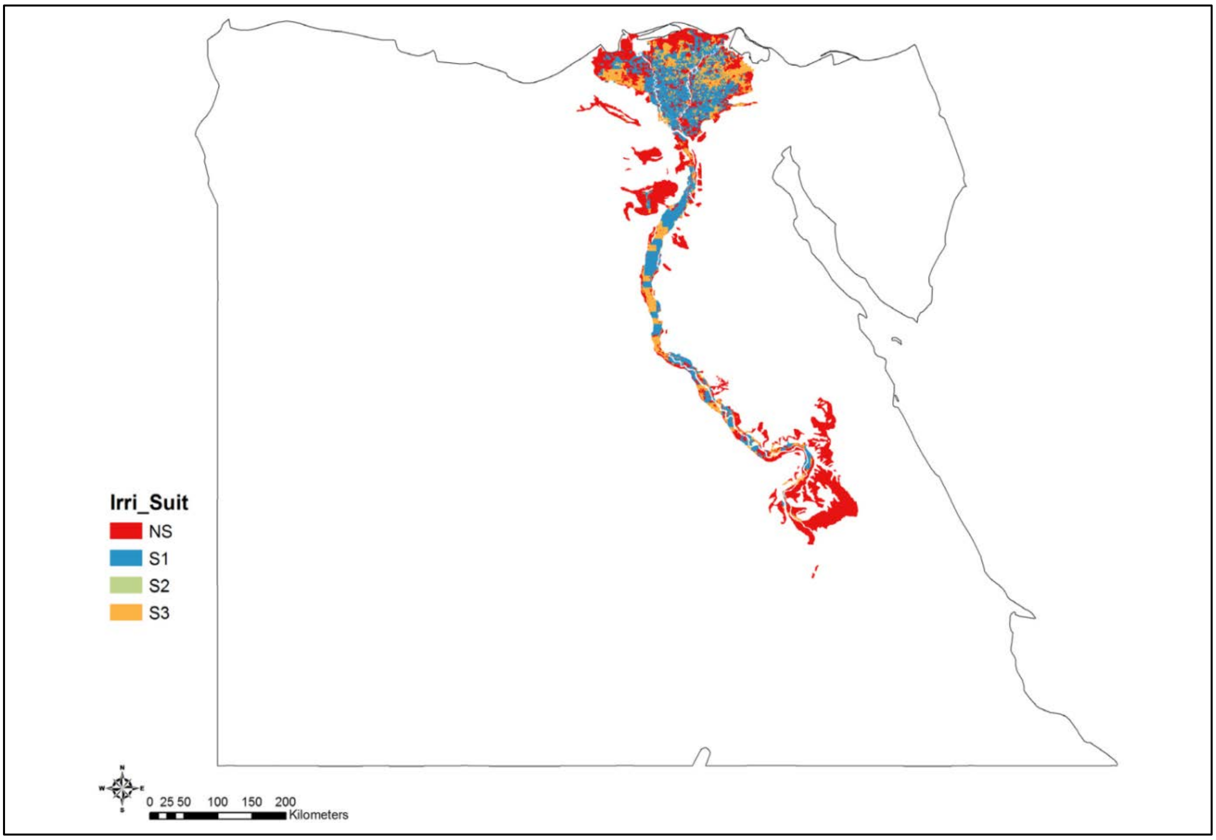
- The output after overlaying: 'Irri_ Suit2'
- Five fields were added to give numerical values to the suitability categories [S1 = 1, S2 = 2, S3 = 3, S4 = 4]. The added fields are the following:
  - SD_SV: numerical values of the suitability categories of soil depth
  - TS_SV: numerical values of the suitability categories of soil texture
  - SS_SV: numerical values of the suitability categories of soil salinity
  - SL_SV: numerical values of the suitability categories of slope classes
  - CS_SV: numerical values of the suitability categories of agricultural land use of irrigated agriculture
- The maximum values from the five fields are calculated in 'Suit_max' field, using Visual Basic code, in order to represent the overall suitability of the irrigated land in the field 'Irri_suit'
- The suitability limitations for each parameter are calculated in another five fields – SD_lim, TS_lim, SS_lim, SL_lim, and CS_lim. The limitations are aggregated in one field of 'Sum_lime'
- Limitation codes:
  - SD: soil depth
  - TS: soil texture
  - SS: soil salinity
  - SL: slope
  - CS: agricultural land use of irrigated agriculture.

