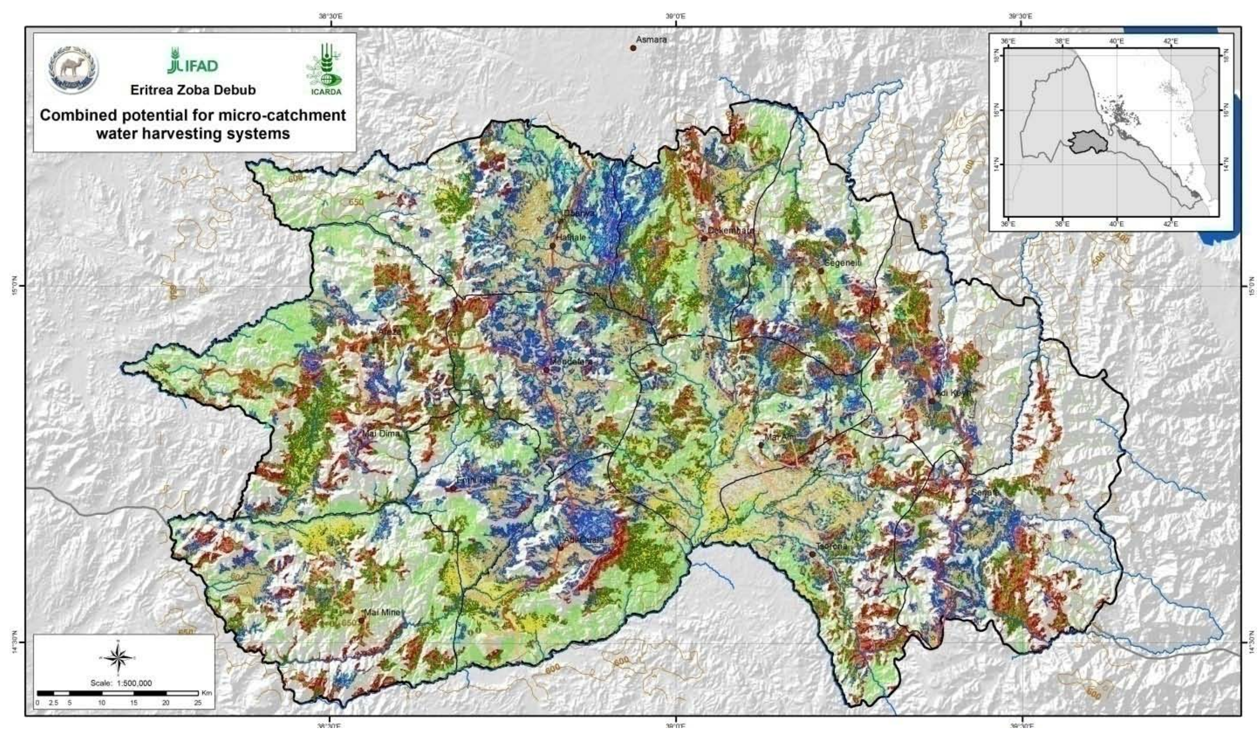
## National Agricultural Program Eritrea

# ASSESSING POTENTIAL FOR WATER HARVESTING, SPATE IRRIGATION AND SOIL-WATER CONSERVATION INTERVENTIONS IN ZOBA DEBUB, ERITREA

## Final Technical Report




**International Center for Agricultural Research in the Dry Areas (ICARDA)**

**January 2011**

**ACKNOWLEDGEMENTS**

This report has been commissioned by the International Fund for Agricultural Development (IFAD) on behalf of the Government of Eritrea under an institutional contract with ICARDA.

The completion of this report is the outcome of a true team effort. The authors wish to thank in particular the consultant, Mr. Jan Venema, for the successful data collection in a country in which the authors had no prior experience, and for the excellent documentation of his field observations in Zoba Debub. Our thanks extend to Mr. Tedros Ukbay, IFAD focal point in the Eritrea Ministry of Agriculture for facilitating the consultant's field work and interactions with different institutions and agencies in Asmara and Zoba Debub. We also thank Mr. Fawaz Tulaymat and Ms. Layal Atassi for their contributions in developing the maps of Zoba Debub and in the GIS training of the Eritrea Ministry of Agriculture staff. Last but not least, we appreciated the leadership by Mrs. Abla Benhammouche, IFAD East Africa Country Director, in support of this project.

Theib Oweis
Director, Water and Land Management Program
ICARDA

Eddy De Pauw
Head, GIS Unit
ICARDA

**TABLE OF CONTENTS**

**List of figures**



**List of tables**

**List of attachments (consultant report)**

**List of maps**

# EXECUTIVE SUMMARY

## The framework and process

This study has been undertaken by ICARDA in response to a request by the International Fund for Agricultural Development (IFAD) and the Government of Eritrea to provide, within the framework of the National Agricultural Program (NAP), scientific support to a development project for agriculture in Zoba Debub, with possibility of extension to all of Eritrea. The proposed NAP aims at enhancing food security, alleviating poverty and sustaining the natural resource base through agricultural development.

A conceptual framework for the current study was formulated during a visit to IFAD in Rome by Theib Oweis, Director of ICARDA's Water and Land Management Program, following an IFAD mission to Eritrea in May 2009. The framework (Annex 1) addresses potential agricultural development programs based on optimizing rainwater in rainfed systems, runoff water harvesting and irrigation, in order to enhance agricultural and water productivity, improve livelihoods, mitigate the effects of drought and climate change at the community level, and advance food security at the national level. The basic principle of the framework is to implement agricultural development programs, related to crops, livestock and other agricultural activities, in the context of an integrated watershed management

The framework (Annex 2) was communicated to the Eritrean government and approved. In response IFAD fielded a consultant to Eritrea in order to formulate recommendations for potential development. His report served as a basis for the identification of possible interventions, and recommended as follow-up study a GIS component in order to target the various development options to specific locations.

In order to help the design team with implementing the conceptual framework IFAD issued an institutional contract to ICARDA (Annex 1) to conduct a pilot study in one Zoba (Debub) with as main deliverables: a GIS study focusing on mapping suitability for potential water harvesting interventions, identification and characterization of potential watersheds, selection of watersheds to implement a pilot project and recommendations for appropriate soil and water interventions.

A GIS/land management consultant (Jan Venema) visited the Zoba Debub from May-June 2010 and collected the needed information for the watershed characterization and mapping. The consultant's final report is included as Annex 3.
A visit was made by Theib Oweis in June 2010 to Eritrea where he visited Zoba Debub and conducted meetings with relevant officials in Asmara and in the Zoba including H.E. the governor Mr Hussain Mustafa. This was followed by a visit of IFAD and associated people from Eritrea to ICARDA. During that visit two Ministry of Agriculture staff were trained for one week at the GIS Unit at ICARDA. Their training program is included as Annex 6.

## GIS desk study

Given the scarcity of basic maps for Zoba Debub, a number of maps were prepared, first to gain better insights into the agricultural environment of the Zoba, and, in a second stage, to serve as input data for the suitability assessment for water harvesting.

A base map for the location of all spatial data, compiled by the GIS consultant in Zoba Debub was prepared by extraction from the 2000 Geocover series of ortho-rectified Landsat 7 ETM+ Mosaics . The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) was the source of major topography-related data, such as watersheds and drainage lines (Map 2), elevation (Map 4), slopes (Map 5), and Compound Topographic Index (CTI).
Precipitation data, available from meteorological stations, were converted into continuous grids. Maps of mean annual precipitation (Map 7), reliable/effective precipitation for assessing water harvesting potential (Map 8) and annual potential evapotranspiration (Map 9) were prepared using these grids.

These input data were then transformed into suitability maps for water harvesting, using an adaptation of a methodology developed for Syria, to take into consideration the datasets available in Eritrea and local conditions. Suitability was evaluated for both micro-and macro-catchment systems. Suitability was evaluated separately for the following systems:

- Micro-catchment systems
    a. System 11: contour ridges/ range shrubs
    b. System 12: contour ridges/ field crops
    c. System 13: contour ridges/ tree crops
    d. System 21: semi-circular bunds – range shrubs
    e. System 22: semi-circular bunds – field crops
    f. System 23: semi-circular bunds – tree crops
    g. System 31: small pits – range shrubs
    h. System 33: small pits – tree crops
    i. System 41: small runoff-basins – range shrubs
    j. System 43: small runoff basins – tree crops
    k. System 51: runoff strips – range shrubs
    l. System 52: runoff strips – field crops
    m. System 6: contour bench terraces
- Macro-catchment systems: evaluated for suitability as
    a. water catchment area
    b. agricultural use: field crops and tree crops

The assessment of suitability for different water harvesting techniques was undertaken by matching in a GIS environment simple biophysical information, systematically available for the entire Zoba Debub, to the broad requirements of the specified water harvesting systems using an expert-based empirical decision model.

The GIS analysis is communicated in the form of maps (Annex 5) and summary tables that contain all areas of the classes distinguished in the base maps and suitability maps. Areas were calculated in hectare and refer to both the entire Zoba and selected watersheds.
The results from the GIS analysis indicate that overall the potential for most water harvesting systems in Zoba Debub is high. One exception are the micro-catchment systems with tree crops. For these systems (S13, S23, S33, S43, S52) the potential is considered low due to soil depth limitations. However, it has to be reiterated that knowledge of soil depth in Zoba Debub is currently inferred from land use/land cover, not from any direct soil observations or even remote sensing. The accurate positioning of water harvesting interventions therefore requires a second stage of studies in which soil survey will have to play a major role, in order to identify at greater detail important properties such as soil depth, stoniness, texture, salinity.

The high potential for water harvesting is summarized in the following table, which estimates the total areas that are considered 'suitable' (suitability score >60) for different combinations of micro-catchment water harvesting systems. While roughly 30% of the Zoba is considered unsuitable for any micro-catchment system, about 70% is assessed as being suitable for at least one micro-catchment system.

<u>Areas suitable for various combinations of micro-catchment systems in Zoba Debub</u>

| Class | % of Zoba | hectare |
|---|---|---|
| Unsuitable for any system | 30.25 | 292,055 |
| Suitable for S11 | 3.27 | 31,602 |
| Suitable for S11, S12 | 3.07 | 29,615 |
| Suitable for S11, S12, S13 | 7.23 | 69,798 |
| Suitable for S21 | 10.50 | 101,364 |
| Suitable for S11, S21 | 12.70 | 122,645 |
| Suitable for S21, S22, S31, S41, S51 | 2.60 | 25,057 |
| Suitable for S11, S21, S22, S31, S41, S51 | 9.39 | 90,654 |
| Suitable for all systems except S11, S12, S13,S6 | 1.48 | 14,300 |
| Suitable for all systems except S6 | 9.17 | 88,578 |
| Suitable for S6 | 6.83 | 65,986 |
| Suitable for S6, S21, S22, S31, S41, S51 | 2.39 | 23,108 |
| Suitable for all systems except S11, S12, S13 | 1.11 | 10,728 |

**Watersheds selection**

On the basis of the following criteria a shortlist of 8 potential watersheds was prepared:

a) Communities concentration and the urgency for development
b) Higher potential for water and land resources availability and utilization
c) Potential coverage of the three important agro-ecosystems, rainfed, spate irrigation and rangelands in each watershed.
d) The geographical distribution and political feasibility
e) Existing local experiences in major interventions
f) Accessibility and availability of data for development

The candidate watersheds considered for the pilot project were Tselema, Hazemo, Maitekela, Tsaidakelay, Oubel, Megerba, Alla, and Shemejana.

As the development of all eight watersheds requires resources which are currently not available, and requires a long time, additional criteria were used to further screen the watersheds and select two for immediate development as a pilot project. As outcome of the second round of selection, two watersheds were selected for this startup pilot project;
No 1. Tselema watershed in the northwest of Zoba Debub focusing on spate irrigation but include also some rainfed and rangeland development and,
No 2. Hazemo watershed in the southeast of the Zoba Debub focusing on rainfed systems development but include also some irrigation and rangelands development.

- ***Tselema Watershed:*** This watershed, with an area of about 51,000 ha, has about 30,000 ha of rainfed cropping systems, 20,000 rangelands and about 600 ha of irrigated agriculture. Main towns are Dbarwa and Halhale. Major agricultural activities are rainfed and rangelands with crops including wheat, barley, teff and chickpea. Tselema watershed is a typical watershed to primarily develop rainfed agriculture. Current rainfed agriculture productivity is poor and way below it potential. Soil and water resources if used efficiently should make significant contribution to farmers' income and to alleviating poverty. In addition to availability of good soils and relatively adequate rainfall for rainfed systems, farmers practice rainfed agriculture on large scale. Potential improvement in productivity is high especially though improving natural resources management and introducing better crop varieties and fertilizers.
- ***Hazemo watershed:*** This watershed, with an area of about 56000 ha with irrigated areas of 2000 ha, rainfed areas of 19000 ha and rangelands of 35000 ha. Major town is May Aini with several smaller communities. Agricultural activities include spate irrigation, rainfed and rangelands. Crops include sorghum, teff and maize. The watershed was selected primarily because it can demonstrate development of agriculture based on spade irrigation in addition to other forms. The watershed has great potential for water flow from mountainous areas to the plains with suitable soil and landscape for spate irrigation development. There are limited previous experiences of this form of irrigation in the watershed which can be improved and expanded.

**Characterization and management of selected watersheds**

In both watersheds basic studies should be conducted in ensure integrated watershed management and monitoring of the watersheds. Characterization should include natural resources available and potential use, human resources, social and economic aspects including population activities and workforce etc. It should also include developing a spatial database in a GIS framework with capacity to update and use. Land use maps with location, extent and potential of various cropping systems should be included. Watershed management should ensure equitable distribution of water but also optimizing the allocation and use of this scarce resource. The catchments usually provide water to agricultural areas but also support rangelands and forests with natural environmental services. Rangelands improvement, catchment protection, erosion control, upstream-downstream flows and sediments monitoring, environmental services, etc. should be the core of the catchment management. Interventions include terracing for water catchment, ridging for rangelands improvement, check dams in streams, re-vegetation, control wood cutting and grazing management.

**Proposed interventions in Tselema watershed**

This watershed will be a benchmark model for development of rainfed systems in the Zoba Debub and probably all Eritrea. Development objectives are; improving rainfed production systems leading to higher farmers' income and livelihoods enhancement in rural areas. The development should help converting part of subsistent agriculture to market oriented systems. As rainfall is the major source of water for crops, its management and conjunctive use through supplemental irrigation will make the basis for improving the system Improved soil water status for crops will allow the use of more inputs such as fertilizers and better seeds, crop varieties and intensification in selected areas when additional water resources are available. This should result in sustainable higher crop yields, better crop-livestock integration and improved natural resources management. Achieving the development objectives will need in addition to technical interventions a better institutional setup and a network of inputs suppliers, market chains, expansionists and research support to ensure sustainability. Land tenure systems may need to be aligned with the development needs. Within the watershed there exist areas of rangelands and forests. Those areas effect rainfed systems in that runoff water and erosion may be altered as it is managed. Improving rangelands and protecting the slope areas against erosion will have stabilized and more sustainable rainfed systems. Other intensified agriculture such as full irrigation for cash crops may also be supported at small scale when water resources are available especially from groundwater resources.

Interventions in Tselema watershed for rainfed production systems may include:

- Soil management: Improved soil preparation may be encouraged by providing appropriate machinery. Conservation agriculture may be tested. Land grading and terracing may be adopted in steep areas.
- Fertility is key to improved yields. Access to deficient fertilizers nay needs to be ensured.
- Crops varieties: improved crop verities together with fertility and moisture improvements are the three main contributors to improved rainfed yields.
- Supplemental irrigation: in suitable areas small earth dams should be built to store water for supplemental irrigation. Locations and capacity need hydrological studied to decide. Also supplemental irrigation may be practiced using ground water. Full irrigation during dry season can be adopted for cash crops on limited areas.
- Check dams to control erosion: erosion in rainfed areas is common and need to be minimized. Check dams, contour ridges and other soil conservation measures are suitable on slopes to control erosion and support groundwater recharge.
- Seed system need to be developed to ensure improved and healthy seed production for the system.
- Livestock integrated within the cropping system as supplement to rangelands.

**Proposed interventions in Hazemo watershed**

Hazemo watershed will be a benchmark model for the development of spate irrigation in Zoba Debub and Eritrea. The development objectives are to primarily capture runoff water from the catchment in the plans in spate irrigation systems for improved and intensified cropping systems that will result in improved farmers income and livelihoods of the rural communities. Substantial amounts of runoff flow downstream and mostly leave the watershed with little benefits. It is envisaged that most of the runoff remaining after satisfying the catchments environmental is captured and applied to crops. The management of spate irrigation to overcome variable rainfall and drought is an important component of the development. Conjunctive use of available groundwater together with innovative design of spate structures and distribution systems and crops selection should help achieving the sustainability objectives.

The spate irrigation project should start with a relatively small size pilot (3000-5000 ha) that can be expanded to 10,000 ha in a second phase. The project will include diversion structures, water distribution network and controls, land leveling and levees formation. It may better be built on the old project in Hadadim. A detailed hydrological study should be conducted to determine potential runoff currently and that expected after developing the catchment. Potential runoff is expected to be way above the requirements of the 1$^{st}$ phase (3000-5000 ha), so work on both may start in parallel.
The strategy for designing the spate project will have the following elements:

- *Diversions:* multiple diversions providing water to small units of about 500 ha each of the system is recommended. Diversions along the stream should be designed to allow equitable amounts of water to all the units of the system. They should have enough control to modify schedules of water diversion as required.
- Basins: basins should be level with area not greater than one hectare each. Levees should be compacted with height of 1.0-1.5 m.
- Distribution network: Overflow from one basin to the other should be minimized to a maximum of one basin. This requires that field canals with gates be constructed along all basins. Higher level canals should be designed up to the diversion.
- Management of water/area: Basins should get maximum depth of water in one storm to satisfy full soil water holding capacity of the available soil depth. Following basins should be filled up after filling the first. This should ensure good crop in irrigated areas. If water is enough all the system will be satisfied. If water flow is not enough, then part of the system will get enough water and have good crop where the rest does not get any water. This is better than having all the areas with partial water which produces very low or no yields.
- Conjunctive use with groundwater: As a strategy against drought, groundwater may be developed to overcome surface flow shortage or dry spills during the season.
- Cropping patterns: priority may be given to strategic crops. Cash crops may be grown in limited areas using mainly grown water.

***Supporting activities***

Most important is developing the local institutions to carry on the development. Community level institutions should be supported. Extension services need enhancement and may also be supported by the project. All activities require capacity building of it members as integrated component of the development. Training will include water harvesting, supplemental irrigation, soil conservation, agronomic practices and institutional setups. Finally, adaptive research program should be implemented to test new options and adapt practices and options to the conditions of the Zoba Debub. Research may be focused in the research stations but also at the community level and with farmers. Topics may include determining irrigation water needs, testing crops verities, deficit irrigation, soil conservation and testing new practices such as conservation agriculture.

# 1. BACKGROUND

Drought is a recurrent phenomenon in Eritrea. Due to a variety of reasons, related to poor infrastructure, poor agricultural practices and governance issues, drought in Eritrea causes immediately food shortages. Inadequacies in the country's ability to respond to or mitigate the failure of rains may even lead to famine.

Water harvesting/soil-water conservation are among the possible strategies for coping with drought, while also offering in the longer-term prospects for increasing land and water productivity for resource-poor farmers. Whether water harvesting is a feasible option depends on many factors, biophysical as well as socioeconomic. The fact remains that not everywhere there will be physical potential, but also that where there is some degree of potential, some techniques will be more suited than others to make use of that potential. A spatial analysis of suitability for various water harvesting techniques could therefore be useful for development agencies in the country.

This study has been undertaken in response to a request by the International Fund for Agricultural Development (IFAD) and the Government of Eritrea to offer, within the framework of the National Agricultural Program (NAP), scientific support to a development project for agriculture in Zoba Debub, with possibility of extension to all of Eritrea. The proposed NAP aims at enhancing food security, alleviating poverty and sustaining the natural resource base through agricultural development.

A framework for the current study was formulated during a visit to IFAD in Rome by Theib Oweis, Director of ICARDA's Water and Land Management Program, following an IFAD mission to Eritrea in May 2009. The framework addresses potential agricultural development programs based on optimizing rainwater in rainfed systems, runoff water harvesting and irrigation. The framework aimed at designing a program that, if implemented, can contribute to improved agricultural and water productivity, to better livelihoods, to mitigating the effects of drought and climate change at the community level, and to food security at the national level.

The basic principle of the framework is to implement agricultural development, crops, livestock and other agricultural activities, in the context of an integrated watershed management approach. The framework elements include:

a) Recognition of the three main agro-ecosystems in Eritrea, the rainfed, the irrigated and the rangelands. Each has its features and characteristics but are interrelated and each affects the others.
b) The watershed is a suitable unit for sustainable agricultural development. As water is the main limiting factor for agricultural development, the watershed provides the opportunity to developing proper allocation and integration in various development projects. It also ensures equitable and sound upstream-downstream relations.
c) Communities are the center for development and should be involved in the planning and implementation of the measures. Institutional setups and capacity building for developments are critical for successful development. The access of the communities to natural resources is an important element in the watershed management approach.
d) Interventions within the watershed approach include not only water management but all elements of agricultural development in an integrated manner. Rainfed systems, spate irrigation, soil conservation, agronomic aspects and crops and livestock are only examples.

The framework (Annex 2) was communicated to the Eritrean government and approved. In response IFAD fielded a consultant (Harry Denecke) to Eritrea in order to formulate recommendations for potential development. His report served as a basis for the identification of possible interventions, His report served as a basis for the identification of possible interventions, and recommended as follow-up study a GIS component in order to target the various development options to specific locations.

In order to help the design team with implementing the conceptual framework, IFAD issued an institutional contract to ICARDA (Annex 1) to conduct a pilot study in one Zoba (Debub) with as main deliverables: a GIS study focusing on mapping suitability for potential water harvesting interventions, identification and characterization of potential watersheds, selection of watersheds to implement a pilot project and recommendations for appropriate soil and water interventions.

Basic information for watershed characterization and mapping was collected by a GIS/land management consultant (Jan Venema) during a visit to Zoba Debub in May-June 2010. The consultant's final report is included as Annex 3. A visit was made by Theib Oweis in June 2010 to Eritrea where he visited Zoba Debub and conducted meetings with relevant officials in Asmara and in the Zoba including H.E. the Governor Mr Hussain Mustafa. This was followed by a visit of IFAD and associated people from Eritrea to ICARDA. During that visit two Ministry of Agriculture staff received a 1-week training at the GIS Unit at ICARDA.

# 2. METHODOLOGIES

## 2.1. FIELD OBSERVATIONS AND DATA COLLECTION

In order to develop a list of criteria relevant to the selection of possible water harvesting interventions, an experienced land resources expert was fielded to Zoba Debub. During his mission the consultant collected data on geology, soils, climate, land use, land cover, water harvesting infrastructure and practices, farming systems, cropping pattern and markets. These data were obtained from government departments and other institutions in Asmara and Zoba Debub. Details are given in Attachments 4 and 9 of the consultant's final report (Annex 3).
Fieldwork was carried out to make observations and recordings, including photographs. All observation sites have been geo-referenced and are listed in Attachment 6 of Annex 3. The observations themselves and photographs are included in the CD (Annex 6).

## 2.2. BASE MAPS

Given the scarcity of basic maps for Zoba Debub, a number of maps were prepared, first to gain better insights into the agricultural environment of the Zoba, and, in a second stage, to serve as input data for the suitability assessment for water harvesting.

An overall birds-eye view of the Zoba (Map 1) was extracted from the 2000 Geocover series of ortho-rectified Landsat 7 ETM+ Mosaics . This dataset is from the Landsat 7 Enhanced Thematic Mapper (ETM+) with the 15m band panchromatic band fused with the 30m multi-spectral bands 7-4-2. The pixel size is 14.25 meters and the absolute positional accuracy is 50 meters Root Mean Square Error. The projection is Universal Transverse Mercator (UTM)/World Geodetic System 1984 (WGS84). Apart from ortho-rectification these Landsat images have been tonally balanced, mosaiced, tiled and wavelet compressed, and are of the highest quality. The spatial extent of each mosaic used is shown in Figure 1. The coverage date is scene-dependent, nominally 2000 +/- 2 years. Onto this image all observation points compiled by the consultant were mapped.

The 'professional' version of Google Earth (Google Earth Pro ) was used to 'zoom' into the Zoba and view a high-resolution Quickbird image as a form of ground truthing. QuickBird is currently the highest resolution commercial optical satellite (operated by Digital Globe) and provides through Google Earth multi-spectral imagery at a resolution of 2.44 m, giving visibility to small or narrow objects such as trees, tracks, check dams, ploughing, drainage lines, houses etc.. Quickbird imagery is available for about 60-70% of the Zoba. Quickbird imagery provided a basis for the accurate positioning of small and medium-sized dams, mapped by the Ministry of Agriculture.

The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) was the source of major topography-related data, such as elevation (Map 4), slopes (Map 5), watersheds and drainage lines. Slopes were calculated using the Slope function of the Spatial Analyst Tools in ESRI ArcGIS software.

Watersheds and drainage lines (Map 2) were delineated using the Arc Hydro Tools utility for ArcGIS. Using the SRTM DEM as input grid, the following steps were followed for creating watersheds and drainage lines:

- Fill Sinks : If a cell in DEM is surrounded by higher elevation cells, the water is trapped in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate these problems.

- Flow Direction: create flow direction grid from a DEM grid.
- Flow Accumulation: create flow accumulation grid from a flow direction grid.
- Stream Definition: create a new grid (stream grid) with cells from a flow accumulation grid that exceed user-defined threshold.
- Stream Segmentation: create a stream link grid from the stream grid (every link between two stream junction gets a unique identifier).
- Catchment Grid Delineation: create a catchment grid for a link grid. It identifies areas draining into each link.
- Catchment Polygon Processing: create catchment polygons out of the catchment grid.
- Drainage Line Processing: create streamlines out of the stream link grid.

Watersheds and drainage lines were created at 2 different levels, with 25,000 and 5,000 upstream pixels as thresholds. With 25,000 pixels threshold there are fewer but smaller watersheds, in which sub-watersheds are nested based on the 5,000 upstream pixels threshold.

The Compound Topographic Index (CTI), a.k.a. the Wetness Index, is a quantification of the position of a site in the local landscape, expressed as a measure of concavity of the land surface. It is a useful guide to water and sediment movement in particular landscapes. Smaller values indicate a tendence to shed water, i.e. to generate runoff, and higher values to receive runoff water.

The CTI is calculated as:

$$CTI = \ln ( As / \tan B )$$

where *'As'* is the specific catchment area expressed as $m^2$ per unit width orthogonal to the flow direction and *'B'* is the slope angle.

Precipitation data, available from meteorological stations (Table 1), were converted into continuous grids, a.k.a. 'climate surfaces'. Maps of mean annual precipitation (Map 7) and reliable/effective precipitation for assessing water harvesting potential (Map 8) were prepared using these climate surfaces. The procedure followed is explained in more detail in section 2.3.2.1.
The surface of annual potential evapotranspiration was extracted from the CWANA surface of annual potential evapotranspiration at 30 arc-seconds (about 1 km, 0.00833 decimal degrees) spatial resolution using the Zoba Debub vector mask and resampled to a spatial resolution of 3 arc-seconds (about 90 m , 0.000833 decimal degrees).

## 2.3. MAPPING SUITABILITY FOR WATER HARVESTING

### 2.3.1. General principles

The methodology used for mapping suitability for water harvesting is an adaptation of the method used in Syria (De Pauw et al., 2008) to take into consideration the datasets available in Eritrea and local conditions. The key elements of the methodology are the following:

1. The assessment of suitability for different water harvesting techniques was undertaken by matching in a GIS environment simple biophysical information, systematically available for the entire Zoba Debub, to the broad requirements of the specified water harvesting systems using an expert-based empirical decision model.

2. Suitability was evaluated for both micro-and macro-catchment systems. Suitability was evaluated separately for the following systems:

- Micro-catchment systems
    a. System 11: contour ridges/ range shrubs
    b. System 12: contour ridges/ field crops
    c. System 13: contour ridges/ tree crops
    d. System 21: semi-circular bunds – range shrubs
    e. System 22: semi-circular bunds – field crops
    f. System 23: semi-circular bunds – tree crops
    g. System 31: small pits – range shrubs
    h. System 33: small pits – tree crops
    i. System 41: small runoff-basins – range shrubs
    j. System 43: small runoff basins – tree crops
    k. System 51: runoff strips – range shrubs
    l. System 52: runoff strips – field crops
    m. System 6: contour bench terraces
- Macro-catchment systems: evaluated for suitability as
    a. water catchment area
    b. agricultural use: field crops and tree crops

For details on each of these systems is referred to section 2.3.2.

3. Suitability was evaluated through a scoring system based on climate and land criteria, using threshold values that are considered relevant for the different systems evaluated. The scoring system itself was based on the expert judgment documented in the guidelines for selecting water-harvesting techniques in the drier environments (Oweis et al. , 2001), but modified in function of the current data availability and new research findings. The criteria used in the current suitability maps were the 80% minimum annual precipitation, the slope, the soil depth and the land use/land cover type. In the case of precipitation and slope, the scoring system is *continuous*, with values between 0 and 100. In the case of the soil depth and land use/land cover, the scores are based on classes, which can have only 2 values, 0 (suitable) or 100 (unsuitable).

4. The scores for precipitation, slope, soil type and land use/land cover type were combined using the 'minimum rule': the lowest factor score determines the final score.

5. For each micro-catchment system one evaluation was undertaken. For macro-catchment systems two separate evaluations were undertaken: one to assess suitability for use as water catchment area, the other to assess suitability for agricultural use. The two suitability maps were then overlaid to assess where areas with high suitability for catchment and for agricultural use are within a distance that can be overcome by technical means.

### 2.3.2. Description of evaluated water harvesting systems

These systems are briefly described in the following paragraphs, based on Oweis et al. (2001) and Oweis (2004).

#### *2.3.2.1. Contour ridges*

These are bunds or ridges constructed along the contour lines, usually spaced between 5 and 20 m apart (Fig. 1). The first 1–2 m upstream of the ridge is used for cultivation, whereas the rest is used as a catchment. The height of each ridge varies according to the slope's gradient and the expected depth of the runoff water retained behind it. Bunds may be reinforced by stones if necessary.

Contour ridges are one of the most important techniques for supporting the regeneration and new plantations of forages, grasses and hardy trees on gentle to steep slopes in the steppe. In the semi-arid tropics, they are used for arable crops such as sorghum, millet, cowpeas and beans.

**Figure 1.** Contour ridges at the IWLM Water Harvesting Site, ICARDA, Tel Hadya

#### *2.3.2.2. Semi-circular and trapezoidal bunds*

These are usually earthen bunds in the shape of a semi-circle, a crescent, or a trapezoid facing directly upslope. They are created at a spacing that allows sufficient catchment to provide the required runoff water, which accumulates in front of the bund, where plants are grown. Usually they are placed in staggered rows. The diameter or the distance between the two ends of each bund varies between 1 and 8 m and the bunds are 30–50 cm high.

Bunds are used mainly for the rehabilitation of rangeland or for fodder production, but may also be used for growing trees, shrubs and in some cases field crops and vegetables.

**Figure 2.** Overview of the semi-circular bunds area at the IWLMP Water Harvesting Site, ICARDA

**Figure 3.** Semi-circular bunds, reinforced with stones, at the IWLMP Water Harvesting Site, ICARDA

#### *2.3.2.3. Small pits*

Pitting is a very old technique used mainly in Western and Eastern Africa, but adopted in some WANA areas. It is used for rehabilitating degraded agricultural lands. The pits are 0.3–2 m in diameter. The most famous pitting system is the *zay* system used in Burkina Faso (Fig. 4). This consists of digging holes with a depth of 5–15 cm. Pits are applied in combination with bunds to conserve runoff, which is slowed down by the bunds. This system allows much degraded agricultural land to be put back into use. Pitting systems are used mainly for the cultivation of annual crops, such as cereals. If the pits are dug on flat instead of sloping ground, they may be regarded more as an *in situ* moisture-conservation technique than as water harvesting one.

**Figure 4.** Example of small pits in Burkina Faso (photo from Oweis et al. 2001)

### *2.3.2.4. Small runoff basins*

Sometimes called *negarim*, small runoff basins consist of small diamond- or rectangular-shaped structures surrounded by low earth bunds (Fig.5). They are oriented to have the maximum land slope parallel to the long diagonal of the diamond, so that runoff flows to the lowest corner, where the plant is placed. The usual dimensions are 5–10 m in width and 10–25 m in length. Small runoff basins can be constructed on almost any gradient, including plains with 1–2 % slopes. They are most suitable for trees. The soil should be deep enough to hold sufficient water for the whole dry season.

**Figure 5.** Small runoff basins at the IWLMP Water Harvesting Site, ICARDA

### *2.3.2.5. Runoff strips*

In this technique the farm is divided into strips along the contour (Fig.6). An upstream strip is used as a catchment, while a downstream one is cultivated. The strip with crops should not be too wide (1–3 m), while the catchment width is determined in accordance with the amount of runoff water required. This technique is highly recommended for barley cultivation and other field crops in large steppe areas of WANA, where it can reduce risk and substantially improve production. The catchment area can be used for grazing after the crop has been harvested.

**Figure 6.** Runoff strips at the IWLMP Water Harvesting Site, ICARDA

### *2.3.2.6. Contour bench terraces*

Contour-bench terraces are constructed on very steep slopes to combine soil and water conservation with water harvesting. Cropping terraces are built level with supporting stonewalls to slow down the flow of water and control erosion. They are supplied with additional runoff water from steeper, non-cropped areas between the terraces. The terraces are usually provided with drains to release excess water safely. They are frequently used to grow trees and bushes, but rarely used for field crops in the WANA region. The historic bench terraces in Yemen are a good example of this system (Fig. 7).

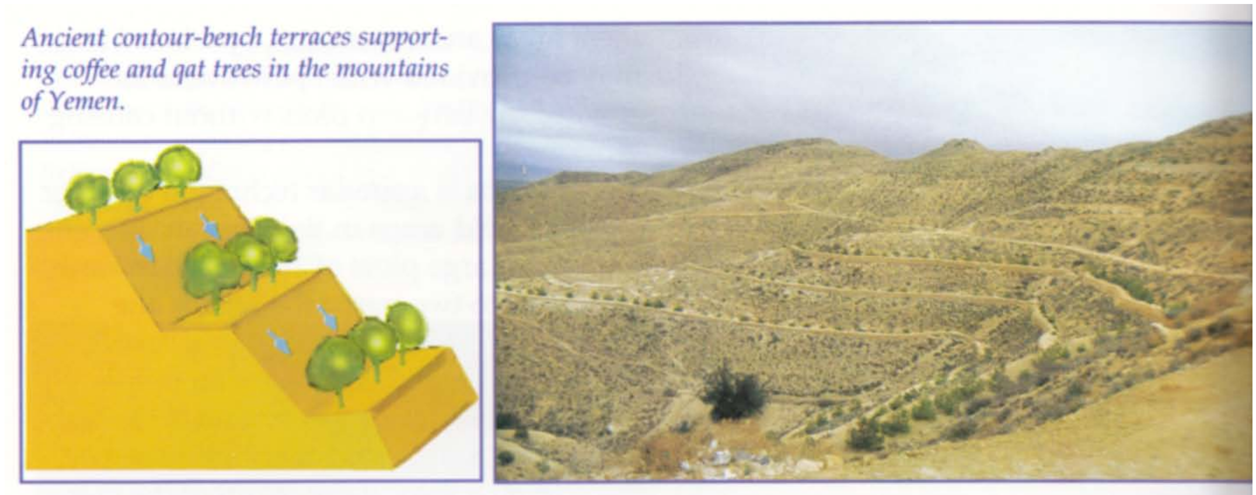



**Figure 7.** Example of contour bench terraces in Yemen (photo from Oweis et al. 2001)

### 2.3.3. Scoring suitability for micro-catchment systems

#### *2.3.3.1. Factor scoring: precipitation*

For precipitation, the scoring of suitability was NOT based on the mean annual precipitation, as in the Syria methodology, but on the 80% minimum annual precipitation, which is the annual precipitation that can be expected to be exceeded in at least 4 years out of 5 (based on frequency counts within a time series). This has two advantages:

(i) A safety factor was considered to account for high precipitation variability in Eritrea;

(ii) the area where water harvesting can be useful was more realistically approximated than by using average annual rainfall.

The location-specific 80% minimum probability annual precipitation was derived by the following procedure:

Step 1. A list of precipitation stations in Zoba Debub and neighbouring areas (other Zobas and northern Ethiopia) was compiled. Data sources were meteorological records for Zobab Debub provided by the Ministry of Agriculture and the FAOCLIM2 database (FAO, 2001). In order to qualify, only stations with at least 15 years of complete monthly records were accepted. All 13 stations in Zoba Debub had a fairly complete monthly precipitation record between 1992 and 2009. Only in a few cases some infilling, using averages, was required, and then only for dry season months. For stations in the FAOCLIM database the data record was longer, but the time period different. The stations finally selected for spatial interpolation are given in Table 1 and shown in Figure 1.

Step 2. For each station the average annual precipitation (PrecYr) for the years of record was calculated.

Step 3. The calculation of the 80% probability minimum annual precipitation assumes a standard reference period of 1978-2007. For the stations inside Zoba Debub no adjustment was required, as they already contain the most recent data. For those stations in Eritrea and Ethiopia with older data (Table an adjustment was made by adding the trend precipitation per decade as follows:

$$PrecYr_{adj} = PrecYr * (1 + {}^{DecChg\% * No_{Dec}}/_{100})$$

With PrecYr_adj: annual precipitation for the reference period, adjusted for the trend
PrecYr: mean annual precipitation, based on the available record
Dec_Chg%: percentage change (+ or -) of the annual precipitation per decade (10 year period)
No_Dec: number of decades difference with the reference period (1978-2007)

The trend precipitation per decade was obtained from a 1-km trend surface grid for the Horn of Africa (Fig. 8).

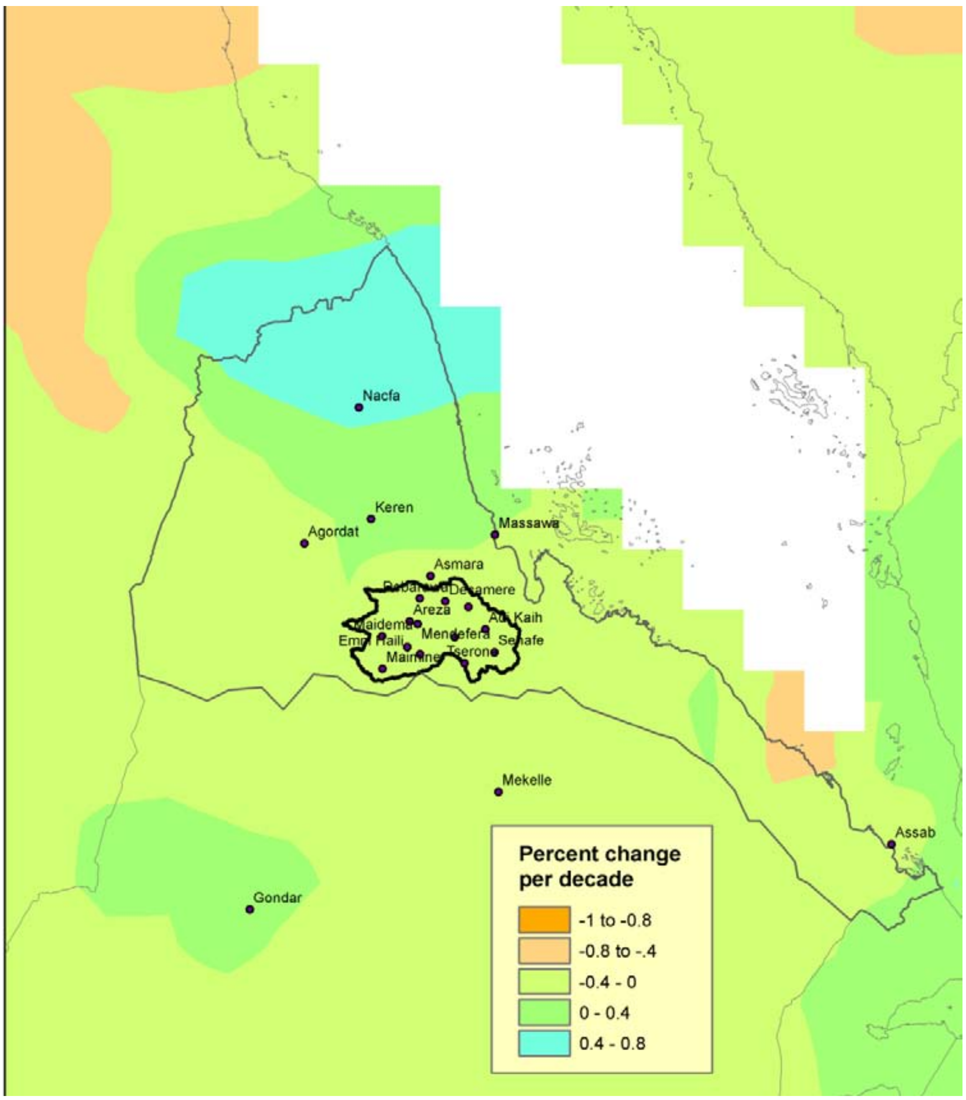



**Figure 8.** Trend in annual precipitation in the Horn of Africa 1901-2007

<u>Step 4.</u> The individual annual precipitation totals were sorted from low to high and given a rank number n.

For each ranked value $Prec_{nn}$ the frequency of exceedance $freqex_n$ was calculated as:

$$\frac{N-n}{N}$$

the precipitation to be exceeded in 4 years out of 5 was calculated as:

$$80\%P = Prec_{n,l} + \frac{0.8-freqex,h}{freqex,l-freqex,h} * (Prec_{n,l} - Prec_{n,h})$$

with $Prec_{n,l}$: the ranked precipitation value immediately below the 0.8 frequency
$Prec_{n,h}$: the ranked precipitation value immediately above the 0.8 frequency
freqex,l: the frequency of exceedance immediately below the 0.8 frequency
freqex,h: the frequency of exceedance immediately above the 0.8 frequency

Step 5. A station-specific ratio Ratio_80%P2Av was calculated as $\frac{80\%P}{PrecYr}$. It was assumed that this ratio remains a constant throughout, in other words that no change in precipitation variability occurred, irrespective of the time period of actual measurements.

Step 6. The final value for the precipitation to be exceeded in 4 years out of 5 was then calculated as:

*Adj_80%P2Av = PrecYr_adj *Ratio_80%P2Av*

Step 7. For the purpose of giving a suitability score to precipitation (Step 9), it was necessary to account for differences in effectiveness of precipitation between Syria and Zoba Debub. The precipitation scoring is calibrated for winter rainfall patterns in non-tropical areas, with relatively lower levels of potential evapotranspiration (PET). In tropical areas with summer rainfall, the PET is higher and, as a result, the effectiveness of precipitation is lower. To adjust for differences in precipitation effectiveness between Syria and Zoba Debub, the effective precipitation in Zoba Debub was calculated as:

*P_eff = Adj_80%P2Av * 0.9368*

The value 0.9368 is the ratio of the mean annual PET in Syria over the mean annual PET in Zoba Debub.

Step 8. After due correction to obtain values for a comparable time period, the station data were converted into gridded maps of mean annual precipitation, using the 'thin-plate smoothing spline' method of Hutchinson (1995), as implemented in the ANUSPLIN software (Hutchinson, 2000). The Hutchinson method is a smoothing interpolation technique in which the degree of smoothness of the fitted function is determined automatically from the data by minimizing a measure of the predictive error of the fitted surface, as given by the generalized cross-validation (Hutchinson, 2000). The method uses three independent spline variables: latitude, longitude and altitude. The latter was input to the model in the form of a digital elevation model (DEM) grid file. The DEM used to generate the climate surfaces was the SRTM DEM[1] with 3 arc-second (about 90 m) resolution. Parameter estimation was undertaken over a regular grid with the same dimensions and resolution as the user-provided DEM.