Results and conclusions

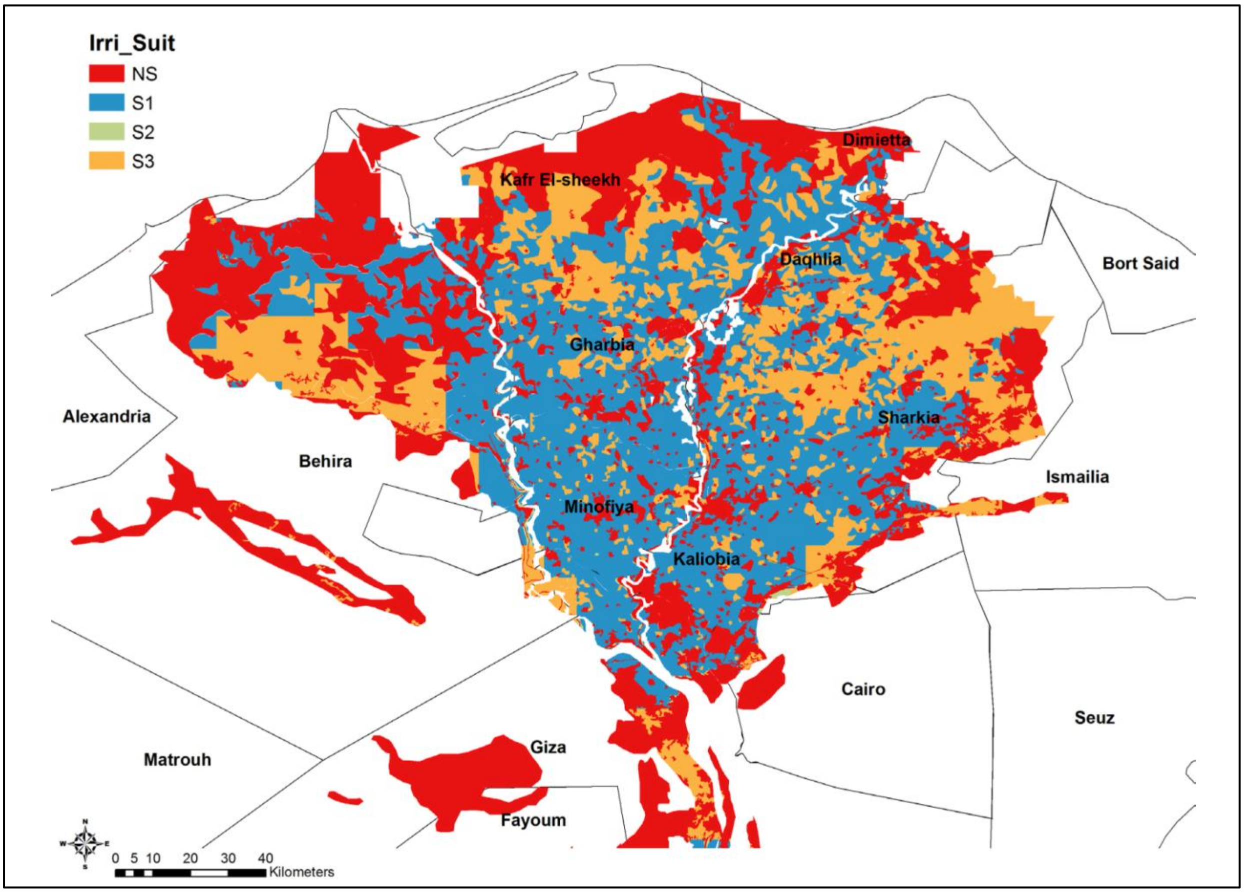
The results of the suitability analysis of the irrigated agricultural lands in Egypt for the application of raised-bed technology, were summarized.
The results revealed that about 79% of the non-sandy irrigated lands in Egypt are suitable for applying raised-bed technology. The majority of these lands are concentrated in the region starting from the middle of the Nile Delta region and expanding to the northern parts of Upper Egypt. Kafer El-Shiekh Governorate has the largest suitable area for applying raised-bed technology, and Ismailia has the smallest Map 53.

Considering the study's assumptions, the agricultural land-use pattern and soil salinity are the most important parameters limiting land suitability. About 61% of the areas identified as unsuitable for this technology (in this analysis) are so categorized because of these parameters Table 40.

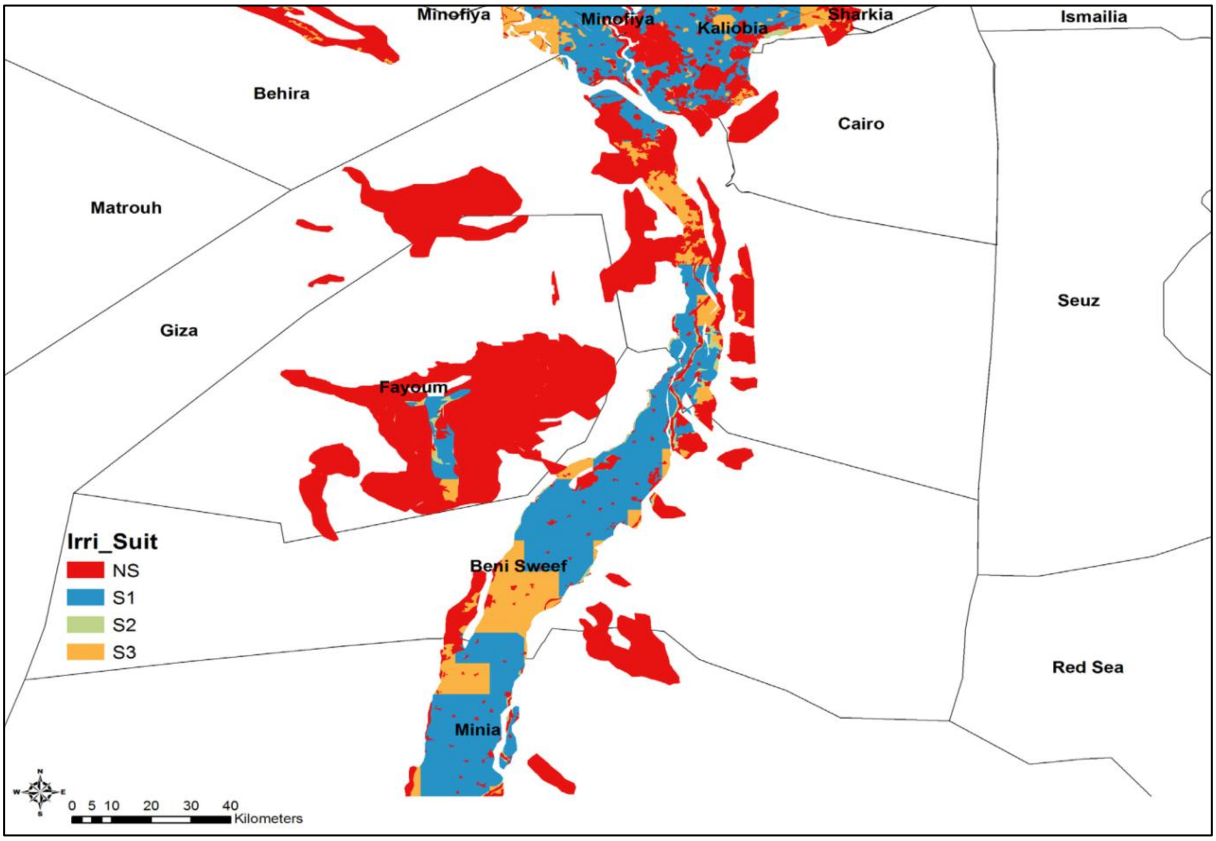
Based on the current results, it can be concluded that raised-bed technology could be applied in more than 70% of the irrigated agricultural lands suitable for the technology that are located in the Nile Delta and valley. However, some of the data used in this analysis was not up-to-date and had low resolution. The current suitability analysis could be enhanced by using updated soil and salinity maps of the agricultural lands of Egypt. Additionally, the resulting suitability maps could be evaluated by using field surveys in some pilot locations.



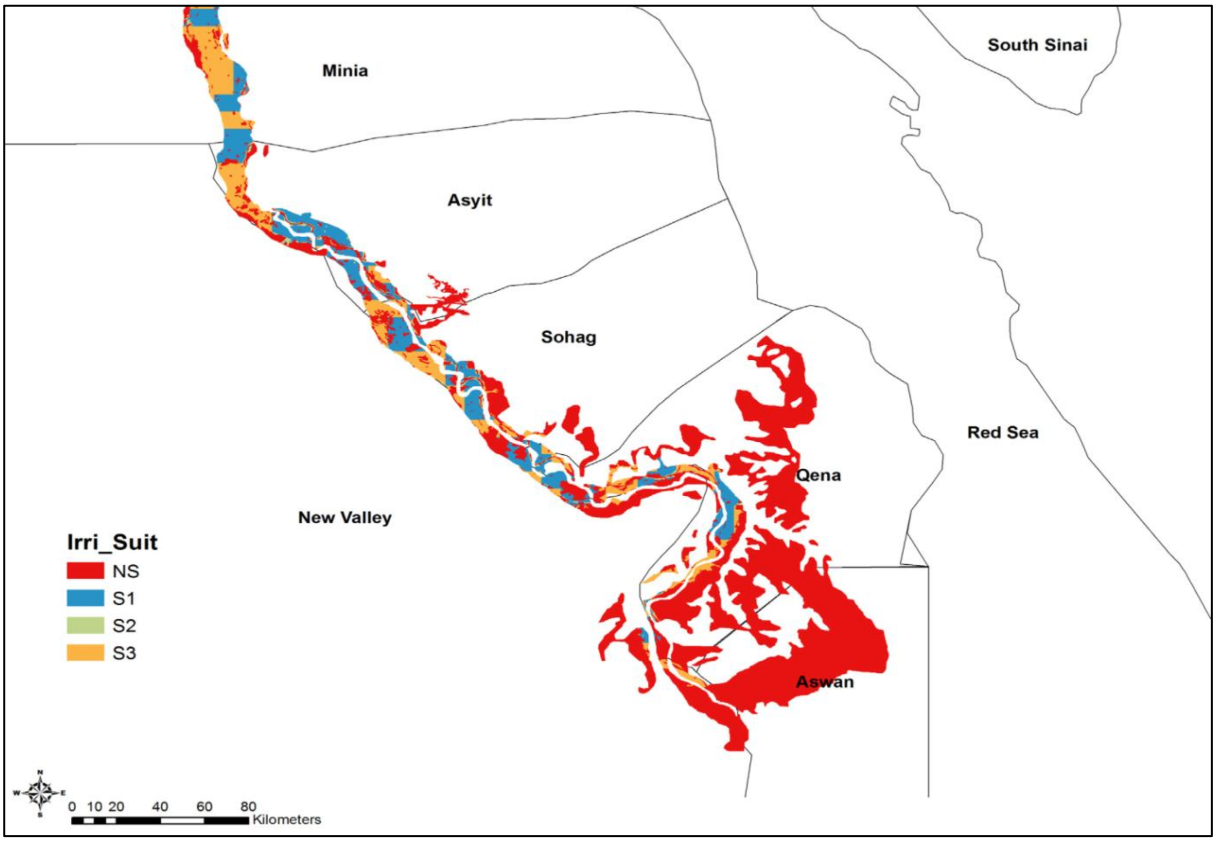
Map 53: General irrigated land suitable for applying raised-bed technology in Egypt