Step 9. Factor scoring: scores for suitability can have a value between 0 (minimum) and 100 (maximum). Scores for the location-specific 80% minimum annual precipitation were obtained by linear interpolation between cardinal points as follows (Fig. 9):

[1] URL: http://www2.jpl.nasa.gov/srtm/

A: 0 mm (score 0)
B: 150 mm (score 100)
C: 250 mm (score 100)
D: 500 mm (score 0)

For all WH micro-catchment systems the same scoring system for precipitation was applied.

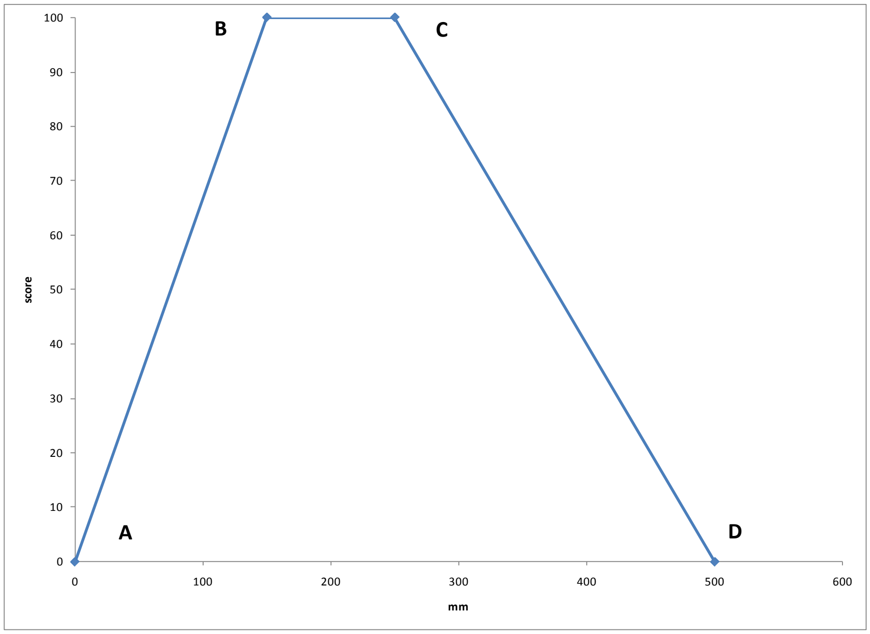



**Figure 9**. Scores for the effective 80% minimum annual precipitation (all systems)

Table 1. Stations used for the spatial interpolation of the mean and 80% probability minimum annual precipitation

| Source | Country | Station name | Lati | Longi | Alti | No. Years | Begin | End | PrecYr | 80%P | Ratio | DecChg % | No_Decades | PrecYr_adj | Adj_80% P2Av | P_eff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MoA | ERITREA | Adi Kaih | 14.841 | 39.371 | 2407 | 15 | 1992 | 2006 | 407 | 296 | 0.7280 | 0.0000 | 0 | 407 | **296** | 278 |
| MoA | ERITREA | Adi Quala | 14.635 | 38.833 | 2046 | 16 | 1992 | 2007 | 652 | 477 | 0.7326 | 0.0000 | 0 | 652 | **477** | 447 |
| MoA | ERITREA | Areza | 14.9071 | 38.7468 | 2070 | 16 | 1992 | 2007 | 384 | 307 | 0.7992 | 0.0000 | 0 | 384 | **307** | 287 |
| MoA | ERITREA | Debarawa | 15.094 | 38.832 | 1932 | 16 | 1992 | 2007 | 491 | 339 | 0.6916 | 0.0000 | 0 | 491 | **339** | 318 |
| MoA | ERITREA | Decamere | 15.071 | 39.041 | 2036 | 16 | 1992 | 2007 | 459 | 361 | 0.7863 | 0.0000 | 0 | 459 | **361** | 338 |
| MoA | ERITREA | Emni Haili | 14.694 | 38.728 | 1975 | 11 | 1999 | 2009 | 447 | 278 | 0.6208 | 0.0000 | 0 | 447 | **278** | 260 |
| MoA | ERITREA | Maidema | 14.785 | 38.52 | 1770 | 14 | 1992 | 2005 | 345 | 178 | 0.5149 | 0.0000 | 0 | 345 | **178** | 166 |
| MoA | ERITREA | Maimine | 14.517 | 38.523 | 1614 | 15 | 1992 | 2006 | 514 | 357 | 0.6958 | 0.0000 | 0 | 514 | **357** | 335 |
| MoA | ERITREA | Main Ain | 14.774 | 39.12 | 1712 | 12 | 1996 | 2009 | 435 | 328 | 0.7551 | 0.0000 | 0 | 435 | **328** | 308 |
| MoA | ERITREA | Mendefera | 14.886 | 38.814 | 1976 | 16 | 1992 | 2009 | 619 | 449 | 0.7256 | 0.0000 | 0 | 619 | **449** | 421 |
| MoA | ERITREA | Senafe | 14.652 | 39.448 | 2637 | 17 | 1992 | 2008 | 519 | 302 | 0.5826 | 0.0000 | 0 | 519 | **302** | 283 |
| MoA | ERITREA | Segheneite | 15.024 | 39.233 | 2205 | 15 | 1993 | 2009 | 450 | 308 | 0.6844 | 0.0000 | 0 | 450 | **308** | 289 |
| MoA | ERITREA | Tserona | 14.561 | 39.201 | 1609 | 13 | 1994 | 2009 | 403 | 267 | 0.6624 | 0.0000 | 0 | 403 | **267** | 250 |
| FAOCLIM | ERITREA | Agordat | 15.55 | 37.88 | 626 | 30 | 1931 | 1960 | 278 | 111 | 0.3997 | -0.5130 | 5.5 | 270 | **108** | 101 |
| FAOCLIM | ERITREA | Asmara | 15.28 | 38.92 | 2325 | 30 | 1961 | 1990 | 518 | 377 | 0.7272 | -0.0048 | 2.5 | 518 | **377** | 353 |
| FAOCLIM | ERITREA | Assab | 13.07 | 42.72 | 14 | 27 | 1961 | 1990 | 42 | 1 | 0.0239 | -0.2451 | 2.5 | 41 | **1** | 1 |
| FAOCLIM | ERITREA | Keren | 15.75 | 38.43 | 1460 | 28 | 1933 | 1963 | 367 | 299 | 0.8134 | 0.5100 | 5.5 | 377 | **307** | 288 |
| FAOCLIM | ERITREA | Massawa | 15.62 | 39.45 | 10 | 30 | 1931 | 1960 | 187 | 100 | 0.5337 | 0.0022 | 5.5 | 187 | **100** | 94 |
| FAOCLIM | ERITREA | Nacfa | 16.67 | 38.33 | 1676 | 21 | 1942 | 1967 | 168 | 50 | 0.2958 | 0.5219 | 5 | 173 | **51** | 48 |
| FAOCLIM | ETHIOPIA | Mekelle | 13.5 | 39.48 | 2212 | 30 | 1960 | 1989 | 626 | 443 | 0.7072 | -0.0792 | 2.5 | 625 | **442** | 414 |
| FAOCLIM | ETHIOPIA | Gondar | 12.53 | 37.43 | 1966 | 30 | 1961 | 1990 | 1,066 | 853 | 0.8006 | 0.0210 | 2.5 | 1,066 | **853** | 800 |

column headers:

Source:source data (MoA: Ministry of Agriculture; FAOCLIM: FAO 2001)

Lati: latitude (in decimal degrees); Longi: longitude (in decimal degrees); Alti: station elevation (in m)

NoYears: number of years with recorded data

Begin: begin year for the record; End: end year for the record

PrecYr: mean annual precipitation, based on the available recordDec_Chg%: percentage change (+ or -) of the annual precipitation per decade (10 year period)

No_decades: number of decades difference with the reference period (1978-2007)

PrecYr_adj: annual precipitation for the reference period, adjusted for the trend

Ratio_80%P: ratio between the 80% minimum probability annual precipitation and the mean annual precipitation

P_80%: adjusted 80% minimum probability annual precipitation

P_eff: effective annual precipitation (the minimum to be expected in 4 years out of 5, adjusted for reference period and for potential evapotranspiration)

#### *2.3.3.2. Factor scoring: slopes*

The main source for slope information was the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM)[2]. Slopes were calculated using respectively the Slope function of the Spatial Analyst Tools in ESRI ArcGIS software.
Slope scores are also obtained by linear interpolation between cardinal points. The cardinal points are different between the considered WH systems (Fig. 10), which can be divided into 3 'slope response groups':

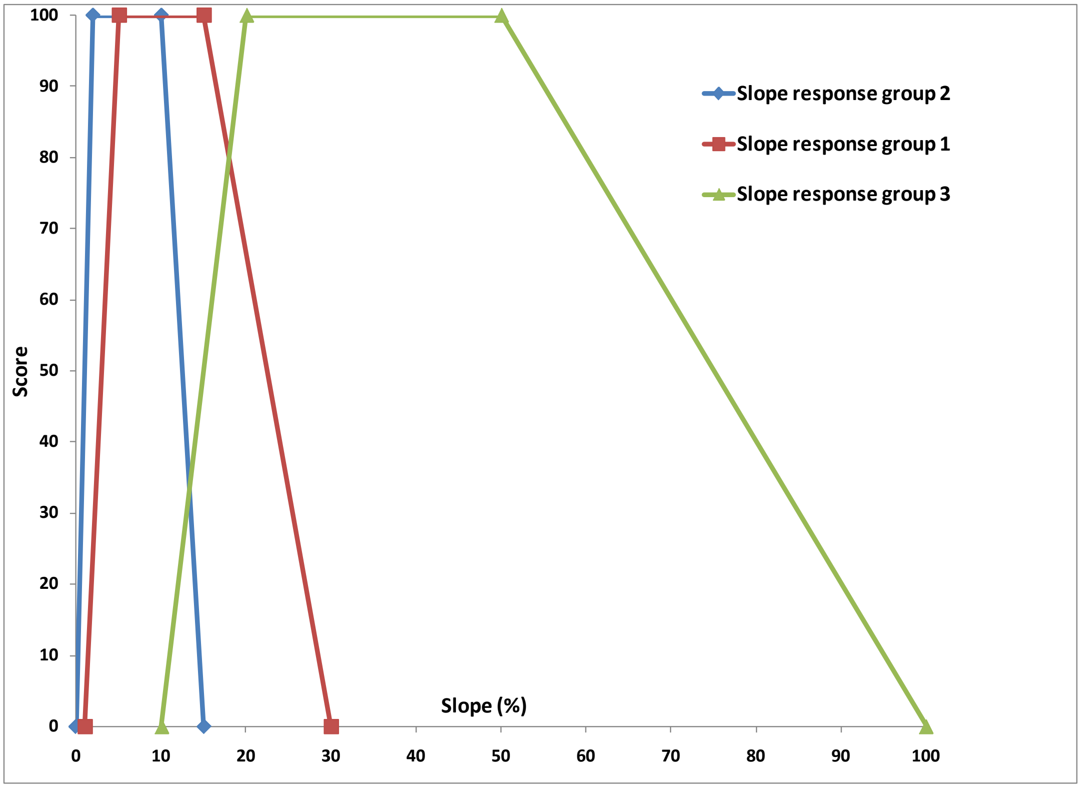



**Figure 10.** Slope scores for micro-catchment systems

*Slope response group 1: contour ridges*
A: 1% slope (score 0)
B: 5% slope (score 100)
C: 15% slope (score 100)
D: 30% slope (score 0)

*Slope response group 2: small pits, runoff strips, small runoff basins, semi-circular bunds*
A: 0% slope (score 0)
B: 2% slope (score 100)
C: 10% slope (score 100)
D: 15% slope (score 0)

[2] URL: http://www2.jpl.nasa.gov/srtm/

*Slope response group 3:  contour bench terraces*
A:  10% slope (score 0)
B:  20% slope (score 100)
C:  50% slope (score 100)
D:  100% slope (score 0)

The scores are nearly identical to the slope scores used in Syria (De Pauw et al. 2008), with exceptions for response group 1, where point A, previously at 2% slope, has been repositioned to 1 % slope, and for response group 2, where point A, previously at 1% slope, has been repositioned to 0% slope, following new research findings in the Badia area in Jordan[3].

#### *2.3.3.3. Factor scoring: land use/land cover*

The source of land use/land cover information is the Eritrea Multi-purpose Land Cover Database (FAO/ Africover, 2002). Land use/land cover can be a constraint for the development of water harvesting in two ways: from a land use planning/zoning perspective, and from the physical nature of the land cover. The presence of urbanized areas is an example of the first type of constraint, forest areas an example of the second type of constraint. None of these constraints is important in Zoba Debub. For this reason land use/land cover has not been considered a limiting factor for water harvesting development at the scale of the Zoba.

#### *2.3.3.4. Factor scoring: soils*

There is a severe scarcity of good soil information in Eritrea in general, and for Zoba Debub in particular. The best source of soil data is the Soil Map of IGADD countries, including Eritrea. However, this map is still at an exploratory level (scale: 1:2,000,000) with mapping units that are associations of FAO soil classification groups: a limited number of broad soil types that occur in groups, which could not be further separated and characterized at the scale of the study. In some countries (e.g. Palestine, see De Pauw and Wu, 2010) it has been possible to improve the resolution of the soil map, with respect to critical soil properties for water harvesting (such as soil depth), by visual interpretation of high-resolution QuickBird[4]  imagery in Google Earth Pro.
Despite the fact that Zoba Debub is covered for more than 60% by Quickbird imagery, and the remainder by SPOT imagery, with lower but still very good resolution, the properties of the soils of Zoba Debub, relevant to water harvesting, cannot be quantified or even estimated without major soil survey investigations in the field. This was not feasible in the context of this project.

All soils are acceptable for micro-catchment systems unless they are too shallow, too saline, too stony or have very severe limitations of soil texture (De Pauw et al., 2008). The most critical determinant of soil suitability for different water harvesting systems is soil depth. As the available soil map and satellite imagery did not provide a sound basis for estimating soil depth, this factor was inferred from the Eritrea Multi-purpose Land Cover Database using a land cover/depth conversion table (Table 2). Using expert judgment, each land use/land cover class was associated with a soil depth class.

---

[3] T. Oweis, personal communication.
[4] URL: http://www.digitalglobe.com/index.php/85/QuickBird

Table 2. Land cover and estimated soil depth and hydrological classes

| Land cover | Depth Class | Estimated_depth | DRG_1 | DRG_2 | DRG_3 | DRG_4 | Hydro-class |
|---|---|---|---|---|---|---|---|
| Artificial Waterbodies | n.a. | n.a. | 0 | 0 | 0 | 0 | n.a. |
| Bare rocks and river banks | Bare | <25 cm | 0 | 0 | 0 | 0 | D |
| Bare soil | Bare | <25 cm | 0 | 0 | 0 | 0 | D |
| Closed Herbacous Vegetation (Seasonally Flooded) | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Closed Shrubs | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Closed to Open Herbaceous Vegetation | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Closed Trees (Broadleaved Evergreen) | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Closed Trees (Needle leaved Evergreen) | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Closed Woody Vegetation Thickets | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Irrigated Herbaceous Fields | Deep | >75 cm | 100 | 100 | 100 | 100 | B |
| Irrigated Herbaceous Fields (mixed unit with natural vegetation or other) (field area approx. 60% polygon area | Mixed1 | 60% deep; 40% shallow | 100 | 80 | 60 | 80 | B |
| Irrigated Shrub Crop - Banana | Deep | >75 cm | 100 | 100 | 100 | 100 | B |
| Irrigated Tree Crop - Citrus | Deep | >75 cm | 100 | 100 | 100 | 100 | B |
| Irrigated Tree Crop - Citrus (mixed unit with natural vegetation or other) (field area approx. 60% polygon area | Mixed1 | 60% deep; 40% shallow | 100 | 80 | 60 | 80 | B |
| Isolated (in natural vegetation or other) Rainfed Small Herbaceous Fields (field frequency 10-20% polygon are | Mixed3 | 20% deep; 80% shallow | 100 | 60 | 20 | 60 | C |
| Open Shrubs | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Open Trees | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Rainfed Large to Medium Herbaceous Fields | Deep | >75 cm | 100 | 100 | 100 | 100 | B |
| Rainfed Small Herbaceous Fields | Mixed1 | 60% deep; 40% shallow | 100 | 80 | 60 | 80 | B |
| Rainfed Small Herbaceous Fields (mixed unit with natural vegetation or other) (field area approx. 60% polygor | Mixed1 | 60% deep; 40% shallow | 100 | 80 | 60 | 80 | B |
| Savannah (Shrub or Tree and Shrub) | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Scattered (in natural vegetation or other) Irrigated Herbaceous Fields (field frequency 20-40% polygon area) | Mixed2 | 40% deep; 60% shallow | 100 | 70 | 40 | 80 | B |
| Scattered (in natural vegetation or other) Rainfed Small Herbaceous Fields (field frequency 20-40% polygon ar | Mixed2 | 40% deep; 60% shallow | 100 | 70 | 40 | 80 | B |
| Scattered (in natural vegetation or other) Tree Plantation - Eucalyptus (field frequency 20-40% polygon area) | Mixed2 | 40% deep; 60% shallow | 100 | 70 | 40 | 80 | B |
| Sparse Herbaceous Vegetation | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Sparse Shrubs | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Sparse Trees | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | C |
| Tree Plantation - Eucalyptus | Mixed2 | 40% deep; 60% shallow | 100 | 70 | 40 | 80 | B |
| Tree Plantation - Eucalyptus (mixed unit with natural vegetation or other) (field area approx. 60% polygon are | Mixed2 | 40% deep; 60% shallow | 100 | 70 | 40 | 80 | B |
| Urban and Associated Areas | Shallow | 25-75 cm | 100 | 50 | 0 | 0 | D |

Notes:

DRG_1,DRG_2, DRG_3, DRG_4: soil depth suitability scores for the 4 depth response groups (Table 3)

Hydro-Class: soil hydrological class

Using this simple classification, a map of estimated soil depth map was prepared. On this basis it was possible to subdivide the soils of the Zoba into a limited number of 'soil depth response classes' and provide suitability scores to the latter (Table 3).

Table 3. Scores of soil depth by WH system and soil depth response group

| WH class | Depth response group | Deep | Shallow | Mixed1 | Mixed2 | Mixed3 | Other |
|---|---|---|---|---|---|---|---|
| Micro | S11, S21 | 100 | 100 | 100 | 100 | 100 | 0 |
| Micro | S12, S22, S31, S41, S51 | 100 | 50 | 80 | 70 | 60 | 0 |
| Micro | S13, S23, S33, S43, S52 | 100 | 0 | 60 | 40 | 20 | 0 |
| Micro | S6 | 0 | 0 | 80 | 80 | 60 | 0 |
| Macro | Tree crops | 100 | 33 | 73.2 | 59.8 | 46.4 | 0 |
| Macro | Field crops | 100 | 50 | 80 | 70 | 60 | 0 |

#### *2.3.3.5. Combined suitability*

Individual factor scores are integrated by the 'minimum' rule: the lowest factor score sets the overall suitability score.

$$\text{Combined score} = \text{minimum}(\text{Score}_{\text{precipitation}}, \text{Score}_{\text{slope}}, \text{Score}_{\text{soil depth}}, \text{Score}_{\text{land use/land cover}})$$

### 2.3.4. Scoring suitability for macro-catchment systems

The suitability criteria for the 'catchment' and 'use' areas are different: for the catchment area, strongly sloping land with soils that are shallow, rocky, or have poor infiltration capacity is preferable. On the other hand, for the use area, level or gently undulating land with deep soils and no other limitations to agricultural use is preferable. In addition, land suitable for use as a catchment, must be within a certain distance of land suitable for agricultural use that can be overcome by technical means.

Using these simple rules of thumb, the problem of identifying, in a GIS environment, land with these contrasting requirements is then reduced to a separate assessment of suitability for catchment and agricultural purposes, followed by an assessment of the constraint imposed by distance between these two different environments.

#### *2.3.4.1. Suitability for catchment use*

The following factors are considered: precipitation, slope and hydrological properties of soils.

Factor scoring:  Precipitation

For macro-catchment systems precipitation suitability is different from micro-catchment systems. The basic principle is: other factors (soil, slope, land cover) being equal, the more rainfall, the better the catchment is for capturing water.

As in the micro-catchment systems, suitability is approximated using the 80% minimum annual precipitation, with the precipitation score calculated by linear interpolation between only 2 inflection points A: 150 mm (0); B: 250 mm (100).

Factor scoring: Slope

Any surface can act as a catchment as long as it has some slope, very limited permeability for precipitation and no obstacles. As a first approximation, one could consider the slope as non-limiting, as long as it is not near zero. This condition can be simulated by a score function with two inflection points A: 0% (0); B: 5% (100) and intermediate values obtained by linear interpolation (Fig. 11).