Map 54: General irrigated land suitable for applying raised-bed technology in the Nile Delta region of Egypt



Map 55: General irrigated land suitable for applying raised-bed technology in the middle of Egypt



Map 56: General irrigated land suitable for applying raised-bed technology in Upper Egypt

Table 38: Total areas and proportions (%) of the general irrigated land classes suitable for applying raised-bed technology in irrigated agriculture in Egypt

Suitability class	Area [ha]	Proportion of the area (%)
S1	864,520	29.23
S2	657,580	22.24
S3	822,950	27.83
NS	612,220	20.70
Total area	**2,957,270**	**100**

Table 39: General irrigated land suitable for applying raised-bed technology in Egypt analyzed by governorate

Governorate	Area (ha)			
	S1	**S2**	**S3**	**NS**
Alexandria	49,290		84,990	33,580
Behira	11,110	14,830	86,570	26,650
Gharbia	12,200	14,810	40,360	30,620
Kafr El-Sheekh	46,170		56,270	11,460
Daqhlia	14,370	32,350	76,120	81,770
Dimietta	34,270	93,740	42,730	18,650
Sharkia	19,780	64,550	13,180	13,960
Minofiya	94,990	98,250	93,570	16,630
Kaliobia	52,670	14,740	10,310	17,300
Ismailia			46,650	42,340
Cairo	42,190	88,820	10,490	19,480
Giza	57,800	36,590	25,530	14,410
Fayoum	86,710	14,690	20,610	19,590
Beni Sweef	83,940	27,700	34,250	37,100
Minia	99,280	25,900	68,770	50,910
Asyit	52,270	44,130	29,550	42,320
Sohag	32,370	32,080	30,480	63,980
Qena	33,900	24,510	28,810	35,450
Aswan	21,930			23,650
New Valley	19,280	29,890	23,710	12,370

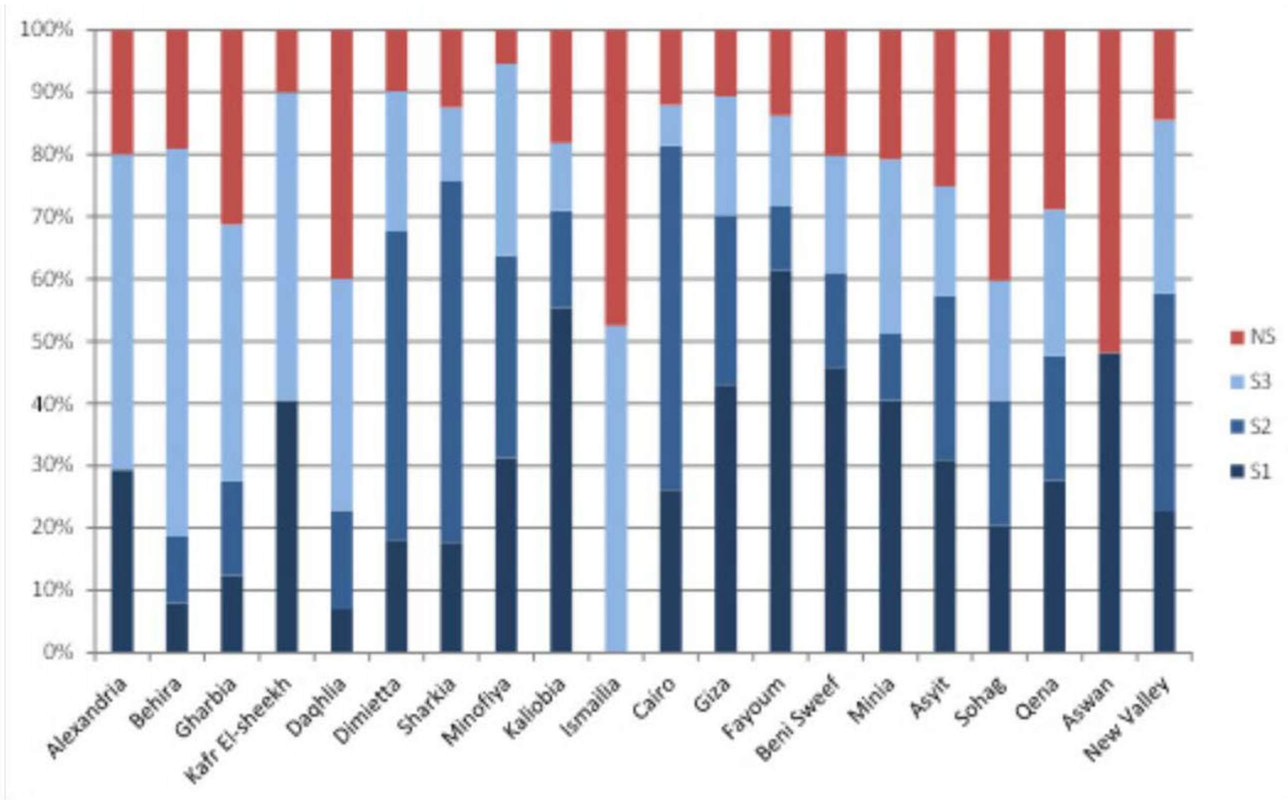
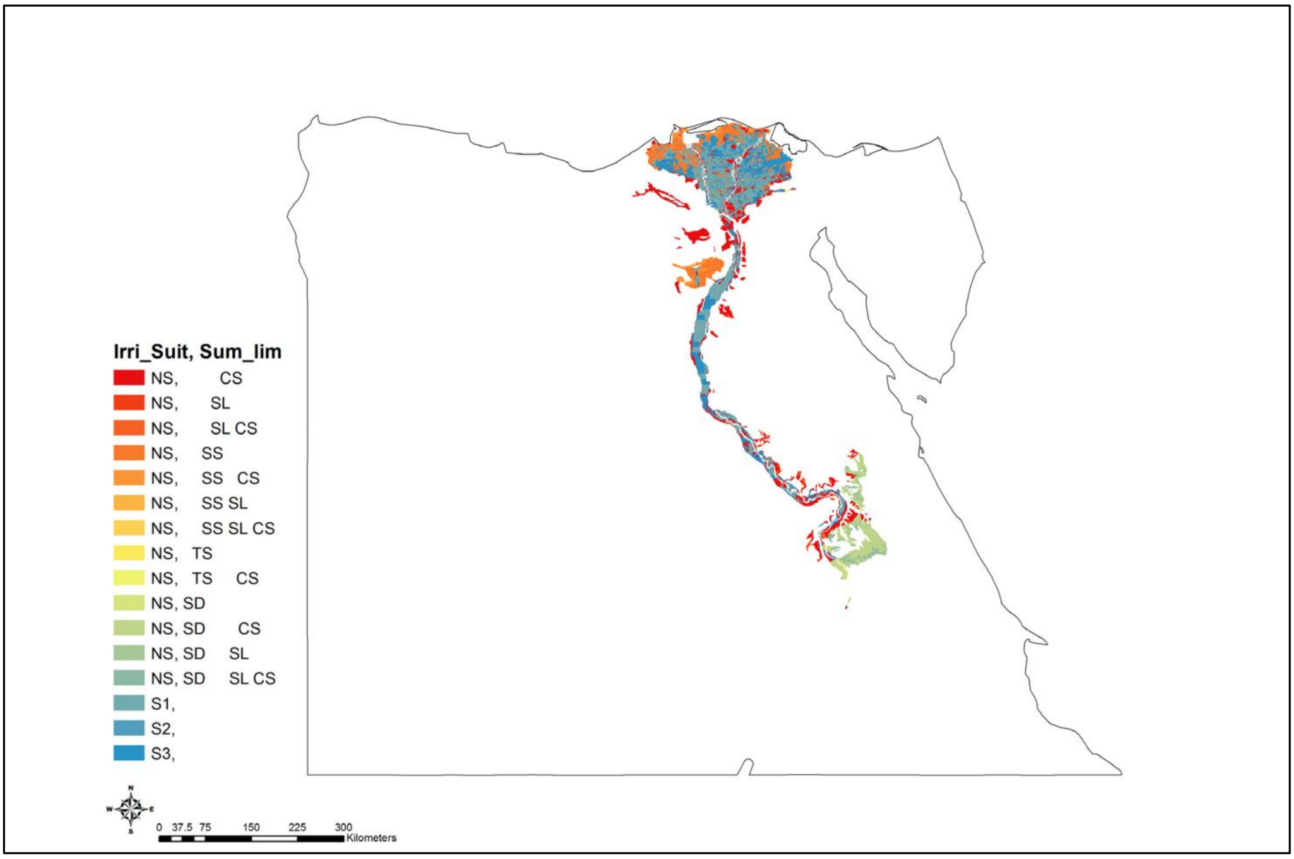