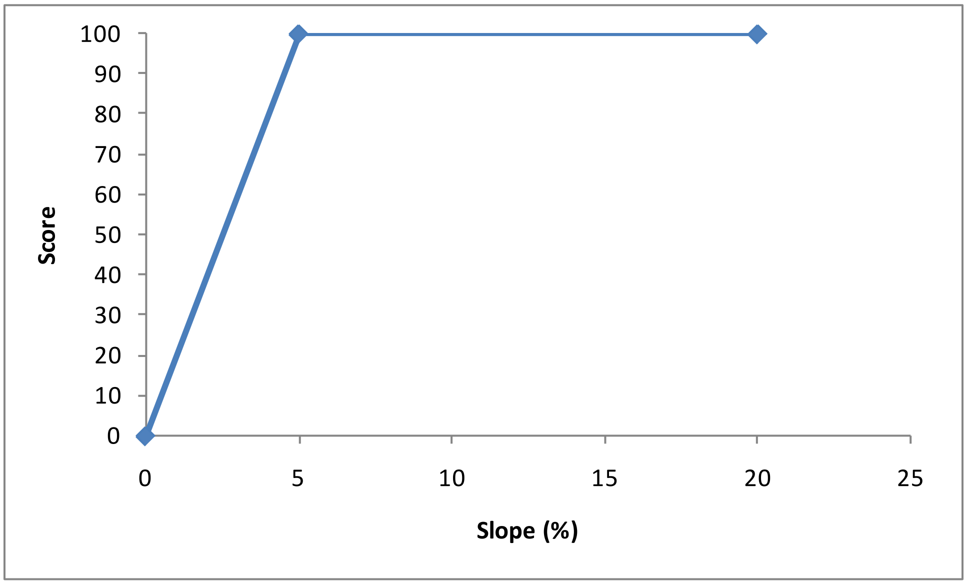



**Figure 11.** Catchment suitability scores for slope assuming very limited permeability

*Taking into consideration soil hydrological properties*
Soils have different hydrological properties and as such are a major factor in the run-off generating potential of catchments. The Soil Conservation Service of the US Department of Agriculture (1969) differentiates four major hydrological classes:

- Class A (low run-off potential): deep sandy soils;
- Class B: shallow sandy soils and medium-texture soils with above average infiltration rates;
- Class C: shallow soils of medium to heavy texture with below-average infiltration rates;
- Class D (high run-off potential): clay and shallow soils with hardpan, high groundwater table etc.

The hydrological properties of the soils were inferred from the combinations of soil depth class and land use/land cover class (Table 2).

Referring to the values [a] and [b] in Table 4, a reduction factor was applied for each soil hydrological class as follows:

if Slope ≥a then $RF_i = 0$

if Slope ≤b then $RF_i$ = 100

if Slope between (a,b) then $RF_i = \frac{Slope - a_i}{b_i - a_i} * 100$

with RF= reduction factor for soil hydrological class i.

Table 4. Reduction factors for slope in relation to hydrological classes

| Hydrological class | a | b |
|---|---|---|
| A | 40 | 15 |
| B | 15 | 8 |
| C | 8 | 3 |
| D | 3 | 0 |

The relationship between the reduction factor and slope per soil hydrological class is shown in Figure 12.

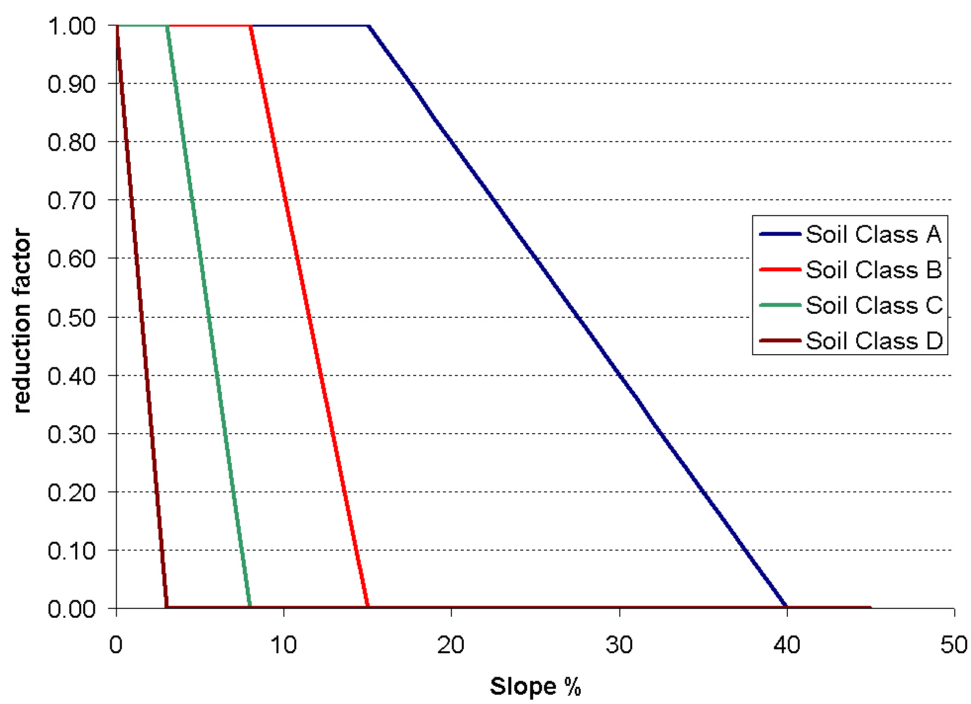



**Figure 12.** Reduction factors for soil hydrological classes

The interpretation of Figure 5 is that if, for example, the soil in a particular pixel belongs to hydrological class D, there will be no reduction in runoff if the slope is 3% or higher; if, on the other hand, the soil belongs to hydrological class C, a reduction factor of .5 will be applied as compared to the optimal slope range for this class (> 8%).

It is useful to use for Class D, with its very low permeability, the analogy of a plastic sheet. No water will run away from the sheet if the slope is zero. However, the slightest slope will be cause for runoff. At the other end one could visualize for Class A the same plastic sheet, but full of holes. Water poured over the sheet will drain through the holes. To generate runoff, the slope must be quite steep for the water to run off before it has the time to seep through the holes. Classes B and C have intermediate drainage properties.

The soil-corrected score for slope is then taken as the lowest value of either the slope score or the reduction factor as follows:

$$\mathbf{S_{slope,cor} = Min( S_{slope}, 100\text{-}RF_i)}$$

Apart from its influence on the hydrological class (Table 5), no land use/cover category has a prohibitive effect on the suitability as a catchment. Thus, the final score for suitability as a catchment is then taken as the lowest of the precipitation score and the soil-corrected slope score:

$$\mathbf{S = Min (S_{slope,cor}; S_{precip})}$$

### *2.3.4.2. Suitability for agricultural use*

The same precipitation criterion and thresholds apply as in the micro-catchment systems.
In terms of slope suitability, 'flat to gentle' slopes are optimal for agricultural use. This condition is simulated by a score function with two inflection points A: 0% (100); B: 15% (0) and intermediate values obtained by linear interpolation (Fig. 13).

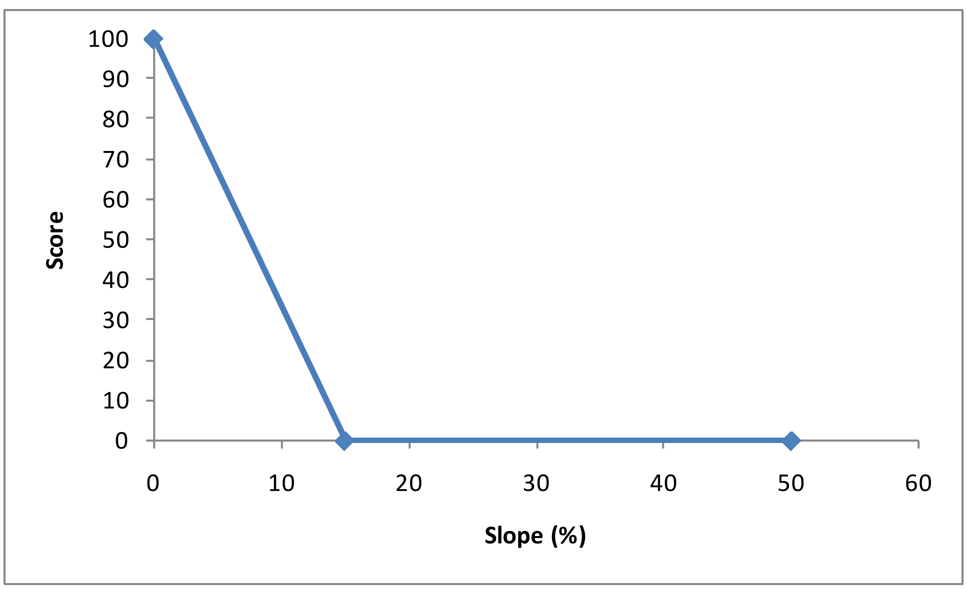



**Figure 13.** Slope suitability scores for agricultural use

Soil suitability is, as in the micro-catchment systems, evaluated using the soil depth classes (Table 3).

#### *2.3.4.3. Combining suitability for catchment and agricultural uses*

The combined suitability for catchment and agricultural purposes is assessed by identifying those areas where suitable catchments and agricultural areas are close together. The limiting distance between the two is taken as 1km.
This is implemented in a GIS environment through the following steps:

- Step 1: suitability scores for catchment use are reclassified into 5 groups (score: 0, >0 – 20, >20 – 40, >40 – 60, > 60)
- Step 2: to avoid over-fragmented patterns, a smoothing function is applied
- Step 3: the reclassified smoothened suitability score rasters are converted to vector layers.
- Steps 1-3 are repeated for the suitability scores for agricultural use
- Step 4: 1km buffer zones are created around the vector features that represent the highest score class (>60)
- Step 5: The geometric intersection is calculated of the buffer zones for both the high-score catchment and agricultural use classes, as well as with the watershed boundary.

The output of the intersection procedure is the area suitable for catchment and agricultural use within 1km proximity of each other.

# 3. RESULTS

## 3.1. GIS analysis

This analysis is based on the calculation of areas of the classes distinguished in the base maps and suitability maps. Areas were calculated in hectare, using an equal-area projection in the GIS software, and converted into percent of Zoba Debub.

### 3.1.1. Base maps

Map 4 (‘Elevation’) and Table 5a indicate major differences in elevation in Zoba Debub: in nearly 80% of the Zoba an elevation range of 800 m exists. Although not directly affecting the potential for water harvesting, these differences in elevation and, consequently, temperature, may affect the physical suitability and comparative advantage for different crops.

Table 5a. Areas in different elevation classes (meter)

| Class (m) | Area (%) |
|---|---|
| 900-1000 | 0.08 |
| 1000-1200 | 2.05 |
| 1200-1400 | 8.37 |
| 1400-1600 | 20.09 |
| 1600-1800 | 20.35 |
| 1800-2000 | 23.87 |
| 2000-2200 | 13.77 |
| 2200-2400 | 6.79 |
| 2400-2600 | 3.55 |
| 2600-2800 | 0.98 |
| 2800-3000 | 0.12 |

Map 5 (‘Slopes’) and Table 5b show a wide range in slopes, ranging from very flat (0-2%) to very steep (>30%). The well balanced spread of slope classes indicates that both water-shedding and water-receiving areas exist in the Zoba.

Table 5b. Areas in different slope classes (%)

| Slope class (%) | Area (%) |
|---|---|
| 0-2 | 7.35 |
| 2-5 | 17.79 |
| 5-8 | 11.41 |
| 8-15 | 18.18 |
| 15-30 | 23.56 |
| >30 | 21.71 |

Map 6 (‘Compound Topographic Index’) basically shows only two classes: areas of which the curvature is such as to promote shedding runoff water, and those that tend to promote concentration of runoff. The first CTI class (value 9-12) covers about 52% of the Zoba, the second CTI class (12-19) covers about 46% of the Zoba. A third CTI class (>19) covers only 2% of the Zoba, and is associated with river beds.

Map 7 ('Mean annual precipitation') and Table 6 indicate that the vast majority of the Zoba (80%) receives a mean annual precipitation between 400 and 500 mm.

Table 6. Areas in different precipitation classes (mm)

| **Class (mm)** | **Area (%)** |
|---|---|
| 350-400 | 1.83 |
| 400-450 | 61.01 |
| 450-500 | 29.23 |
| 500-550 | 7.92 |
| 550-600 | .003 |

This may appear high, certainly in comparison with winter precipitation areas, where 300-400 mm is quite acceptable for growing crops, but as Map 8 ('Reliable/Effective Annual Precipitation') indicates, the annual fluctuations are of such magnitude that on average only 60-70% of that precipitation can be considered reliable (i.e. to be expected in at least 4 years out of 5). In about 80% of the Zoba the reliable annual precipitation is in the 250-300 mm range, in the remaining 20% it is in the range 300-350 mm.

Despite major differences in elevation in the Zoba, annual potential evapotranspiration (PET) rates do not vary that much (Map 9, 'Annual Potential Evapotranspiration'). As indicated by Table 7, the vast majority of the Zoba (80%) is in the PET range 1600-1800 mm.

Table 7. Areas in different PET classes (mm)

| **Class (mm)** | **Area (%)** |
|---|---|
| 1400-1500 | 0.37 |
| 1500-1600 | 4.59 |
| 1600-1700 | 29.68 |
| 1700-1800 | 50.94 |
| 1800-1900 | 14.17 |
| 1900-2000 | 0.25 |

### 3.1.2. Suitability for water harvesting in Zoba Debub

Suitability by system in Zoba Debub is summarized in Table 8 (hectare) and Table 9 (% of the Zoba). Areas are provided for 10 suitability score classes, with increments of 10 points, as well as the totals for the suitability score classes from 60 to 100, with 60 considered the minimum value for 'suitable'.

Table 8. Suitability score classes by system in Zoba Debub (hectare)

| Suitability scores | Micro-catchment systems | | | | | | | | | | | | | Macro-catchment systems | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
| 0-10 | 451,285 | 451,285 | 639,425 | 267,314 | 267,314 | 591,129 | 267,314 | 591,129 | 267,314 | 591,129 | 267,314 | 591,129 | 811,498 | 197,766 | 471,827 | 471,827 |
| 10-20 | 12,389 | 12,389 | 65,253 | 37,222 | 37,222 | 102,450 | 37,222 | 102,450 | 37,222 | 102,450 | 37,222 | 102,450 | 13,402 | 15,450 | 34,358 | 34,358 |
| 20-30 | 14,672 | 14,672 | 6,355 | 44,380 | 44,380 | 21,091 | 44,380 | 21,091 | 44,380 | 21,091 | 44,380 | 21,091 | 11,977 | 16,616 | 37,822 | 37,822 |
| 30-40 | 16,880 | 16,880 | 82,523 | 46,756 | 46,756 | 110,403 | 46,756 | 110,403 | 46,756 | 110,403 | 46,756 | 110,403 | 10,503 | 17,588 | 40,711 | 40,711 |
| 40-50 | 18,510 | 180,204 | 6,901 | 45,563 | 292,010 | 13,658 | 292,010 | 13,658 | 292,010 | 13,658 | 292,010 | 13,658 | 9,603 | 17,929 | 180,757 | 145,511 |
| 50-60 | 19,056 | 62,791 | 155,772 | 47,876 | 88,329 | 124,441 | 88,329 | 124,441 | 88,329 | 124,441 | 88,329 | 124,441 | 45,212 | 17,803 | 65,529 | 59,016 |
| 60-70 | 27,340 | 81,134 | 1,760 | 51,310 | 89,750 | 359 | 89,750 | 359 | 89,750 | 359 | 89,750 | 359 | 6,535 | 16,970 | 23,353 | 65,112 |
| 70-80 | 75,684 | 139,997 | 1,364 | 111,823 | 98,273 | 503 | 98,273 | 503 | 98,273 | 503 | 98,273 | 503 | 56,761 | 16,684 | 98,335 | 98,335 |
| 80-90 | 326,292 | 6,138 | 6,138 | 308,806 | 1,457 | 1,457 | 1,457 | 1,457 | 1,457 | 1,457 | 1,457 | 1,457 | | 16,744 | 12,800 | 12,800 |
| 90-100 | 3,382 | | | 4,441 | | | | | | | | | | 631,942 | | |
| >60 | **432,698** | **227,270** | 9,262 | **476,381** | **189,480** | 2,319 | **189,480** | 2,319 | **189,480** | 2,319 | **189,480** | 2,319 | 63,296 | **682,339** | **134,489** | **176,247** |

Table 9. Suitability score classes by system in Zoba Debub (percent)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 46.7 | 46.7 | 66.2 | 27.7 | 27.7 | 61.2 | 27.7 | 61.2 | 27.7 | 61.2 | 27.7 | 61.2 | 84.1 | 20.5 | 48.9 | 48.9 |
| 10-20 | 1.3 | 1.3 | 6.8 | 3.9 | 3.9 | 10.6 | 3.9 | 10.6 | 3.9 | 10.6 | 3.9 | 10.6 | 1.4 | 1.6 | 3.6 | 3.6 |
| 20-30 | 1.5 | 1.5 | 0.7 | 4.6 | 4.6 | 2.2 | 4.6 | 2.2 | 4.6 | 2.2 | 4.6 | 2.2 | 1.2 | 1.7 | 3.9 | 3.9 |
| 30-40 | 1.7 | 1.7 | 8.5 | 4.8 | 4.8 | 11.4 | 4.8 | 11.4 | 4.8 | 11.4 | 4.8 | 11.4 | 1.1 | 1.8 | 4.2 | 4.2 |
| 40-50 | 1.9 | 18.7 | 0.7 | 4.7 | 30.2 | 1.4 | 30.2 | 1.4 | 30.2 | 1.4 | 30.2 | 1.4 | 1.0 | 1.9 | 18.7 | 15.1 |
| 50-60 | 2.0 | 6.5 | 16.1 | 5.0 | 9.1 | 12.9 | 9.1 | 12.9 | 9.1 | 12.9 | 9.1 | 12.9 | 4.7 | 1.8 | 6.8 | 6.1 |
| 60-70 | 2.8 | 8.4 | 0.2 | 5.3 | 9.3 | 0.0 | 9.3 | 0.0 | 9.3 | 0.0 | 9.3 | 0.0 | 0.7 | 1.8 | 2.4 | 6.7 |
| 70-80 | 7.8 | 14.5 | 0.1 | 11.6 | 10.2 | 0.1 | 10.2 | 0.1 | 10.2 | 0.1 | 10.2 | 0.1 | 5.9 | 1.7 | 10.2 | 10.2 |
| 80-90 | 33.8 | 0.6 | 0.6 | 32.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.0 | 1.7 | 1.3 | 1.3 |
| 90-100 | 0.4 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 65.5 | 0.0 | 0.0 |
| **>60** | **44.8** | **23.5** | 1.0 | **49.3** | **19.6** | 0.2 | **19.6** | 0.2 | **19.6** | 0.2 | **19.6** | 0.2 | 6.6 | **70.7** | **13.9** | **18.3** |

Notes:

S11, S12, S13, S21, S22, S23, S31, S33, S41, S43, S51, S52, S6: symbols for micro-catchment systems explained in section 2.3.1. , step 2.
Cat: suitability for catchment use; Tree: suitability for use as target area (tree crops); Field: suitability for use as target area (field crops)
In grey: areas with suitability score above 60.

These tables indicate that overall the potential for most water harvesting systems in Zoba Debub is high. One exception are the micro-catchment systems with tree crops. For these systems (S13, S23, S33, S43, S52) the potential is considered low due to soil depth limitations. However, it has to be reiterated (see also section 2.3.2.4.) that knowledge of soil depth in Zoba Debub is currently inferred from land use/land cover, not from any direct soil observations or even remote sensing. The accurate positioning of water harvesting interventions therefore requires a second stage of studies in which soil survey will have to play a major role, in order to identify at greater detail important properties such as soil depth, stoniness, texture, salinity.

The high potential for water harvesting is also made clear by Map 26 ('Combined suitability for micro-catchment water harvesting systems'} and Table 10, which show the location and areas that are considered 'suitable' (suitability score >60) for different combinations of micro-catchment water harvesting systems. While roughly 30% of the Zoba is considered unsuitable for any micro-catchment system, about 70% is assessed as being suitable for at least one micro-catchment system.

Table 10. Areas suitable for various combinations of micro-catchment systems in Zoba Debub

| Class | % of Zoba | hectare |
|---|---|---|
| Unsuitable for any system | 30.25 | 292,055 |
| Suitable for S11 | 3.27 | 31,602 |
| Suitable for S11, S12 | 3.07 | 29,615 |
| Suitable for S11, S12, S13 | 7.23 | 69,798 |
| Suitable for S21 | 10.50 | 101,364 |
| Suitable for S11, S21 | 12.70 | 122,645 |
| Suitable for S21, S22, S31, S41, S51 | 2.60 | 25,057 |
| Suitable for S11, S21, S22, S31, S41, S51 | 9.39 | 90,654 |
| Suitable for all systems except S11, S12, S13,S6 | 1.48 | 14,300 |
| Suitable for all systems except S6 | 9.17 | 88,578 |
| Suitable for S6 | 6.83 | 65,986 |
| Suitable for S6, S21, S22, S31, S41, S51 | 2.39 | 23,108 |
| Suitable for all systems except S11, S12, S13 | 1.11 | 10,728 |

In addition to Tables 8 and 9, a set of tables were created in the GIS that show the areas in each suitability class for all water harvesting technologies in the selected watersheds (see following section 3.2). These tables are included in Annex 4.

## 3.2. Selection of watersheds

### 3.2.1. General Approaches

The selection of watersheds for locating and defining interventions was based on the following approaches:

a) review of documents developed earlier for this project, a visit by an ICARDA water management specialist to Eritrea, communications with IFAD and Eritrean people in charge, and meetings with project associated personnel from Eritrea and IFAD at ICARDA.
b) developing a GIS database for Zoba Debub. The collection of spatial data, geo-referenced field data and general observations made by the consultant Jan Venema (Annex 3) fitted within this activity. On the basis of all available spatial data, the watersheds in the Zoba were mapped and their major characteristics described. Statistics on available interventions and communities were also included.
c) An expert evaluation of the potential watersheds in Zoba Debub and pilot watersheds was made based on predetermined criteria. Field visits to the various parts of the Zoba and meetings with farmers, specialists and officials including the Governor and researchers were held. Analysis of the maps and application of the criteria resulted in narrowing down the potential watersheds to eight candidates. Two of these were further screened for immediate development. The selection of water and land interventions was based on local and regional experiences, ICARDA and consultants expert evaluation.
d) Visits and meetings by IFAD specialists and a delegation from Eretria to ICARDA in July 2010. Preliminary results and conclusions were discussed and refined.