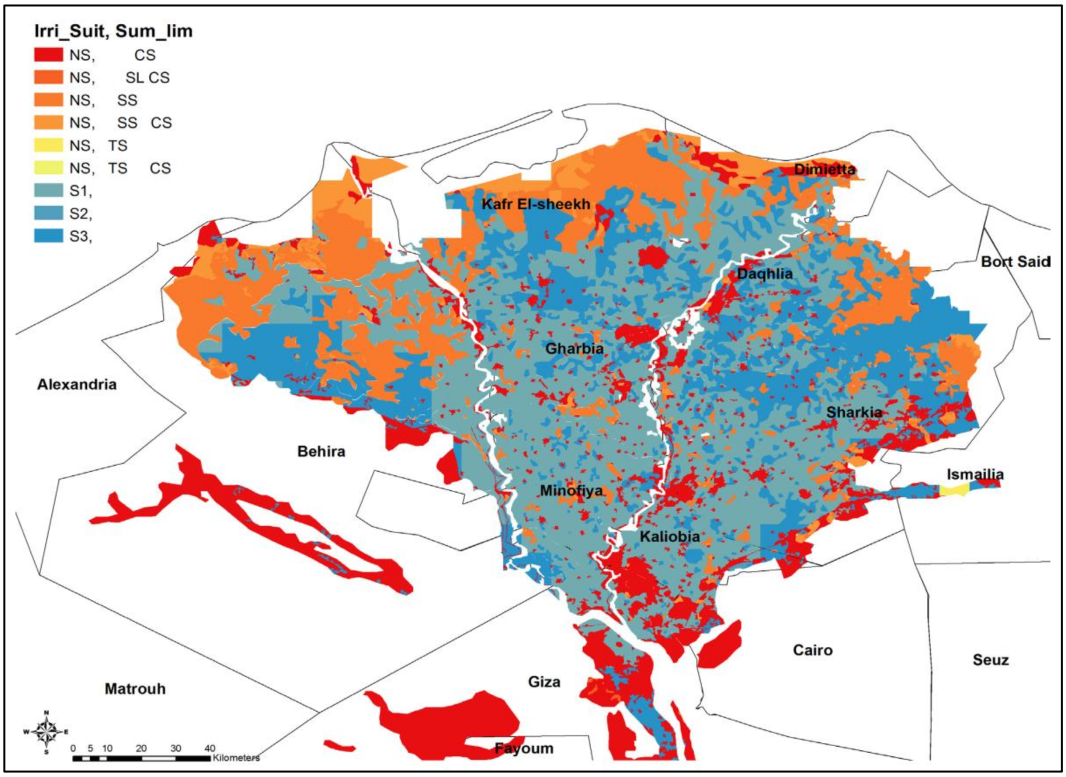


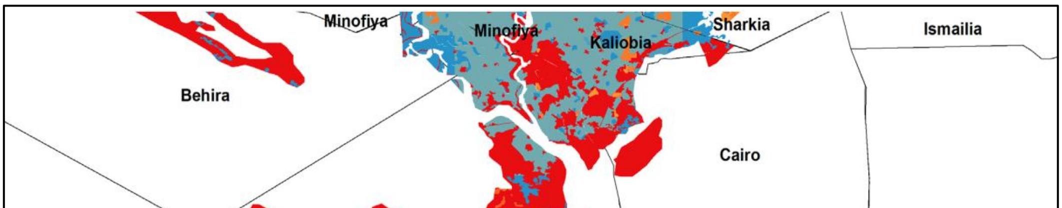
Figure 2: Proportions (%) of the area of general irrigated land in Egypt suitable for applying raised-bed technology, by suitability class, analyzed by governorate



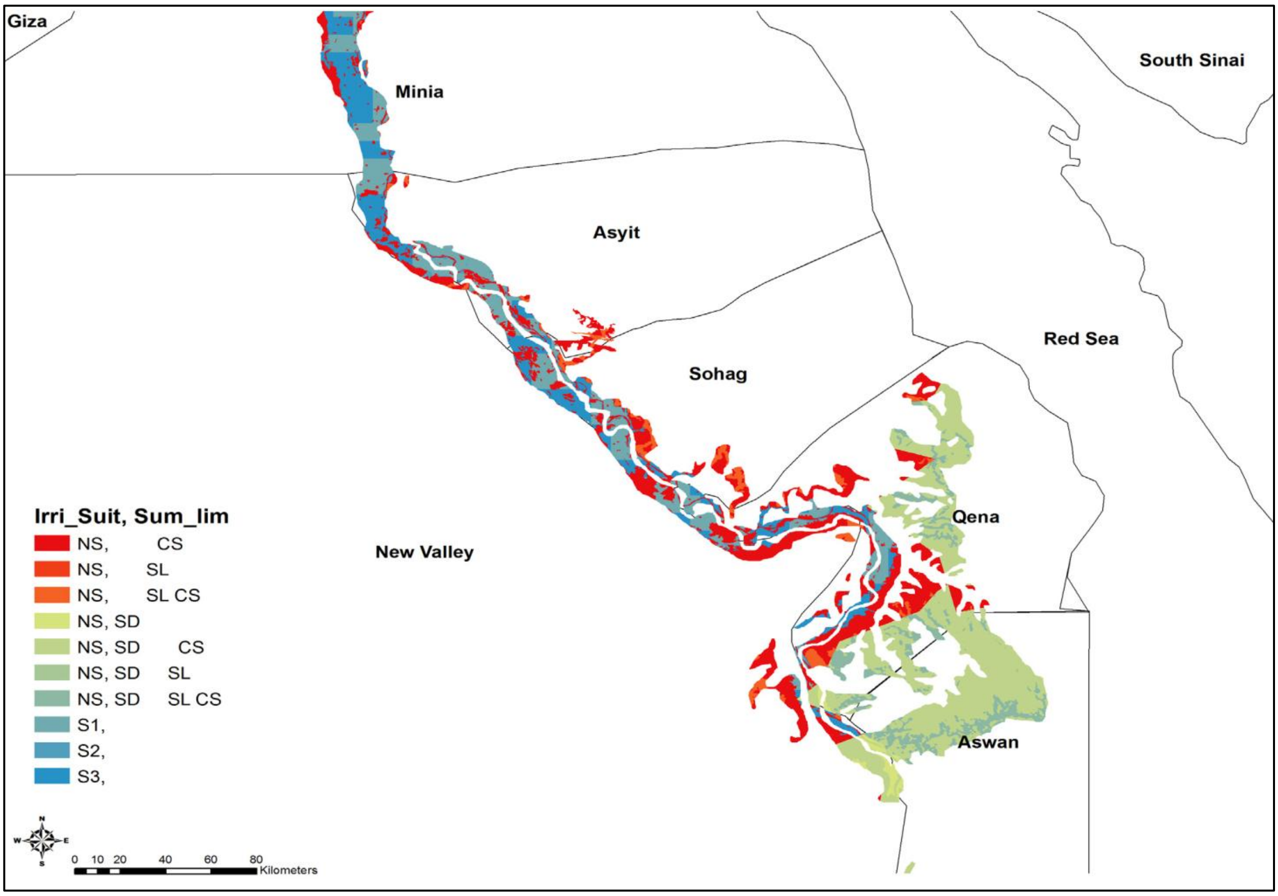
Map 57: Detailed irrigated land suitable for applying raised-bed technology in Egypt



Map 58: Irrigated land suitable for applying raised-bed technology in the Nile Delta region, Egypt



Map 59: Irrigated land suitable for applying raised-bed technology in the middle of Egypt



Map 60: Irrigated land suitable for applying raised-bed technology in Upper Egypt

Table 40: Proportions (%) of the area in the irrigated land for using raised-bed technology in Egypt, analyzed by governorate

Gov.	Area [ha]	Proportion of NS area [%]												
	NS	SD	TS	SS	SL	CS	SL CS	SS CS	SS SL	TS CS	SD CS	SD SL	SS SL CS	SD CS SL
Alexandria	33,580	0	0	0	0	55	0	45	0	0	0	0	0	0
Behira	26,650	0	0	12	0	66	0	22	0	0	0	0	0	0
Gharbia	30,620	0	0	71	0	19	0	10	0	0	0	0	0	0
Kafr El-Sheikh	11,460	0	0	48	0	37	0	15	0	0	0	0	0	0
Daqhlia	81,770	0	0	54	0	32	0	13	0	0	0	0	0	0
Dimietta	18,650	0	0	38	0	30	0	31	0	0	0	0	0	0
Sharkia	13,960	0	0	30	0	22	0	37	0	11	0	0	0	0
Minofiya	16,630	0	0	34	0	7	0	59	0	0	0	0	0	0
Kaliobia	17,300	0	0	25	0	25	0	50	0	0	0	0	0	0
Ismailia	42,340	0	28	0	0	34	0	0	0	38	0	0	0	0
Cairo	19,480	0	0	22	0	20	0	59	0	0	0	0	0	0
Giza	14,410	0	0	57	0	12	18	12	0	0	0	0	0	0
Fayoum	19,590	0	0	5	0	9	9	19	21	0	0	0	36	0
Beni Sweef	37,100	0	0	8	27	22	29	13	1	0	0	0	0	0