#### 3.2.2. Selection criteria

The following criteria were developed and used to evaluate and select potential and pilot watersheds:
a) Communities concentration and the urgency for development
b) Higher potential for water and land resources availability and utilization
c) Potential coverage of the three important agro-ecosystems, rainfed, spate irrigation and rangelands in each watershed.
d) The geographical distribution and political feasibility
e) Existing local experiences in major interventions
f) Accessibility and availability of data for development

#### 3.2.3. Potential and pilot watersheds

Matching the above criteria to the information generated from the GIS study and after discussions with local people, eight watersheds were considered for the pilot project. Those are: Tselema, Hazemo, Maitekela, Tsaidakelay, Oubel, Megerba, Alla, and Shemejana (Fig. 14).

The potential watersheds meet the minimum requirements for sound agricultural development. The major characteristics of the eight watersheds are presented in Table 11. The areas occupied by each of these selected watersheds in the sub-Zobas are shown in Table 12.

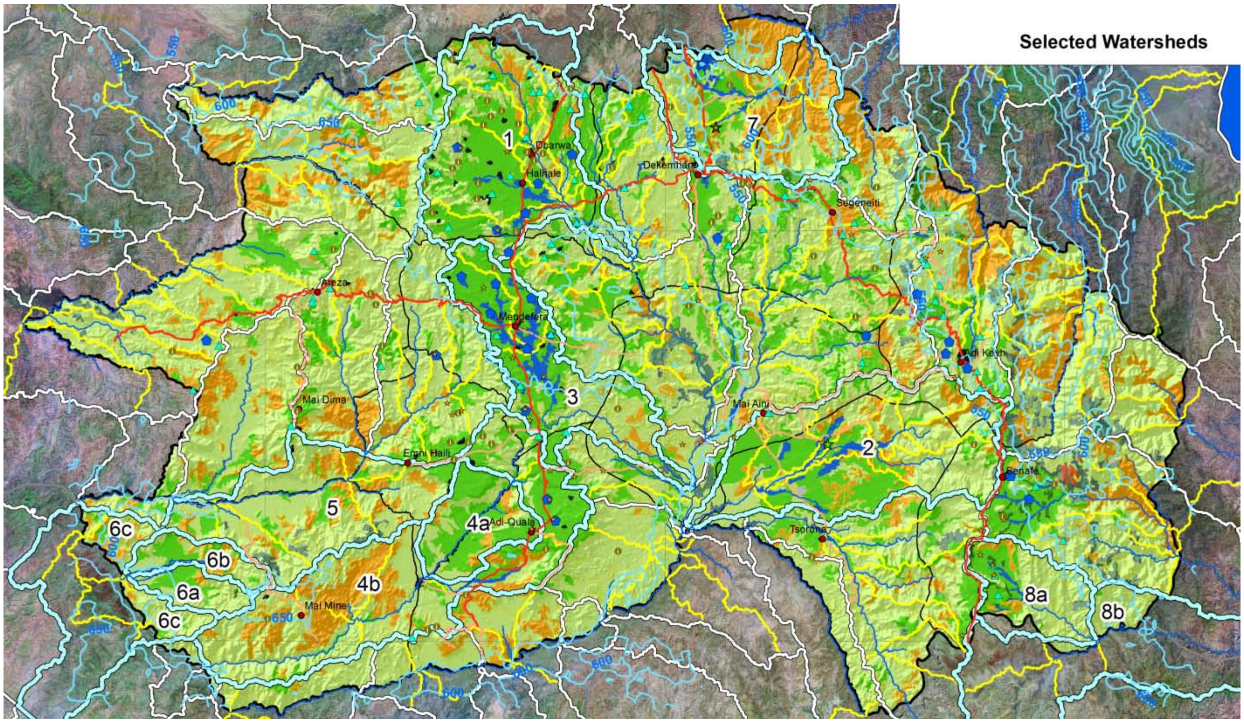



**Figure 14.** Potential watersheds for development in Zoba Debub.

As the development of all eight watersheds requires resources which are currently not available, and requires a long time, the additional criteria were used to further screen the watersheds and select two for immediate development as a pilot project. Those new criteria include (i) local and economic importance, (ii) political priority, (iii) size of agricultural communities, (iv) area, (v) accessibility, (vi) potential for agricultural development, (vii) cost of development, and (viii) availability of data. This selection process and criteria were discussed and agreed upon.

Table 11. Areas of potential watersheds for development in each sub-Zoba

| Priority | 7 | 1 | 3 | 2 | 5 | 4 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|
| | Watersheds | | | | | | | |
| SUBZOBA | 3333 | 3352 | 3391 | 3402 | 3403 | 3412 | 3423 | 3453 |
| Outside | 1,215 | 5,356 | | 10 | | 3 | 27,829 | 48,010 |
| Adi Keih | | | | 6,822 | | | | |
| Adi Kuala | | | 1,359 | | | 26,310 | | |
| Areza | | | | | 8,280 | | | |
| Dbarwa | | 47,653 | | | | | | |
| Dekemhare | 21,958 | 2,236 | | | | | | |
| Emni Haili | | | 9 | | 7,814 | 13,962 | | |
| Mai Aini | | | 8,684 | 7,764 | | | | |
| Mai Mne | | | | | 24,557 | 36,091 | 24,966 | |
| Mendefera | | 1,532 | 25,146 | | | 1,341 | | |
| Segeneiti | 15,482 | | | | | | | |
| Senafe | | | | 6,536 | | | | 21,742 |
| Tsorona | | | | 35,900 | | | | |
| Total Area | 38,654 | 56,777 | 35,198 | 57,032 | 40,651 | 77,707 | 52,795 | 69,751 |

The selection was discussed and endorsed by the people involved, including HE the Governor of Zoba Debub. Other watersheds have various levels of potential, which can be considered when more resources become available. The development to be initiated in the two watersheds can be out-scaled at a later stage to other areas in Zoba Debub, building on the experiences gained in the pilot watersheds.

Two watersheds were selected for this startup pilot project;
No 1. Tselema watershed in the northwest of Zoba Debub focusing on spate irrigation but include also some rainfed and rangeland development and,
No 2. Hazemo watershed in the southeast of the Zoba Debub focusing on rainfed systems development but include also some irrigation and rangelands development.

Table 12. Characteristics and major agro-ecosystems of potential watersheds in Zoba Debub

| Watershed No | Watershed Name | Total area (ha) | Rainfed area (ha)[5] | Irrigated area (ha)[5] | Range lands(ha)[5] | Major communities | Major crops | Available water structures | Priority rank |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Tselema | 50,691 | 29,467 | 697 | 20,527 | Tgigrigna | wheat, barley, teff, chickpea | 38 dams and 19 ponds | 1 |
| 2 | Hazemo | 56,353 | 18,881 | 2,192 | 35,281 | Tgigrigna Saho, Tigre | teff, maize, sorghum | One spate project , 3 dams and 14 ponds | 2 |
| 3 | Maitekela | 34,596 | 18,846 | 3,140 | 12,610 | Tgigrigna | wheat, barley, teff, chickpea | 13 dams and 7 ponds | 5 |
| 4 | Tsaedakelay | 77,291 | 24,157 | 743 | 52,391 | Tgigrigna | teff , sorghum, finger millet | 12 dams and 25 ponds | 3 |
| 5 | Oubel | 39,142 | 4,830 | 574 | 33,738 | Tgigrigna | sorghum, finger millet | 20 ponds | 4 |
| 6 | Megerba | 24,862 | 5,897 | 173 | 18,792 | Tgigrigna | sorghum, finger millet | 3 ponds | 7 |
| 7 | Alla | 36,335 | 4,315 | 1,719 | 30,300 | Tgigrigna Tgre | citrus trees, maize | One spate project, 4 dams and 20 ponds | 6 |
| 8 | Shemejana | 21,107 | 4,696 | 353 | 16,058 | Tgigrigna | wheat, barley | 3 dams and 8 ponds | 8 |

[5] Source: Eritrea Multi-purpose Land Cover Database (FAO/Africover, 2002)

### *3.2.3.1. Tselema watershed*

This watershed is approximately located within latitudes 14°55'N to 15°15'N and longitudes 38°40' E to 38°55' E with an area covering about 51,000 ha (Fig. 15).

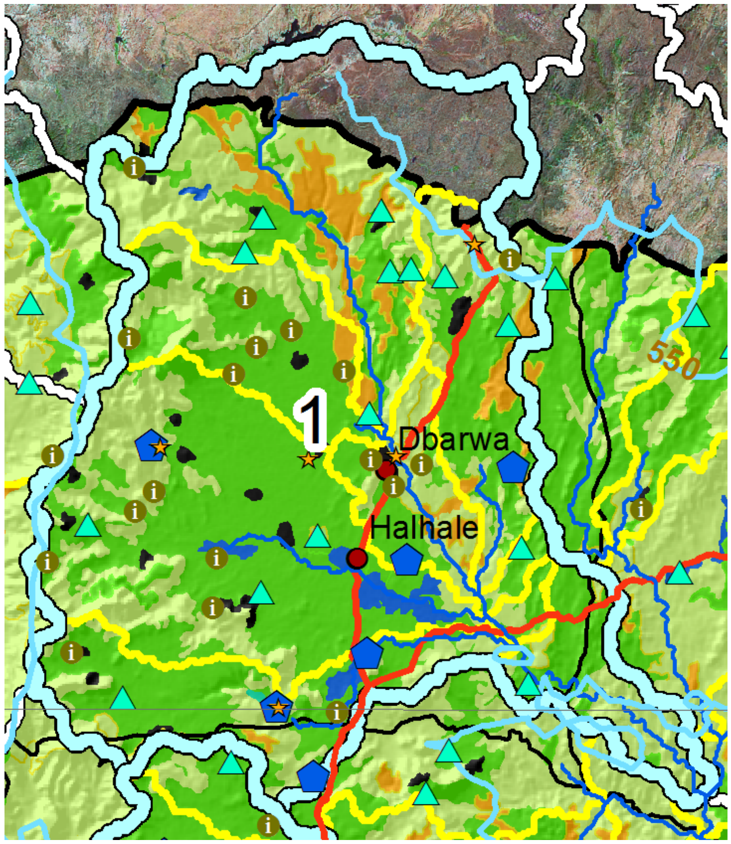



**Figure 15.** Watershed with priority 1 for development: Tselema
(colors: cyan for Tselema watershed; yellow for sub-watersheds; other colors related to land cover)

It has about 30,000 ha of rainfed cropping systems, 20,000 ha of rangelands and about 700 ha of irrigated agriculture. The main towns are Dbarwa and Halhale. Major agricultural land uses are rainfed cropping, including wheat, barley, teff and chickpea, and rangelands. Tselema watershed is a typical watershed for developing primarily rainfed agriculture. Current rainfed agriculture productivity is poor and way below it potential. Soil and water resources, if used efficiently, should make a significant contribution to farmers' income and to alleviating poverty. In view of the availability of good soils and adequate amounts of annual rainfall for a rainfed agriculture, farmers practice rainfed agriculture on a large scale. Constraints include strongly fluctuating rainfall amounts and suboptimal rainfall distribution, in addition to shallow soils and low soil water holding capacity causing dry spells and soil water stress. Due to poor soil fertility, lack of inputs and poor agronomic practices, yields are low. The potential for improvement in productivity is high, especially though improving water resources management, such as supplemental irrigation and introducing better crop varieties and fertilizers. Some water can be used for cash crops through irrigation. Management of the catchments can sustain rainfed areas and improve productivity.

### *3.2.3.2. Hazemo watershed*

This watershed is approximately located within latitudes 14°40’N to 14°50’N and longitudes 39°00’ E to 39°25’ E, in the southeast part of the Zoba (Fig. 16).

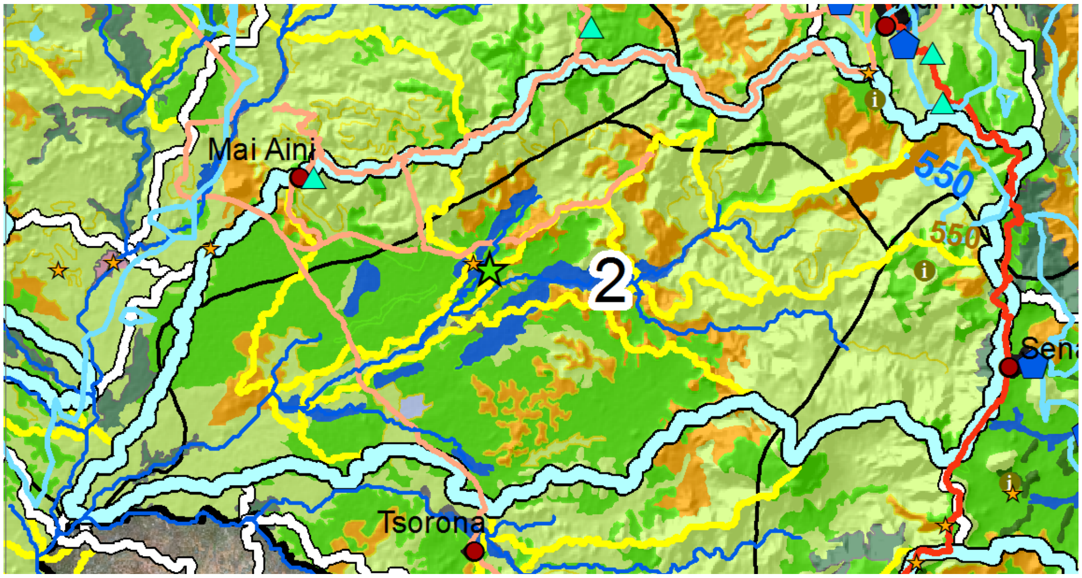



**Figure 16.** Watershed with priority 2 for development: Hazemo
(colors: cyan for Tselema watershed; yellow for sub-watersheds; other colors related to land cover)

The total area is about 56,000 ha, with irrigated areas of 2,000 ha, rainfed areas of 19,000 ha and rangelands of 35,000 ha. The main town is May Aini with several other smaller communities. Agricultural systems include spate irrigation, rainfed cropping and rangelands. Crops include sorghum, teff and maize. This watershed is strongly favored because it can demonstrate primarily development of agriculture based on spate irrigation, in addition to other forms. The watershed has great potential for water flow from mountainous areas to the plains, with suitable soil and landscape for spate irrigation development. There are few previous experiences of this form of irrigation in the watershed, which can be improved and expanded through this pilot project. The existing spate irrigation system is very inefficient and may not satisfy farmer’s needs, which include diversion and control structures, distribution and application systems. Spate irrigation has high potential in this watershed but requires appropriate design and conjunctive use with groundwater to alleviate drought impacts. Appropriate catchment management to secure flow to the spate systems and associated rainfed system is also essential in this Zoba.

## 3.2.4. Interventions

### *3.2.4.1. Tselema watershed*

This pilot watershed will be a benchmark model for development of rainfed systems in Zoba Debub and probably all of Eritrea. Development objectives are: improving rainfed production systems leading to higher farmers’ income and livelihoods enhancement in rural areas. The development should help converting part of subsistence agriculture to market-oriented systems. As rainfall is the major source of water for crops, its management and conjunctive use through supplemental irrigation, will provide a foundation for improving the system. Improved soil water status for crops will allow the use of more inputs such as fertilizers and better seeds, crop varieties and intensification in selected areas when additional water resources are available. This should result in sustainable higher crop yields, better crop-livestock integration and improved natural resources management. Achieving these development objectives will need, in addition to technical interventions, a better institutional setup and a network of inputs suppliers, market chains, extension workers and research support to ensure sustainability. Land tenure systems may need to be aligned with the development needs. Within the watershed there exist areas of rangelands and forests. Managing these areas may alter runoff water and erosion, which in turn may have a spill-over effect on rainfed systems. Improving rangelands and protecting the slope areas against erosion will improve the stability and sustainability of the rainfed systems. Other intensified agriculture, such as full irrigation for cash crops, may also be supported at small scale when water resources are available, especially from groundwater resources.

The main interventions for rainfed production systems in Tselema watershed may include:

a) *Soil management*: improved soil preparation may be encouraged by providing appropriate machinery. Conservation agriculture may be tested at small scale before expansion. Land grading and terracing may be adopted in steep areas.

b) *Crop Nutrition*: Fertility is key to improved yields. Access to currently deficient fertilizers may need to be ensured. However, only when water is available, more fertilizers can be beneficial. Supplemental irrigation can allow large amounts of fertilizers for higher yields.

c) *Crops varieties*: improved crop varieties together with fertility and moisture improvements are the three main contributors to improved rainfed yields. Improved varieties, however, need to be tested for local adaptation. This should also be associated with developing a functional seed system.

d) *Supplemental irrigation*: in suitable areas small earth dams should be built to store water for supplemental irrigation. There are many locations and potential storage areas for supplemental irrigation reservoirs. However, locations and capacity of water harvesting reservoirs need hydrological studies to decide. Also supplemental irrigation may be practiced using ground water when available. Full irrigation during the dry season can be adopted for cash crops, such as vegetables and fruit trees on limited areas.

e) *Check dams to control erosion*: erosion in rainfed areas is common and needs to be minimized. Check dams, contour ridges and other soil conservation measures are suitable for mild to steep slopes to control erosion and support groundwater recharge.

f) *A seed system* need to be developed to ensure improved and healthy seed production for the system.

g) *Rangelands* are important in the catchment part of the watershed and need to be included in the development. Mainly through protection, restoration with micro-catchment water harvesting and management of grazing and wood cutting.

#### ***3.2.4.2. Hazemo watershed***

The Hazemo watershed will be a benchmark model for the development of spate irrigation, initially in Zoba Debub and later for all of Eritrea. The development objectives are to primarily capture runoff water from the catchment in the plains in spate irrigation systems for improved and intensified cropping systems, that will result in improved farmers income and livelihoods of the rural communities. Substantial amounts of runoff flow downstream and mostly leave the watershed with little benefits. It is envisaged that most of the runoff remaining after satisfying the catchments environmental requirements is captured and applied to crops. The management of spate irrigation to overcome variable rainfall and drought is an important component of the development. Conjunctive use of available groundwater together with innovative design of spate structures and distribution systems and crops selection should help achieving the sustainability objectives.

The spate irrigation project should start with a relatively small size pilot (3,000-5,000 ha) that can be expanded to 10,000 ha in a second phase. The project will include diversion structures, water distribution network and controls, land leveling and levees formation. It may better be built on the old project in Hadadim. A detailed hydrological study should be conducted to determine current runoff and potential runoff expected after developing the catchment. Potential runoff is expected to be way above the requirements of the 1st phase (3,000-5,000 ha), so work on both may start in parallel.

The strategy for designing the spate irrigation project will have the following elements:

a) *Diversions:* multiple diversions providing water to small units of the system of about 500 ha each are recommended. Diversions along the stream should be designed to allow equitable amounts of water to all the units of the system. They should have enough control to modify schedules of water diversion as required.

b) *Basins*: basins should be level with an area not greater than one hectare. Levees should be compacted with height of 1.0-1.5 m.

c) *Distribution network*: overflow from one basin to the other should be minimized to a maximum of one basin. This requires that field canals with gates be constructed along all basins. Higher level canals should be designed up to the diversion.

d) *Management of water/area*: basins should get maximum depth of water in one storm to satisfy the full water holding capacity of the available soil depth. The following basins should be filled up after filling the first. This should ensure a good crop in irrigated areas. If water is adequate all the system will be satisfied. If water flow is not enough, then part of the system will get enough water and have good crop where the rest does not get any water. This is better than having all the areas with partial water which produces very low or no yields.

e) *Conjunctive use with groundwater*: As a strategy against drought, groundwater may be developed to overcome surface flow shortage or dry spells during the season.

f) *Cropping patterns*: priority may be given to strategic crops. Cash crops may be grown in limited areas using mainly groundwater.

### 3.2.5. Other design considerations

#### ***3.2.5.1. Institutional setup***

Most important is developing the local institutions to carry on the development. Community level institutions should be supported. Extension services need enhancement and may also be supported by the project. All activities require capacity building of it members as integrated component of the development. Training will include water harvesting, supplemental irrigation, soil conservation, agronomic practices and institutional setups. Finally, adaptive research program should be implemented to test new options and adapt practices and options to the conditions of the Zoba Debub. Research may be focused in the research stations but also at the community level and with farmers. Topics may include determining irrigation water needs, testing crops verities, deficit irrigation, soil conservation and testing new practices such as conservation agriculture.

#### *3.2.5.2. Research*

Adaptive research should go in parallel to the development of the two watersheds. Three types are recommended to be conducted at the research stations and in participatory mode on farmers fields:

- On-farm and station demonstrations and comparisons of proven technology, packages and options
- Testing and adaptation of technologies and options proven in similar areas but need verification and adaptation
- Development of new suitable options for local conditions

Areas of research on water and land management recommended are:

a) Crops water requirements, irrigation schedules, modern irrigation systems, water harvesting, supplemental irrigation, runoff-rainfall relations, watershed management

b) Agronomy/ soil: Characterization, soil-water-plants relations, tillage, crop varieties testing, fertility, erosion, agronomic practices

c) On farm demonstrations of: supplemental irrigation, water harvesting, fertility impacts, new varieties, deficit irrigation, conservation agriculture.

#### **3.2.5.3. Training**

The human capacity to implement the program needs substantial enhancement. This may be done at three levels:

- NARES who will supervise the development: participatory approaches, extension, agronomic practices, water harvesting, supplemental irrigation, spate irrigation, irrigation scheduling, conservation agriculture, data base development and use, research methods, analysis and reporting,
- Community leaders: institutional setups, communication, major technological packages,
- Farmers; specific technology use, modern irrigation systems use and management, improved soil management, conservation agriculture.

# 4. REFERENCES


E. De Pauw, T. Oweis, and J. Youssef. 2008. Integrating Expert Knowledge in GIS to Locate Biophysical Potential for Water Harvesting: Methodology and a Case Study for Syria. ICARDA, Aleppo, Syria. iv + 59 pp. ISBN: 92-9127-207-2

E. De Pauw and W. Wu. 2010. Climate change, drought and potential for water harvesting in the occupied Palestinian Territory. Technical Report, ICARDA, Syria.