Gov.	Area [ha]	Propor-tion of NS area [%]														
Minia	50,910	0	0	0	18	51	32	0	0	0	0	0	0	0
Asyit	42,320	0	0	0	31	28	41	0	0	0	0	0	0	0
Sohag	63,980	0	0	0	48	38	15	0	0	0	0	0	0	0
Qena	35,450	12	0	0	26	9	9	0	0	0	11	0	0	33
Aswan	23,650	17	0	0	0	36	0	0	0	0	8	19	0	20
New Val-ley	12,370	21	0	0	13	21	24	0	0	0	6	4	0	11

Table 41: Total proportions (%) of the land suitability limitations for applying raised-bed technology in irrigated agriculture in Egypt

Limitations	Proportion of NS total area (%)
SD (soil depth)	4.7
TS (soil type)	0.6
SS (soil salinity)	18.2
SL (slope)	8.2
CS (crop)	26.2
SL CS	10.0
SS CS	17.1
SS SL	1.8
TS CS	1.7
SD CS	2.0
SD SL	1.9
SS SL CS	3.1
SD CS SL	4.6

Concluding remarks

The analysis indicated the possibility of producing fair similarity maps using the available coarse resolution data for the WANA region. These maps could be used to guide the targeting of areas within the three agro-ecosystems for the dissemination and promotion of the implementation of sustainable water and land management interventions. This would be of interest to decision makers, planners, and donors who seek to identify areas for the out-scaling of sustainable water and land management interventions. Identification of the proper criteria for characterizing each agro-ecosystem is important for generating good results. In this work, a multi-disciplinary team of experts from eight countries and ICARDA worked together to identify and fine-tune these criteria.

Furthermore, the maps generated using the preliminary criteria were refined based on local national experts from eight countries and using more detailed information. This helped in developing better criteria and maps. A comparison of the similarity maps for the WANA region using coarse data with those derived at the national level, using the same similarity criteria, but with more detailed information, was very important in fine-tuning the former maps. The resulting similarity maps cover the whole area with acceptable accuracy. They can used to guide decision makers at the regional and national levels to potential areas for out-scaling and dissemination of sustainable water and land management interventions.

However, the work so far has not evaluated an obvious situation that project implementation in similar areas would be dealing with socio-economic backgrounds.
The purpose of this report is not to evaluate potential communities, but rather to identify technically sufficient geographic locations for out-scaling. Therefore, a follow up socio-economic analysis would be needed at the community level before interventions can be implemented. Without community acceptance and ensuring that a proper enabling environment exists, implementation of the Vallerani water-harvesting system, raised-beds, or supplemental irrigation will not be successful.

The final suitability maps for the irrigated benchmark show the spatial distribution of different suitability classes. These maps also show the type(s) of limitation(s) for each suitability class. This is important information for planning the management of the irrigated areas. Decision makers can identify areas with potential for improvement and areas where other uses might be more beneficial and sustainable. They can also identify areas where land management to reduce the harmful effect of certain limiting factors is possible and so improve the suitability of the land to implement this technology. It is anticipated that these results will help decision makers to achieve more sustainable and feasible uses of the limited land and water resources.

The analysis of the rangeland benchmark shows that three suitability calculation approaches lead to generally comparable results in terms of identifying the areas classified for different suitability classes. There are generally limited areas that are highly, moderately, or marginally suited for the Vallerani water-harvesting systems.

This highlighted the importance of the suitability analysis for identifying areas that should be targeted for the out-scaling of this technology. The second approach showed the best results in identifying the spatial distribution of different suitability classes. This is because the approach uses field observations to map the distribution of suitability classes, while the other approaches use the soil mapping units. Since the soil map used here contains large polygons, the identification of the spatial distribution of suitability classes was less representative than using individual field observations. Nevertheless, these suitability maps are useful to guide the decision makers to areas with potential for implementing successful and sustainable water-harvesting systems. It is anticipated that the out-scaling of this technology will improve the productivity of the low-rainfall zone, reduce land degradation, and improve the livelihoods of the inhabitants of these areas.

The suitability analysis for the rainfed benchmark indicated that there are large areas that are highly, moderately, and marginally suitable for the implementation of a supplemental irrigation package when surface water resources were considered. These areas were reduced and more 'not suitable' areas were identified when ground water resources were considered as a source of supplemental irrigation. This is because of the low quality of the water derived from the ground water resources. This information is valuable for decision makers when identifying areas suitable for promoting and expanding supplemental irrigation packages in the rainfed areas. The decisions should take into consideration not only the quantity of supplemental irrigation water, but also the quality of the water resources. Expanding the supplemental irrigation package is expected to increase water productivity in the rainfed areas and help to achieve more crop productivity using the available water resources.

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