FAO. 1998. The Soil and Terrain Database for northeastern Africa. Crop Production System Zones of the IGAD subregion. Land and water Digital Media Series 2, FAO, Rome (http://www.fao.org/catalog/book_review/giii/w7374-e.htm)

FAO. 2001. FAOCLIM, a CD-ROM with world-wide agroclimatic data, version 2. Environment and Natural Resources Service (SDRN) Working Paper No.5, Food and Agriculture Organization of the United Nations, Rome, Italy

FAO/ Africover. 2002. Eritrea Multi-purpose Land Cover Database.
(URL: http://www.africover.org/system/africover_data.php)

Ghebru, K.; Radcliffe, D.; Berhe, G.; Yosef, D. 1997. Agro-ecological zones map of Eritrea. Legend. Internal report, FAO, Harare (Zimbabwe). Subregional Office for Southern and East Africa.
(URL: http://www4.fao.org/cgi-bin/faobib.exe?rec_id=581708&database=faobib&search_type=link&table=mona&back_path=/faobib/mona&lang=eng&format_name=EFMON)

Hutchinson, M.F. 1995. Interpolating mean rainfall using thin plate smoothing splines. Int. J. Geogr. Info. Systems 9: 385-403.

Hutchinson, M.F. 2000. ANUSPLIN version 4.1. User Guide. Center for Resource and Environmental Studies, Australian National University, Canberra.
On-line document: http://cres.anu.edu.au

Oweis, T., D. Prinz, and A. Hachum. 2001. Water harvesting: indigenous knowledge for the future of the drier environments. ICARDA, Aleppo, Syria. 40 pp. ISBN 92-9127-116-0

Oweis, T. 2004. Rainwater harvesting for alleviating water scarcity in the drier environments of West Asia and North Africa. Paper presented at the International Workshop on Water Harvesting and Sustainable Agriculture, September 7th, 2004, Moscow, Russia.

U.S. Dept. of Agric. (Soil Con. Service). 1969. Engineering field manual for conservation practices.

**Annex 1.**

**INSTITUTIONAL CONTRACT**

CONTRACT dated as of 5th April 2010 [date], between the International Fund for Agricultural Development, a Specialized Agency of the United Nations established under an Agreement adopted by the United Nations Conference in Rome on 13 June 1976, with its headquarters in Rome, Italy ("IFAD"), and the International Center for Agricultural Research in the Dry Areas, a not-for-profit organization subject to the laws of the Syrian Arab Republic, with registered offices located at Aleppo-Damascus Highway, Tel Hadya, P.O. Box 5466, Aleppo, Syrian Arab Republic ("Contractor").

RECITALS:

WHEREAS, IFAD has determined that it is in its best interests to appoint a provider of Services for the provision of a pilot GIS/watershed development study to identify potential for water harvesting, spate irrigation and soil-water conservation interventions in Debub Zoba, Eritrea; and

WHEREAS, IFAD wishes to appoint the Contractor, and the Contractor wishes to act, as Contractor for IFAD for purposes of providing the Services as defined hereunder, all on the terms and conditions specified herein and in the attachments hereto (each such attachment, as the same may from time to time be amended, an "Attachment"), each Attachment being hereby incorporated into this Contract.

NOW, THEREFORE, IFAD and the Contractor hereby agree as follows:

1. Definitions and Interpretation/ List of Attachments and Exhibits

1.01 In this Contract and the Recitals, the following words and expressions shall have the following meanings:

> "Contract" means: this Contract and any and all Attachments and Exhibits hereto, as amended from time to time, together constituting the entire Contract between the parties;
>
> "Contractor Authorized Persons" means: those persons listed in Section 10 responsible for day-to-day operations;
>
> "IFAD Authorized Persons" means: those persons listed in Section 10 responsible for day-to day operations;
>
> "General Terms and Conditions" means the general terms and conditions of IFAD for the procurement of services attached hereto as Attachment III;
>
> "Services" means: those services listed and described in Attachment I; and

"Signatories" means: those persons listed in Section 10 having the power to sign this Contract and any amendments hereto or thereto.

1.02 Following is a list of Attachments and Exhibits to this Contract:

| | |
|---|---|
| Attachment I | Terms of Reference |
| Attachment II | Payment Schedule |
| Attachment III | IFAD's General Terms and Conditions |
| Exhibit 1 | Vendor Profile Form |

1.03 In the event of a conflict in terms, the following shall be the order of priority for purposes of application and interpretation: First - the terms and conditions contained in the Contract; Second – Attachments I and II; and Third – Attachment III.

2. Appointment

2.01 IFAD hereby appoints the Contractor, and the Contractor agrees to act, as Contractor for purposes of providing the Services to IFAD.

2.02 In connection with the foregoing, the Contractor shall provide such Services and shall act in accordance with the terms and conditions set forth herein and in the Attachments hereto. Without limiting the foregoing, the parties hereto acknowledge that the Attachments hereto set forth certain additional requirements applicable to the performance by the Contractor of its duties hereunder and that such Attachments, as amended from time to time by written Contract between IFAD and the Contractor, shall be deemed incorporated into this Contract.

3. Instructions

3.01 Further to Article 4 of the General Terms and Conditions and subject to Section 3.02 below, the Contractor shall accept and act upon all instructions properly relating to the Services which are given to the Contractor or which the Contractor reasonably believes in good faith to have been given to the Contractor by any IFAD Authorized Person.

3.02 Instructions may be given to the Contractor by telephone, letter, fax, or other electronic or electro-mechanical means the Contractor deems acceptable. Provided, however, any instructions given to the Contractor by telephone shall promptly thereafter be confirmed in writing. IFAD and Contractor agree that Contractor may only act upon written instructions signed by an IFAD Authorized Person or Signatory of IFAD.

4. SubContractors and Employees

4.01 Further to Article 13 of the General Terms and Conditions, the following shall apply in relation to the appointment of any SubContractor:

(a) any SubContractor shall be the agent of the Contractor and not the agent of IFAD; and

(b) the Contractor shall use its reasonable endeavours to procure that officers of or auditors employed by, or other representatives of, the Contractor and the independent public accountants for IFAD, shall be given access to the books and records of such SubContractor insofar as they relate to its actions under its Contract with the Contractor.

4.02 The Contractor shall review the performance and status of any SubContractor appointed, retained or employed by it pursuant to this Contract, including Attachment III, on a continuous basis. Such selection, monitoring and review to include, without limitation, consideration of the creditworthiness, credibility and reputation of any such SubContractor.

4.03 Nothing contained in this Section 4 shall be deemed to limit Contractor's liability vis-à-vis IFAD and Contractor shall at all times remain liable to IFAD under this Contract.

5. Insurance

5.01 See the provisions of Article 19 of the General Terms and Conditions, attached hereto as Attachment III.

6. Records and Reports/Right to Audit

6.01 The Contractor will supply such information relating to the Services in its possession as IFAD may from time to time reasonably require and in any event as set out in the description of Services attached hereto as Attachment I.

6.02 During the Contract period and any renewal term, the Contractor shall annually provide IFAD with:

(a) a statement that its civil liability insurance is still in force as represented herein or has been renewed in accordance with the requirements of this Contract, including Attachment III

(b) notice of any material change of personnel or status of the company; and

(c) reconfirmation of each and every representation and warranty contained in Section 7, below.

6.03 The Contractor agrees that IFAD's employees and auditors (whether internal or external), shall be allowed reasonable access during normal business hours to examine all or any records which the Contractor may hold relating directly to IFAD or the Services provided under this Contract, provided that the Contractor may restrict access to the extent that it may prejudice any duty of confidentiality the Contractor may owe to its other clients.

7. Representations and Warranties of the Contractor

7.01 The Contractor represents, warrants and covenants to IFAD that:

(a) it is non-commercial and or not-for-profit organization established under the laws of

the Syrian Arab Republic;

(b) it is qualified to act as the Contractor of IFAD, and in such capacity, to perform the functions undertaken by it pursuant to this Contract;

(c) it will at all times perform such functions in a manner consistent with the standards applicable to professional Contractors (provided always that where the Contractor delegates any of its duties to a SubContractor pursuant to this Contract, such SubContractor in performing such duties shall act in accordance with the standard of care applicable to a professional Contractor for hire in the jurisdiction where such duties are performed);

(d) it has no outstanding legal judgements or past judgments, nor is it aware of any possible claims which would materially adversely affect or hamper or impede it in the carrying out any of its obligations under this Contract;

(e) to the extent permitted by law, it shall notify IFAD of any judgments or claims which may arise during the terms of this Contract, or any renewal term, and which may have a material adverse effect on it or materially hamper it or impede it in the carrying out of any of its obligations under this Contract;

(f) no plan of reorganisation or merger affecting the Contractor currently exists;

(g) its staff is now, and during the term of this Contract will continue to be, sufficient in size, with the requisite training, experience and other qualifications necessary to perform the Services;

(h) unless expressly prohibited under the disclosure provisions of any applicable law, it shall promptly notify IFAD in the event that it becomes subject to any plan of reorganisation or merger during the term of this Contract and/or any renewal term;

(i) this Contract has been duly authorised, executed and delivered by the Contractor and constitutes the Contractor’s legal, valid and binding obligation;

(j) no employee or officer of IFAD, either directly or indirectly, has received any direct or indirect benefit from the Contractor or any agent, SubContractor or employee of the Contractor or in the execution of this Contract;

(k) each and every representation and warranty is a present and continuing obligation of the Contractor and the Contractor shall annually reconfirm to IFAD each and every representation and warranty in writing; and

(l) the persons whose signatures appear below for and on behalf of the Contractor are duly qualified and acting officers of the Contractor with full power and authority to execute this Contract on behalf of the Contractor and to take such other actions and execute such other documents as may be necessary to effectuate this Contract.

7.02 Contractor further represents that any information, data, and materials (in whatever form or media) provided to IFAD under this Contract does not infringe the privacy rights of any third party.

7.03 Contractor further represents and warrants that it has the requisite insurance coverage set out in Article 19 of the IFAD's General Terms and Conditions.

8. Representations of IFAD

8.01 IFAD represents that:

(a) this Contract has been duly authorised, executed and delivered by IFAD and constitutes IFAD's legal, valid and binding obligation;

(b) the persons whose signatures appear below for and on behalf of IFAD are duly qualified and acting officers of IFAD with full power and authority to execute this Contract on behalf of IFAD and to take such other actions and execute such other documents as may be necessary to effectuate this Contract; and

(c) IFAD shall provide Contractor with all necessary documentation and access to such of its personnel, offices and databases as Contractor and IFAD shall agree may be required in order for Contractor to perform the Services.

9. Payments

9.01 Notwithstanding any provisions to the contrary contained in the General Terms and Conditions, payments hereunder shall be made in the currency specified in Attachment II (either United States Dollars (USD) or Euros (EUR)), as determined by the Parties.

9.02 Notwithstanding the foregoing, IFAD shall have no obligation to pay the Contractor unless the Contractor has provided IFAD with a completed Vendor Profile form, a copy of which is annexed hereto as Exhibit I.

10. Communications and Notices

10.01 Subject to Section 13 below, any instruction or request required or permitted to be given or made in connection with this Contract or its operation shall be in writing by the Authorised Person or Signatory of the sending party referred to in Sections 3.01 and 3.02 of this Contract or by an electronic courier or facsimile transmission (with confirmation of receipt). Such instruction shall be deemed to be duly given or made when it shall have been delivered by hand, cable, facsimile transmission or electronic transfer to the party to which it is required to be given or made at such party's address specified below or at such party's other address as the party shall have specified in writing to the party giving such notice or making such request.

<u>If sent to IFAD</u>*:

for mail INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT (IFAD)

Via Paolo di Dono 44

00142 Rome

Italy

Attention : ____________________________ [IFAD contact, to be decided]

Authorized Person: _________________________ [IFAD Division Director]

Facsimile: +39 065043 463

Signatory: _________________________ [IFAD signatory]

Facsimile: +39 065043 463

<u>If sent to the Contractor:</u>

for mail International Center for Agricultural Research in the Dry Areas

P.O. Box 5466

Aleppo, Syrian Arab Republic

Attention: Dr. Theib Oweis Director, Integrated Water and Land Management (IWLM) Program

Tel: (963) 21 221 3433 / 2225012 / 2225112

* If services payable are USD 50,000 equivalent or less, the Director/Head of Unit is authorized to sign. For services over USD 50,000 equivalent, only the Department Head (Assistant President of the Director's/Head of Unit's division) may sign. Amendments to this Contract or additional contracts with the same Contractor which increase the amount payable to that Contractor to an amount in excess of USD 50,000 or equivalent, in any 12 month period, must be signed by the relevant Department Head.

| | |
|---|---|
| Email: | t.oweis@cgiar.org |
| Authorized Person: | Dr. Mahmoud Solh, Director,General |
| Facsimile: | (963) 21 221 3490 |
| Signatory: | Dr. Mahmoud Solh, Director General] |
| Facsimile: | (963) 21 221 3490 |

11. Term of the Contract/Renewal

11.01 This Contract shall be effective from the date of signature hereof and shall remain in effect for one year. Thereafter, this Contract is subject to renewal by Contract of the Parties. This Contract, or any Service under this Contract, may be terminated by IFAD without cause at any time by giving written notice to the Contractor.

11.02 In the event of termination, other than for breach of this Contract, IFAD will pay the fees of the Contractor to the date of termination, in accordance with the provisions of Attachment III.

12. Miscellaneous

12.01 This Contract together with the Attachments hereto, constitutes the entire Contract between the parties, and any prior understandings or representations, whether oral or written are hereby suspended.

12.02 If any provision or part of any provision of this Contract shall be found or declared to be void or unenforceable, it shall not affect any remaining part of the Contract which shall continue in full force and effect to the extent permitted by law.

12.03 Subject to the applicable provisions of Section 4 of this Contract, the Contractor shall not assign or subcontract all or any portion of its rights or obligations hereunder.

12.04 Nothing in this Contract shall be deemed as a waiver of or otherwise affect the privileges and immunities of IFAD under the Convention on the Privileges and Immunities of the Specialized Agencies of the United Nations (1947), the Agreement Establishing the International Fund for Agricultural Development, any other international treaty or convention, or under international customary law.

13. Amendment and Modification

13.01 Notwithstanding the provisions of Sections 3 and 10 above, any amendment of or modification to this Contract shall only be valid if in writing and signed by the Signatories of both parties. Any unilateral amendment by IFAD shall be effective upon acknowledgement of the Contractor of its receipt thereof or, failing such acknowledgement by the Contractor, on the fifth ($5^{th}$) business day after mailing or faxing of the same by IFAD.

14. <u>General Terms and Conditions</u>

14.01 The Contractor and IFAD acknowledge that the General Terms and Conditions, annexed hereto as Attachment III, are terms upon which IFAD contracts generally with all of its third party contractors, and further agree that:

(a) the General Terms and Conditions are ancillary to and shall in no way supplant, amend or vary the terms of this Contract or each party's responsibilities, duties, rights or liabilities hereunder;

(b) both parties shall observe the provisions of the General Terms and Conditions to the extent that they are not inconsistent with, nor amend or vary each party's obligations under this Contract;

(c) in the event of any inconsistency between the provisions of the General Terms and Conditions and the provisions of this Contract, the provisions of this Contract shall prevail; and

(d) for the purposes of this Section 14 only, the expression "this Contract" shall mean this Contract entered into between IFAD and the Contractor, but excluding the General Terms and Conditions.

IN WITNESS WHEREOF, the Parties hereto, acting through their duly authorized representatives, have caused this Contract to be signed and executed as of the day and year first above written.

| | |
|---|---|
| INTERNATIONAL CENTER FOR AGRICULTURAL RESEARCH IN THE DRY AREAS | INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT |
| ________________________________ | ________________________________ |
| DR. Mahmoud Solh | [name] |
| Director General | [title] |

**ATTACHMENT I. TERMS OF REFERENCE**

## 1. Background

This Attachment is an integral part of the Contract entered into between IFAD and the Contractor and sets out a detailed description of the Services to be provided hereunder and the levels at which the Services are to be provided. This Attachment is intended to reflect the Services of the Contractor under normal conditions and circumstances and not to be an absolute commitment with respect to Services in the context of extraordinary conditions or circumstances. This Attachment is not intended to replace or amend in any way the Contract and in the event there is conflict between this description of Services and the Contract, the provisions of the Contract shall prevail.

## 2. Description of Services Provided

Drought is a recurrent phenomenon in Eritrea. Due to a variety of reasons, related to poor infrastructure, poor agricultural practices and governance issues, drought in Eritrea causes immediately food shortages. Inadequacies in the country's ability to respond to or mitigate the failure of rains may even lead to famine.

Water harvesting/soil-water conservation are among the possible strategies for coping with drought, while also offering in the longer-term prospects for increasing land and water productivity for resource-poor farmers. Whether water harvesting is a feasible option depends on many factors, biophysical as well as socioeconomic. The fact remains that not everywhere there will be physical potential, but also that where there is some degree of potential; some techniques will be more suited than others to make use of that potential. A spatial analysis of suitability for various water harvesting techniques could therefore be useful for development agencies.

The International Fund for Agricultural Development (IFAD) has expressed interest in collaborating with ICARDA to start a pilot GIS/watershed development study, aiming at identifying potential for water harvesting, spate irrigation and soil-water conservation interventions in Debub Zoba (Province). This document identifies objective, general methodology, deliverables, implementation and requested budget.

Against this background, IFAD is contracting the services of ICARDA to provide the following services:

**GIS component**

- 1-month mission to Debub Zoba by ICARDA-appointed GIS consultant (end March 2010) followed by 2 months of data analysis and mapping at ICARDA. The consultant will work 2 weeks at ICARDA with the staff of the GIS Unit to transfer all information obtained from the field into layers ready for modeling suitability.

- 1 week mission at the end of the project by the head of the GIS Unit to Debub Zoba to present the report and maps and provide further training on methodology used and application in other Zobas.

**Watershed management component**

- ICARDA expert makes one week visit to the sites, in association with the GIS component above to outline the work plan and potential major development
- A consultant visit the site for one month to assess appropriate interventions and locations
- Both ICARDA expert and the consultant develop and submit a report and maps for potential design of a development project.

The expected output of the above services would include the following:

a) Watersheds and areas identified within each watershed in Debub Zoba, where water harvesting/soil-water conservation and spate irrigation are likely to lead to substantial water and land productivity increases, and to identify the water harvesting techniques that could make best use of any potential.
b) One major and most relevant watershed in Duba Zoba selected, where specific interventions identified and formulated in an integrated watershed framework for project design and development.

## 4. Deliverables

**GIS component**

a) Maps of suitability for the evaluated interventions, in two A3-size glossy paper prints per map and in PDF format
b) GIS layers in ESRI shape file and raster formats
c) A report with detailed methodology and summary of results

  - Start the study in April, 4, 2010
  - Submission of report and maps in early July 2010

**Watershed management component**

a) A report on the recommended interventions and the extent to its implementation in a pilot watershed and associated criteria.
b) Maps including location and extent of project elements within the pilot watershed.

  - One week visit to the site by ICARDA expert in May 2010 (date depends on GIS maps developed)
  - Consultant mission for one month in May-June 2010-03-24
    - Reports finalization and submission end of July 2010

## 5. Responsiveness

Timely responses to inquiries from IFAD are a part of the Contractor’s standard client service. IFAD will be kept informed on an ongoing basis of any significant developments that occur at the Contractor, which may affect the provision of Services.

Contractor’s staff will respond to all enquiries within 24 hours through the use of the most appropriate communication channel as agreed between the Contractor and IFAD. If further investigation is required, the Contractor will promptly notify IFAD that further action is required with periodic updates on the status of the enquiry.

**ATTACHMENT II. PAYMENT SCHEDULE**

Fees USD 51,000.00 (Fifty one thousand United States Dollars)

| **Deliverable**[6] | **Percentage of Fee** * |
|---|---|
| **Signature of Contract** | **30 %** |
| **Second tranche** | **50 %** |
| **Final payment** | **20 %** |

Fees shall be invoiced according to the Deliverable Timetable agreed between the Parties and set out in Attachment I, hereto.

IFAD shall process and pay over to Contractor according to its banking instructions included in the Vendor's Profile attached hereto as Exhibit 1, amounts properly invoiced for Deliverables provided in respect of this Contract and specifically in accordance with the schedule set out in Attachment II, provided, however, that the Initiating Officer has given his/her prior clearance. For purposes of this Contract, the Initiating Officer shall clear Deliverables when, in his/her sole opinion, such Deliverables conform to the terms and conditions of this Contract. Notwithstanding the generality of the foregoing, the final payment of the fees, as set forth in paragraph 1, above, shall be paid upon the successful completion of the Services, as shall be determined in IFAD's sole discretion

Contractor shall attach original receipts, when invoicing. In the event it is not possible to provide original receipts, for any reason, Contractor may furnish copies; provided, however, that the copies are stamped, certified and signed (i.e., firm stamp as well as signature by an Authorized Person of the Contractor). IFAD shall have no obligation to pay any amounts for which Contractor has not provided originals or conformed copies of receipts.

[6] This list may be shortened or expanded depending on the number of Deliverables as per Attachment I.

**Note to Initiating Officer: Upon Signature hereof, no more than 30% of the value of the contract may be paid to Contractor. In any event, an amount equal to 20% of the total fees shall be retained by IFAD pending successful completion of the Services. Successful completion of the Services shall be determined in IFAD's sole discretion.*

**ATTACHMENT III. GENERAL TERMS AND CONDITIONS**

## GENERAL TERMS AND CONDITIONS FOR THE PROCUREMENT OF SERVICES

**INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT (IFAD)**

The contract or purchase order shall be governed by the following General Terms and Conditions for the Procurement of Services, together with the incorporated attachments or annexes if any. Any departure from these General Terms and Conditions shall only be valid if mutually agreed between the Parties in writing.

**DEFINITIONS**

In these General Terms and Conditions for the Procurement of Services (hereinafter referred to as "General Terms and Conditions") the following definitions shall apply for the interpretation of contracts and purchase orders:

"IFAD or "Organisation" means the International Fund for Agricultural Development, represented by the President or his duly authorised representative.

"Contractor" means the supplier of services named in the contract or purchase order, represented by an official duly authorised to undertake contractual obligations on behalf of the supplier.

"Contract" means the contract relating to the procurement of services between IFAD and the Contractor and includes these General Terms and Conditions.

"Parties" means the Contractor and IFAD collectively, and "Party" means either one of them.

"Purchase Order" (hereinafter referred to as "contract") means a contract in a standard format relating to the procurement of goods or services between IFAD and the Contractor and includes these General Terms and Conditions.

"Services" means any service provided, or to be provided, to IFAD by the Contractor (or any of the Contractor's sub-contractors) pursuant to or in connection with the contract.

**1. STATEMENT OF PRINCIPLE AND ENTRY INTO FORCE OF CONTRACTS**

IFAD declares that it is entering into this contract in pursuit of its public and institutional claims.

A contract shall enter into force on the day after both Parties have signed it. The contract shall be drawn up in English as the only authentic language, each Party receiving one original.

## 2. LEGAL STATUS

The Contractor shall be considered as having the legal status of an independent Contractor. The Contractor's personnel and sub-contractors shall not be considered in any respect as being employees or agents of IFAD.

## 4. SOURCE OF INSTRUCTIONS

The Contractor shall neither seek nor accept instructions from any authority external to IFAD in connection with the performance of its services under this Contract. The Contractor shall refrain from any action which may adversely affect IFAD and shall fulfil its commitments with the fullest regard to the interests of IFAD.

## 5. CONTRACTOR'S RESPONSIBILITY FOR EMPLOYEES

The Contractor shall be responsible for the professional and technical competence of its employees and will select, for work under the contract, reliable individuals who will perform effectively in the implementation of this contract, respect the local customs, and conform to a high standard of moral and ethical conduct.

## 6. DELIVERY

The Contractor shall deliver the services at the place of delivery specified in the contract, and within the delivery period stipulated in the contract.

## 7. PAYMENT

Unless expressly stipulated otherwise in the contract, IFAD shall make payment usually by means of a bank remittance:

(a) Within 30 days of receiving the invoice and any other documents specified in the contract or within 30 days of the date on which performance of the contract was satisfactorily completed, whichever is later.

(b) The price of the services shall be as stated in the contract and may not be increased, except by the express and written Contract of IFAD.

(c) IFAD shall not pay any charge for late payment unless this has been expressly agreed to in writing.

(d) Payment shall not be made for services that have not been accepted in Terms of Article 22 of these General Terms and Conditions. Payment by IFAD shall not be deemed to be acceptance of services.

(e) Payment shall be made in EUROs unless otherwise stipulated in the contract.

(f) Advance payment shall only be made if expressly authorised by IFAD in the contract and only where normal commercial practice or the interests of IFAD require so.

## 8. PRIVILEGES AND IMMUNITIES

Nothing contained in the contract shall be deemed a waiver, express or implied, of any privilege or immunity that IFAD, an Specialized Agency of the United Nations, may enjoy pursuant to: (i) the Agreement Between IFAD and the Italian Republic Regarding the Provisional Headquarters of IFAD ("Headquarters Agreement"); or (ii) any other Agreement to which IFAD is Party. In addition, nothing contained in the contract or related thereto shall confer any privilege or immunity on the Contractor, nor on its employees or its sub-contractors.

## 9. TAX EXEMPTION

Section 9 of the Convention on the Privileges and Immunities of the Specialized Agencies of the United Nations (1947) provides, inter alia, that the specialised agencies such as IFAD are exempt from all direct taxes, custom duties and any other taxes or levies. In addition to the Privileges and Immunities Convention, the Headquarter Agreement between Italy and IFAD as ratified on May 23, 1980 also exempts IFAD from the payment of taxes. The Contractor's price shall reflect any duty or tax to which IFAD is entitled by reason of the privileges that it enjoys. If it is subsequently determined that any taxes and duties from which IFAD is exempted have been included in the price paid by IFAD, the amount of such taxes and duties shall be refunded by the Contractor. Alternatively, IFAD may deduct such amount from the contract price and payment of such corrected amount shall constitute full payment by IFAD.

## 10. LIABILITY OF THE CONTRACTING PARTIES AND FORCE MAJEURE

(a) IFAD shall not under any circumstances or for any reason whatsoever be held liable for loss, damage or injury sustained by the Contractor or by any person acting on behalf of the Contractor during the performance of the contract. IFAD shall not accept any claim for compensation in respect of any such damage. The Contractor shall insure against all risks or loss, damage or injury caused by the Contractor or by any person acting on behalf of the Contractor during the performance of the contract. The Contractor and any person acting on behalf of the Contractor shall, during the performance of the contract, comply with these General Terms and Conditions.

(b) Except in the case of force majeure, the Contractor shall be required to indemnify IFAD for any loss, damage or injury that it may sustain from any act performed by the Contractor.

(c) The term force majeure, as used here, shall include, unforeseen events not within the control of either Party, such as laws or regulations, strikes, lock-outs or either industrial disturbances, acts of terrorism, wars, whether declared or not declared, blockades, embargoes, insurrections, riots, civil disturbances, explosions, epidemics, landslides, earthquakes, storms, lightning, floods and washouts. Any other event could be recognised as force majeure in arbitration proceedings instituted in relation to a dispute as mentioned in Article 28 of these General Terms and Conditions.

(d) If either Party considers that force majeure affecting the performance of its obligations has occurred, it shall promptly notify the other Party, giving full particulars in writing, including its probable duration and its effect on the Party's ability to perform. However, once the condition of force majeure has been agreed by the Parties, the Parties shall be relieved of liability for non-performance of their obligations until it ends.

(e) The Contractor shall not be entitled to payment if it is prevented by force majeure from performing the tasks assigned to it. Part performance of any task shall result in pro-rata payment.

**11. TERMINATION OF CONTRACT**

(a) If the Contractor ceases to practise his profession or carry out his business wholly or for a large part; does not comply with any conditions of the contract; applies for moratorium or applies to be declared insolvent; is granted a moratorium or declared insolvent; is declared bankrupt; offers a settlement in lieu of bankruptcy or if the property of the Contractor is attached; or if the Contractor is not a natural person and loses its status as a legal person, is wound up or in actual fact is liquidated, IFAD had the right to give notice of termination of contract immediately without notice of default. The Contractor shall immediately inform IFAD of the occurrence of any of the above events.

(b) Should IFAD's Headquarters be moved from Rome, the contract shall be cancelled without indemnities or compensation to the Contractor as a result of IFAD's diplomatic privileges provided that notice is sent to the Contractor by registered mail at least three months in advance of such termination.

(c) If any of the circumstances in paragraph (a) of this Article should arise, the Contractor shall be in breach of this contract as a consequence.

(d) The Contractor shall be bound to compensate IFAD for all damage, costs and loss of interest as a result of a situation as mentioned in paragraph (a) of this Article as a result of premature terminations on the contract, even in the event that a moratorium is granted or the Contractor is declared insolvent. This damage shall include in any case all amounts due until the original agreed date of termination of the contract, as well as all costs incurred by IFAD in legal and non-legal proceedings, including those for legal assistance with regard to any circumstances as referred to in paragraph (a) of this Article.

(e) The conditions in paragraphs (a), (b), (c) and (d) of this Article do not exclude the right of IFAD to exercise other legal rights, including its right to impose liquidated damages, demand payment or compensation for damages or for cancellation of the contract.

(f) IFAD, at its own discretion, is legally and without intervention by the courts entitled to carry out itself or to have carried out any contractual obligation for which the Contractor is in default, at the expense and risk of the Contractor.

(g) Each contracting Party may, of its own volition and without being required to pay compensation, terminate the contract by serving formal written notice to the other Party of thirty days in advance, unless the contract provides otherwise. Upon receipt of notice of termination by IFAD, the Contractor shall take immediate steps to bring the work or service to a close in a prompt and orderly manner. The Contractor shall reduce expenses to a minimum and shall not undertake any further commitments under the contract from the date of receipt of such a notice. If the contract is terminated by IFAD, the Contractor shall be entitled to pro-rata payment for any tasks performed prior to such termination. Additional costs incurred by IFAD, resulting either form termination by the Contractor or from the Contractor's failure to complete satisfactory performance, may be withheld from any amount otherwise due to the Contractor from IFAD under this or any other contract. The initiation of arbitral proceedings in accordance with Article 28 below shall not be deemed a termination of contract.

(h) In case of a breach of this contract by the Contractor, included but not limited to failure or refusal deliver the services within the time limit specified, IFAD may procure the services from other sources and may hold the Contractor liable for any excess cost occasioned thereby. Furthermore, IFAD may, by written notice, terminate the right of the Contractor to proceed with performance of the contract or such part or parts thereof as to which there has been a default.

**12. LIQUIDATED DAMAGES**

Without prejudice to the provisions on force majeure in these General Terms and Conditions, if the Contractor fails to provide any or all of the services fully in accordance with the terms and conditions of the contract including the time period specified, IFAD may, by notice given in writing, terminate the performance of such parts or part thereof as to which there has been default without incurring liability or termination charges of any kind. IFAD may at its discretion, accept deviations from the deadline specified in the contract, without prejudice to any other rights and remedies, and deduct from the price stipulated in the contract, as liquidated damages, a sum equivalent to 1% per day of the contractual price of the delayed services for each day of delay up to a maximum 15 days. In the event that this deadline is not respected, IFAD has an option to cancel the contract without incurring any liability for termination charges or any other liability of any kind.

**13. SUB-CONTRACTING, THIRD PARTIES**

(a) The contractor shall not, without the prior and express written approval or IFAD, assign, transfer, pledge or make other disposition of this contract or any part thereof, or any of the Contractor's rights or obligations arising out of the contract to third parties or sub-contract any part of the work required under this contract to third parties.

(b) In the event where IFAD authorises the Contractor to sub-contract part or all of the obligations under the contract to third parties, the Contractor shall nonetheless remain bound by its obligations to IFAD under the contract.

(c) Except where IFAD expressly authorises an exception, the Contractor shall be required to include in any sub-contract provisions enabling IFAD to enjoy the same rights and guarantees in relation to sub-contractors as it enjoys in relation to the Contractor.

(d) The terms of any sub-contract shall nonetheless be subject to the provisions of this contract.

**14. NON-WAIVER OF RIGHTS**

Failure of, or delay by IFAD in the exercise of any rights or remedies provided by the contract shall not be deemed a waiver of any rights of IFAD, and shall not release the Contractor from fulfilling its obligations.

**15. CONFIDENTIALITY**

(a) The Contractor, or its employees, shall not use any information acquired or developed in the course of this contract for any purpose not authorised in writing by IFAD.

(b) The Contractor is required to exercise the utmost discretion during the performance of the contract. The Contractor may not communicate to any other person, government or authority external to IFAD any information known to it by reason of its contractual relationship with IFAD which has not previously been make public, except with the written authorisation of IFAD. Nor shall the Contractor at any time use such information to private advantage.

(c) The Contractor shall be liable for any breach of confidentiality or any indirect disclosure that could vitiate the interests of IFAD. The extent of any such liability shall be directly proportional to the extent of the damage caused.

(d) All maps, drawings, photographs, mosaics, plans, reports, recommendations, estimates, documents and all other data compiled by or received by the Contractor under this contract shall be the property of IFAD, shall be treated as confidential and shall be delivered only to IFAD authorised officials in completion of work under this contract.

(e) The obligations under this Article do not lapse upon cessation of the contract

**16. WARRANTY**

The Contractor warrants that the services are:

(a) of the quality, quantity and description required by the contract;

(b) free from any right or claim of a third party, including rights or claims based on copyright, patent or other industrial or intellectual property rights;

**17. BANK GUARANTEE**

If IFAD so requests in the contract, the Contractor shall guarantee the due fulfilment of its obligations under the contract by providing an unconditional and irrevocable bank guarantee from an established bank of good standing for the amount determined in the contract.

### 18. INDEMNITY

The Contractor shall indemnify, hold and save harmless, and defend, at its own expense, IFAD, its officials, agents, servants and employees from and against all suits, claims, demands, and liability of any nature or kind, including their costs and expenses, arising out of acts or omissions of the Contractor, or the Contractor's employees, officers, agents or sub-contractors, in the performance of this contract. This provision shall extend, inter alia, to claims and liability in the nature of workmen's compensation, products liability and liability arising out of the use of patented inventions or devises, copyrighted material or other intellectual property by the Contractor, its employees, officers, agents, servants or sub-contractors. The obligations under this Article do not lapse upon termination of this Contract.

### 19. INSURANCE AND LIABILITIES TO THIRD PARTIES

(a) The Contractor shall provide and thereafter maintain insurance against all risks in respect of its property and any equipment used for the execution of this Contract

(b) The Contractor shall provide and thereafter maintain all appropriate workmen's compensation insurance, or its equivalent, with respect to its employees to cover claims for personal injury or death in connection with this contract.

(c) The Contractor shall also provide and thereafter maintain liability insurance in an adequate amount to cover third party claims for death or bodily injury or loss of or damage to property, arising from or in connection with the provision of services under this contract or the operation of vehicles, boats, aeroplanes or other equipment owned or leased by the Contractor or its agents, servants, employees or sub-contractors performing work or services in connection with this contract.

(d) The Contractor shall, upon IFAD's request, provide IFAD with satisfactory evidence of the insurance required under this Article.

### 20. TITLE TO EQUIPMENT SUPPLIED BY IFAD

Title to any equipment and supplies that may be furnished by IFAD shall rest with IFAD and any such equipment shall be returned to IFAD at the conclusion of this Contract or when no longer needed by the Contractor. Such equipment, when returned to IFAD shall be in the same condition as when delivered to the Contractor, subject to normal wear and tear. The Contractor shall be liable to compensate IFAD for equipment determined to be damaged or degraded beyond normal wear and tear.

## 21 COPYRIGHT, PATENTS AND OTHER PROPRIETARY RIGHTS

IFAD shall be entitled to all intellectual property and other proprietary rights including but not limited to patents, copyrights, and trademarks, with regard to products or documents and other materials which bear a direct relation to or are produced or prepared or collected in consequence of or in the course of the execution of this contract. At IFAD's request, the Contractor shall take all necessary steps, execute all necessary documents and generally assist in securing such proprietary rights and transferring them to IFAD.

## 22. EXAMINATION AND ACCEPTANCE

(a) IFAD shall have the right, before payment, to examine at its expenses the services provided under the contract on the premises of IFAD, or elsewhere. The Contractor shall provide, when possible, all facilities for any such examination.

(b) In case of rejection of the services provided, a new examination may be carried out by the representatives of both Parties if promptly requested by the Contractor and before IFAD exercises any legal remedies. The Contractor shall bear the expenses of such an examination.

(c) The examinations shall be carried out in good faith.

## 23. TITLE

The contractor guarantees that the services provided by it are unencumbered by any third party's proprietary rights. Title to any services shall pass to IFAD upon delivery.

## 24. ADVERTISING

Unless authorised in writing by IFAD, the Contractor shall not advertise or otherwise make public the fact it is supplying services to IFAD. The Contractor shall not use the name, emblem or official seal of IFAD or any abbreviation of the names of IFAD for advertising or for any other promotional purpose.

## 25. AMENDMENTS AND ADDITIONS TO THE CONTRACT

The provisions of the contract and the annexes thereto may be amended or supplemented only by means of a supplementary written Contract signed by all of the Parties or their authorised representatives.

## 26. OFFICIALS NOT TO BENEFIT

(a) IFAD warrants that no official or employee of the Contractor has been or shall be admitted by it to any direct or indirect benefit arising from this contract or the award thereof. Failure to comply with the foregoing provision shall constitute a material breach of this contract.

(b) The Contractor warrants that no official or employee of IFAD has been or shall be admitted by it to any direct or indirect benefit arising from this contract or the award thereof. The Contractor agrees that breach of this provision is a breach of an essential term of this contract.

## 27. APPLICABLE LAW

The contract will be governed by (A) the Headquarters Agreement; (B) the UNCITRAL Model Law on Procurement of Goods and Construction; and (C) recognised principles of international trade law. The Contractor shall comply with all laws, ordinances, rules and regulations bearing upon the performance of its obligations under the terms of this Contract.

## 28. SETTLEMENT OF DISPUTES

(a) Without prejudice to the privileges and immunities of IFAD and to these General Terms and Conditions, any disagreement or legal dispute relating to this contract shall be settled amicably by negotiation and direct dealings.

(b) Any dispute which cannot be settled by negotiation within 60 (sixty) days shall, without prejudice to the relevant privileges and immunities of IFAD, at the request of either Party, be submitted at the seat of IFAD to an Arbitration Board composed of (i) two arbitrators, one being appointed by each of the parties and (ii) a third as president chosen by the two arbitrators.

(c) In the event of a disagreement as to the nomination of the president or a Party's failure to appoint an arbitrator, these appointments shall be made according to the UNCITRAL (United Nations Commission on International Trade Law). The Arbitration Board shall have its seat in Rome, Italy and shall establish its own procedure.

(d) In the absence of contractual provisions, the arbitrators shall apply the UNCITRAL Arbitration Rules as in force on the day both Parties have signed the contract

(e) The parties agree to be bound by any arbitration award, in accordance with this Article 28, as the final adjudication of the dispute.

## 29. CHILD LABOUR, MINES, TERRORISM

(a) The Contractor represents and warrants that neither it nor any of its affiliates is engaged in any practice inconsistent with the rights set forth in the Convention of the Rights of the Child which, inter alia, requires that a child shall be protected from performing any work that is likely to be hazardous or to interfere with the child's education, or to be harmful to the child's health or physical, mental, spiritual, moral or social development.

(b) The Contractor further warrants that neither it, nor any of its affiliates is engaged in the sale or manufacture of anti-personnel mines or of components used in the manufacture of such mines.

(c) The Contractor further warrants that neither it, nor any of its affiliates is engaged either directly or indirectly in terrorism, or in the finance or support of terrorism or in the provision of goods or services to suppliers engaged in such activities.

Any breach of this Article 29 shall entitle IFAD to terminate this contract and suspend payments that may be due, without liability for termination charges or any other liability of any kind of IFAD.

**ANNEX 2.**

National Agriculture Program, State of Eritrea

**FRAMEWORK FOR WATER AND AGRICULTURE PROGRAM DESIGN**

(Draft, to be discussed with the Eritrea Government)

**Theib Oweis**

(Director, Integrated Water & Land Management Program, ICARDA)

## Background

The proposed National Agriculture Program (NAP) would respond to the national needs for enhancing food security, alleviating poverty and sustaining the natural resource base through agricultural development. As water is scarce in Eritrea and will, with climate change, become scarcer, it plays the most crucial role in any sustainable agricultural development. In the context of the NAP, IFAD requested ICARDA to formulate a framework for developing potential agricultural development programs based on rainwater in rain fed systems, runoff water harvesting and irrigation, with crops, livestock and other agricultural activities building upon the recommended water management practices.

The framework aimed at designing a program that, if implemented, can contribute to improved agricultural and water productivity, to better livelihoods, to mitigating the effects of drought and climate change at the community level, and to food security at the national level.

## Agro-ecosystems in Eritrea

There are three major agro-ecosystems in Eritrea

1. ***The rainfed system***

   This is an important system, as it occupies most of the arable lands and many people depend on it. Major crops include wheat, barley, sorghum, pearl millet and maize. However, rainfall is often either inadequate or poorly distributed. In addition, due to poor cultural practices, shortage of improved crop varieties and inadequate plant nutrition, the rainfed system's productivity is far below its potential. Investment in this system may focus on better management of rainwater, conjunctive use of rainwater and supplemental irrigation, ensuring adoption of improved crop varieties, access to fertilizer and enhancement of human capacity to use improved technologies. Adaptive research to solve local problems and test the options will be essential.

2. ***The irrigated system***

   Although this system occupies less land than the rainfed system, its productivity is higher due to the availability of irrigation water and more use of inputs. Most of the irrigated lands are under the traditional spate system, based on runoff water harvesting from upper catchments. In other areas the irrigation development is at smaller scale, using ground water or small surface reservoirs. Previous studies indicate that the spate irrigation systems are inefficient, very risky and inequitable, especially when floods are not adequate. Crops grown are sorghum, pear millet and maize. Major issues to be addressed are improving diversion control, water distribution among farmers, managing fluctuating water supply during drought and potential conjunctive use of ground and surface water. Cultural practices and inputs also are issues to consider.

***3. The Rangelands System***

This system occupies large but mainly marginal lands and supports livestock. It is usually located in either the upper catchments or in low rainfall areas where there is no irrigation water. Often water flowing downstream to be used for spate irrigation or other systems comes partially from these lands. Generally the system is degraded and its capacity to support livestock is declining due to overgrazing, erosion and mismanagement. As this is part of the watersheds, its status is reflected downstream and has a very important environmental dimension. Improving the rangelands vegetation can reduce downstream sedimentation, which lowers the effectiveness of the reservoirs and water structures and promote a more equitable distribution of water at the catchment level. Re-vegetation, controlling grazing and wood cutting and introducing soil and water conservation measures are potential solutions.

## The Watershed Management Approach

The three agro-ecosystems above are interlinked and occur in most of the cases in one watershed. Particularly the water flows in the upper catchments of the watershed strongly influence the lower parts. Most obvious is the flow to the spate irrigation systems which comes from the upper watershed carrying the sediments and sometimes causes the destruction of structures and farmlands.

Water resources within the watershed include rainfall, surface flow and groundwater. There is a definite advantage of managing the natural resources within the watershed context to maximize its productivity and efficiency and to optimize distribution. Many watersheds occur in each Zoba in Eritrea and several are shared between two or more Zobas, some even extend outside the borders of the country. Each of the proposed projects in the NAP is located within one or more watersheds. Some proposed projects focus on managing the catchment area in order to control sediments downstream. This fits very well within the context of a watershed management approach. In fact, all proposed projects can be arranged in this context but need to be adjusted to be able to realize maximum benefits, especially in the long term.

It is proposed here that the “watershed” be the basic hydrologic unit for development. The agricultural interventions including water works and management, crops production, vegetables and cash crops, rangelands/livestock need to be arranged and developed within this context. Three major spate irrigation development projects lie downstream of watersheds in Zoba North Red Sea, in Zoba Zoba Gash Barka and in Zoba Debub. The watersheds with development projects need to be delineated and characterized, after which other interventions can also be developed. For example, in the watershed for spate irrigation in Gash Barka, suitable sites can be selected for building a dam. Another dam is needed in Mansoura to support small scale irrigation, where spate irrigation development can be implemented in other parts of the watershed. The dam will store water for ground water recharge, for supporting small scale irrigation for vegetables and fruit trees, and for supplemental irrigation of field crops around and downstream of the reservoirs. Further upstream in the upper catchment of the same watershed, rainfed systems and rangelands can be developed for livestock raising and for controlling degradation and erosion, which negatively affects spate irrigation structures and reservoirs downstream. The watershed approach will provide a platform for understanding upstream-downstream relations and help making development sustainable.

A fourth watershed may be selected in Zoba Anseba where spate irrigation is not an option, but where rainfed systems are present and potential exists for dams and small scale irrigation. Dams may be build in the middle and downstream parts for supporting groundwater recharge, supplemental irrigation of rainfed crops and small scale irrigation of cash crops. Further upstream rangelands and upper catchment improvement can be developed.

The mapping of the watersheds of Eritrea is an essential basis for selecting those most appropriate for this Program. It should be noted that watersheds are not necessarily confined to a single Zoba, which requires that the risk of administrative control needs to be looked into.

### Communities as center for development

The proposed development projects within this Program are mainly associated with settled communities. These will be the center of the whole project within the watershed. The interventions to be implemented will be tailored to the potential of the natural resources and the needs of these communities. Subprojects can serve one or more communities and may be integrated within the local system. Community local institutions are vital for design consultations, for the implementation, and later for running the project and maintaining it. Throughout the program development, the communities in each watershed will be identified in association with each type of intervention. However, as agricultural development needs integration for any substantial improvement, it is not advisable to do different components in isolation from each other. Water management, crop management, livestock improvement, and other components of the agricultural development will need to be integrated at the watershed scale. In fact even access to markets and other socioeconomic aspects should be considered. It is true that communities can be specialized as mainly herders, irrigators or dry farming but each system may be developed in an integrated manner.

It is suggested here that the components of the Agricultural development Program be integrated at this level.

### Program Components

**A. Watershed-based projects**

1. ***Gash Barka Integrated Agricultural Project***
    a. Spate irrigation project
    b. Reservoir or more upstream for supplemental irrigation of rainfed crops, groundwater recharge, wells for small scale irrigation
    c. Improved rainfed systems, water harvesting/supplemental irrigation at the farm level + varieties, fertilizers, seeds etc (to be checked)
    d. Livestock improvement in rangelands ( to be checked)

2. ***North Red Sea spate-based development project***
    a. Spate irrigation project
    b. Upper catchment and rangelands development

3. ***Anseba watershed management project***
    a. Enhancements of water resources (recharge dams etc),
    b. Introduction on improved irrigation, conjunctive use of various water resources,

c. Rainfed systems improvement and rangelands for livestock

4. ***Debub spate-irrigation based development project***
    a. Spate main system in Mendifera
    b. Upper catchment development and rangelands for livestock

5. ***Other projects if needed***

**B. Cross cutting support components**
1. Seed system development
2. Capacity building and institutional set up
3. Adapted research program
4. Monitoring and evaluation

## Interventions

### *1. Spate irrigation systems*

The project will address the problems of existing systems for improvement and build new pilot systems. The major problems and constraints of the existing systems are:

a. fluctuating annual runoff water due to drought;
b. inadequate diversion control from main stream to the basins;
c. inadequate land leveling causing non uniform distribution of water at the basin level with irregular levees heights and size,
d. inequitable water allocations among farmers, especially under drought when water supply is less than the total needs of the system;
e. low water use efficiency and productivity due to suboptimal water management and agricultural practices and inputs.

For productivity to increase in a sustainable manner, the projects associated with spate irrigation should address the above constraints. The engineering component of the project is important but even more so is the institutional setup and management of the system.
As data on water flow in the streams are rare, estimates will need to be made. A level of over-design will be required to guarantee safety and diversion assurance. As there are several existing diversion structures functioning, lessons and experiences of local engineers will be needed to modify or install new diversion structures for each system that can divert the designed amount of water to the system. It is however important to secure flow downstream from a system to another.

The second important issue is how to distribute the smaller amounts of water available during droughts to be both efficient and equitable. This is a major problem and is becoming more frequent with climate change. As water flows from one basin to another, farmers near the head works get their share of water whereas those at the tail get nothing and those in the middle get less than the crop needs. As a result crops may fail or produce much below their potential with low water use efficiency. A strategy to overcome this problem may be based on the following elements:

a) Introduction of modifications on the water distribution system among farmers. Main, secondary and probably tertiary canals need to be constructed in a way that farmers can get water directly from the canal and not from another farmer basin. This will insure that each farmer gets water at the same time and proportional to his land area.

b) Farmer fields may be divided into three or four parts with levees separating them and simple spillways connecting the basins. Basins should be graded near level with sufficient levees heights. Each farmer will then fill his first field, if there is additional water he will fill the second and so on until he completes his fields. However, when water supply is inadequate each farmer can irrigate one or two parts of his fields. When the system gets water again later, he can complete the others. If no water comes later, the farmer secures good production in the parts of the field that are irrigated sufficiently. This will be the case for all the farmers as they will get equitable amounts.
c) During droughts mitigation measures are needed to insure minimum risk of farmers' production. Drought mitigation strategies can cover all aspects of crop production, storage, insurance or cropping patterns, but within the scope of water management an option could be to use groundwater for drought mitigation. Wells may be developed and used at low pumping rates during normal years, but pumping may be increased during drought to irrigate part of the farmer's fields. A conjunctive use strategy may be set between surface and ground water sources to complement each other.
d) The improved system will need an effective institutional setup, good extension and a training and adaptive research program to improve efficiency and productivity. It should not be forgotten that diverting water somewhere will deprive someone downstream, unless water is lost to sinks. So upstream-downstream relations should be considered and this can easily be done in a watershed management context.

### 2. *Small water harvesting reservoirs*

For drought prone countries like Eritrea it is important to store runoff from severe storms before it gets lost to sinks. This is becoming even more important as global warming is likely to be associated with more intensive storms and more frequent drought events. Storage is a must if the water is not to be lost.

Small water harvesting reservoirs can be effective to store runoff water along the main streams. Usually small earth dams are constructed in suitable areas where water is stored behind. Storage can be either surface, so people use it directly, or it can move down to recharge ground water, where people can get the water by pumping from the aquifer. Each method has advantages and disadvantages, but also complements the other. The most important consideration in the selection of the sites is its association with communities and agricultural lands to use the water.

It is proposed that few dams be planned and built or improved within the watersheds. The reservoirs of surface water and probably recharged groundwater should be well planned to support small scale irrigation systems for cash crops and supplemental irrigation of field crops during and immediately after the rainy season. It is also important to study the downstream consequences.

### 3. *Small scale irrigation systems*

Those will be associated with assured availability of water resources (mainly places in the watershed where groundwater is available or dams are built for harvesting runoff water) and areas close to communities and markets. Usually farmers with about 0.5 ha can use the system to intensify production of high value crops. The focus here is on the irrigation system but other aspects are equally important including selection of crops, access to markets and sufficient supply of inputs needed for intensified crops.

From the water management viewpoint, as water is scarce, the issue here is to maximize water productivity, which is the return per cubic meter of water consumed. Return is meant to be crop yield, not only biological yield, also economic return. This is where crop selection and access to markets become important considerations. Most of small scale irrigated lands in the project areas are under surface irrigation systems and only a small portion is occupied by sprinkler or trickle irrigation systems. This is the case not only in Eritrea but all over the world. Surface irrigation is lower in cost, easier to build and farmers know it well. However they lose more water in evaporation and farmer can lose some in runoff outside his farm and in deep percolation (although these losses are recovered by other farmers or by the system). The modern systems can be more efficient in water application but require higher investment, good maintenance and skilled farmers to operate. Improved surface irrigation can overcome many of the constraints of traditional and modern systems.

For this project I would recommended that surface irrigation continues to occupy the majority of the project area. It can be improved as there are several ways to increase its efficiency including introducing gated pipes for furrows and small leveled basins and surge flow irrigation. Pilot farms using drip irrigation or sprinkler irrigation can be introduced with progressive and more educated farmers. Drip systems are recommended for vegetables, and low cost sprinkler systems, such as the single line source, for supplemental irrigation of rainfed crops and forages.

### 4. *Farm water harvesting/supplemental irrigation*

In medium and high rainfall areas (more than 400 mm annual) there is good potential to build in landscape positions where runoff water occurs with intensive storms a small farm reservoir or pond (around 1,000-2,000m$^3$) to store runoff water for later use in supplemental irrigation. The problem in these areas is occurrence of drought spells between intensive storms during the rainy season. Even when the total rain is enough, the soil profile cannot store all the rain to provide it later to the crops. Having stored some water in small reservoirs farmers can alleviate the moisture stress during dry spells by applying limited supplemental irrigation. This practice had shown great potential to increase productivity of rainfed crops in arid and semiarid areas. More information can be provided by ICARDA as it had worked on these systems in many areas.
Pilot systems may be selected and supported in the project in appropriate areas of the watersheds where rainfall is good such as in Debub, Gash Barka and upper parts of Anseba.

### 5. *Upper catchment/rangeland rehabilitation*

Soil erosion is a serious problem in upper parts of the watersheds. Not only that sediments fill up dams and reduce efficiency of hydraulic structures, but also the upper catchments get degraded and lose their potential for normal functions. Proposals for catchment treatments were made for Gash Barka, Northern Red Sea, Maekel and Anseba. Those are associated mainly with spate irrigation to reduce sediments.
Improving upper catchments can be more beneficial than only stopping sediments flowing to spate irrigation systems. If implemented within a watershed approach, they will also improve the environment, increase forages for livestock and increase water flows to groundwater. As most of upper catchments are either rainfed in arable lands or rangelands, the association with livestock production can be made here. Especially for small ruminants this can be applied in the watershed associated with Debub, Gash Barka and Anseba. Measures can include contour ridges with shrubs plantations, bunds, reforestation, grazing management, etc.

### *6. Rainfed system improvement*

These systems occur in areas with rainfall probably above 400 mm per year and are mainly in higher elevations in western areas. The potential of these rainfed systems is much higher than at present, as reported by national documents. Suboptimal rainfall amount and distribution is a main factor in low productivity but also crop varieties, fertility and other cultural practices contribute.

When water resources are available or water harvesting can be practiced, supplemental irrigation of rainfed crops together with improved varieties and better fertility will make a significant difference. In other areas of the watershed, improved seeds and access to fertilizers can improve the system. Other cultural practices may also be introduced.

### *7. Seed system development*

To cover seed needs of both rainfed and irrigated systems

### *8. Livestock system improvement*

To be associated also with rangelands rehabilitation and management

**ANNEX 3.**

Consultant's Report

# Field observation and data collection mission to Eritrea (April-May 2010)

**Jan Venema**
**ICARDA Consultant, Natural Resources**

**Harare, 5 June 2010**

# 1. GENERAL

Zoba Debub is situated south of Asmara and has 12 Sub-Zobas (see Map)[7], 230 Kebabies and 997 Villages. The total area of the Zoba is 1,112,480 ha (11,112 $km^2$).

The Zoba is one of the most densely populated regions of Eritrea. The total population was 710,000 in 2005 and the projected population for 2013 is 930,000. There are over 165,000 households out of which 82% are engaged in agriculture. There are three main ethnic groups, namely Tigrigna, Saho and Tigre.

About 18% (200,000 ha)[8] of the Zoba is suitable for crop production, 13% (147,000 ha) of which is presently cultivated. The remaining land is made up of mountains, hills, rangelands, woodlands, villages and towns.

## 1.1. Livelihood systems

The population is predominantly rural, and most people are engaged in rainfed cropping and/or extensive grazing. Some farmers also practice irrigated cropping. An overview of the most important livelihood systems is given in Table 13.

Table 13. Livelihood Systems in Zoba Debub

| Livelihood System | Climatic Zone | Sub-zoba |
|---|---|---|
| Temporary migrating traditional Agro-naturalism (bee keeping) | Highlands Lowlands | Adi-Keih, Senafe |
| Traditional Agro-Pastoralism | Semi-highlands | Mai-Mine, Areza, Tsorona, Adi Quala, Emni Haili |
| Temporary migrating Traditional Agro-Pastoralism | Semi-highlands Highlands | Areza, Tsorona, Adi Quala, Emni Haili, Mai-Aini, Segeneyti, Mendefera |
| Traditional Mixed Farming (rainfed and irrigated crops & livestock) | Highlands (Semi-highlands) | Adi Quala, Emni Haili, Segeneyti, Dbarwa, Adi-Keih, Senafe, Mendefera |
| Commercial Irrigated Cropping (orchards, vegetables) and Dairy Farming | Highlands | Adi Quala, Emni Haili, Dbarwa, Dekemhare, Segeneyti, Mendefera, Adi Quala, |

[7] There is considerable variation in the spelling of place names. Some places were re-named in recent times (e.g. Mendefera used to be "Adi Ugri"). Different maps show different boundaries of sub-zobas. Information provided by the Zoba was assumed to be the most authoritative.

[8] 140,000 households engaged in crop production over 200,000 ha of cultivable land means that on average there is less than 1.5 ha of cultivable land per farming household.

## 1.2. Land tenure

Traditionally, land is distributed by the village committee, depending on composition and needs of the farm families. Re-distribution of arable land takes place every seven years. Residential plots and associated (small woodlots and haystack enclosures) are more permanent. Each farm family is given the use of parcels of good, marginal and poor agricultural land. Total area of cultivable land per farm family varies according to the resources of the village, but is generally between 1.5 and 5 ha.

Commercial farmers can get a "concession" to use land indefinitely for specific purposes (e.g. dairy, orchards).

## 1.3. Cropping patterns and crop calendar

The main rainfed crops are cereals (sorghum, wheat, barley, millet, teff) and various pulses. Spring crops are planted with first rains in April/May (*Azmera*), followed by summer crops from June (*Keremti*). Chick pea and grass pea are planted in autumn, from end of August to September. The crop calendar for rainfed crops is given in

Table **2**. Prickly pear (*Opuntia ficus*) is also cultivated, both for fodder and fruit.

Irrigated crops include maize (green), potatoes, various vegetables and fruits (citrus, papaya, guava).

Most farmers use animal draught power (usually one pair of oxen) and plough three times. Farmers may own only one ox and share with others. Some commercial farmers own or hire tractors for ploughing.

Table 14. Crop planting calendars

<table>
<tr><td>Crop</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td></tr>
<tr><td>Sorghum</td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maize</td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Finger millet</td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Barley</td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td></tr>
<tr><td>Wheat</td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td></tr>
<tr><td>Teff</td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td></tr>
<tr><td>Chick pea</td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td></tr>
<tr><td>Grass pea</td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td bgcolor="#aaaaaa"></td><td></td></tr>
<tr><td>Faba bean</td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Field pea</td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lentil</td><td></td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td></tr>
<tr><td>Flax</td><td></td><td></td><td></td><td bgcolor="#aaaaaa"></td><td></td><td></td><td></td><td></td></tr>
</table>

# 2. DATA AND OBSERVATIONS

## 2.1. General

Data were collected on geology, soils, climate, landuse, land cover, water harvesting infrastructure and practices, farming systems, cropping pattern and markets. These data were obtained from government departments and other institutions in Asmara and Zoba Debub. Details are given in Attachments 4 and 9 of this report.
Fieldwork was carried out to make observations and recordings, including photographs. All observation sites have been geo-referenced and are listed in Attachment 6**Error! Reference source not found.**. The observations themselves and photographs are not included in this report[9].

## 2.2. Soils

Most of the available soil information on Zoba Debub is based on remote sensing, through the visual interpretation of satellite images. The most valuable resources in this respect are the Agro-Ecological Zones map of Eritrea (MLWE & FAO, 1997) and the Soil Map of the Soil and Terrain Database for northeastern Africa (FAO, 1998). Little fieldwork (soil survey) and soil analysis has been carried out in Eritrea. The only Soil Survey Report available from Zoba Debub is from Halhale Research Station (MoA, 2002), covering 350 ha only.

Variation in soil characteristics within the Zoba are very much determined by lithology[10], slope inclination and slope position, as indicated in Table 15.

Generally soils derived from basalt and related mafic volcanic rocks have a fine texture (clayey). On gentle slopes they are mostly moderately deep to deep. Inherent fertility is relatively high, although present nutrient status may be low through continuous cropping and/or erosion. Main soil types on the "productive plains"[11] are Vertisols and Vertic Cambisols. On moderate to steep slopes soils are shallow, and/or very stony (skeletal), and can be classified as Regosols and Leptosols.

Soils derived from metamorphic rocks mostly have a medium to fine texture (sandy clay loam, sandy clay) and are stony to very stony. Within the Zoba they are mostly on moderate to steep slopes and are shallow to moderately deep. In very eroded areas they are stony Regosols and Leptosols, otherwise they are Cambisols and Luvisols.

Various Quaternary consolidated and unconsolidated sediments occur in large basins in the south and south-west of the Zoba. The main soils are Luvisols, Cambisols and Regosols of varying texture and depth. Within valleys and depressions throughout the Zoba there are deep to very deep soils derived from recent alluvial and colluvial materials. They are mostly Fluvisols.

[9] See files <Field observations April-May 2010> and <Pictures Zoba Debub> respectively
[10] See Geological Map of Eritrea (Department of Mines, 2008)
[11] See Map of Productive Plains produced by the MoA (Zoba Debub)

Table 15. Soil patterns in Zoba Debub in relation to landscape position and geological substrata

| **Lithology** | **Geological Map Symbols** | **Physiography** | **Soils** | | |
|---|---|---|---|---|---|
| | | | **Texture** | **Depth** | **Classification** (WRB, 2006) |
| Basalt and other mafic volcanics | Paas, Pabs, Pasv, Pbzv, Pobs, | undulating plains | fine, partly stony | deep | Haplic Vertisols<br>Vertic Cambisols<br>Vertic Luvisols |
| | | hills, escarpments, steep valley sides | fine & medium, stony | shallow (mostly skeletic) | Leptic Regosols<br>Cambic Leptosols |
| Metamorphic rocks; laterite | Palt, Pmvs, Pzvs, Pgpg, Pbzw | undulating plains | fine, partly stony | moderately deep | Leptic Luvisols |
| | | hills, escarpments, steep valley sides | fine & medium, stony | shallow (mostly skeletic) | Leptic Regosols<br>Cambic Leptosols |
| Consolidated and unconsolidated “Recent Sediments” | Qh (part) | undulating plains | variable, partly stony | moderately deep | Luvisols |
| | | moderately sloping hills, ridges, valley sides | medium, partly stony | shallow (lithic & paralithic) | Leptic Regosols<br>Cambic Leptosols |
| Sandstone | Pzt | mostly hilly terrain | medium & coarse, partly stony | moderately deep & shallow (mostly skeletic) | Leptic Regosols<br>Cambic Leptosols |
| Granite and rhyolite | Pdgt, Port | mostly hilly terrain | medium, stony | shallow (mostly skeletic) | Leptic Regosols<br>Cambic Leptosols |
| Recent alluvium and colluvium | not shown | gentle lower slopes, valley bottoms | medium & fine | deep | Fluvisols |

### 2.3. Climate

Zoba Debub has three main climatic zones, related to altitude, namely:

| | | |
|---|---|---|
| Highland | *Kebesa* | 1500 – 2370 masl |
| Semi-Highland | *Hawsi-Kebesa* | 1200 – 1500 masl |
| Lowland | *Kola* | < 1200 masl |

Most of the Zoba is in the Highland, and that is where most of the people live.

Full climatic data are available from Halhale Agricultural Research Station, situated in the northern part of Zoba Debub. Monthly rainfall data for the period 1992 – 2009 are available from 13 rainfall stations situated in and around Zoba Debub. Details are given in Attachments 5 and 7. Annual rainfall within the Zoba varies from 637 to 389 mm, with most rainfall concentrated in a period of two months in summer (July and August). Four rainfall zones can be distinguished within the Zoba, with mean annual rainfall of 600, 450, 400 and 350 mm respectively[12].
Rainfall varies considerable from year to year. The coefficient of variation (CV) of annual rainfall in the various rainfall stations ranges from 22 to 44%.

Evapotranspiration exceeds precipitation in most months, except for July and August. The Reference Length of Growing Period[13] varies from 65 days in areas with relatively low rainfall to 80 days in higher rainfall areas.

An analysis of historical rainfall data (Attachment) shows than mean annual rainfall has decreased in the area over the last 80 years.

## 2.4. Water Retention Dams and Irrigation

An inventory of the Ministry of Agriculture (Zoba Debub) lists some 132 retention dams[14] with a total capacity of 37 million $m^{3.}$

An analysis of Spot and Quickbird imagery was carried out in Google Earth to locate the existing reservoirs. A map of dams and ponds from the Ministry of Agriculture was used as a guideline. The analysis resulted in the identification of 24 medium-sized dams (approximate surface area more than 1 ha), approximately 60 small dams (surface area < 1 ha)[15] and two spate irrigation schemes.

A map was produced, showing medium and small retention dams, as well as spate irrigation schemes. Since the images used by Google Earth are a few years old (2006 and 2007 mostly), the existence of some recently constructed dams could not be verified.
It appears that most of the dams are located in small sub-catchments in the area. None of the major rivers has retention dams.
Typically the dams are constructed from locally available unconsolidated materials, dug up by bulldozers from the riverbed and subsequently paved with loose stones. Most dams have a spillway.

[12] See Draft map prepared by Consultant
[13] The Reference LGP is defined as the period (in days) that Potential Evapotranspiration exceeds half Precipitation (P> 0.5 PET). The actual LGP may be a few weeks longer, as crops also make use of moisture stored in the soil immediately after the main rainfall period.
[14] As a rule of thumb, a "dam" is a reservoir with a capacity of more than 50,000 $m^3$; a "pond" has a capacity of less than 50,000 $m^3$.
[15] In a few cases it was not clear whether the location was a dam or a natural depression.

Dams have a limited lifetime because of silting. Not all catchments are adequately protected and large quantities of sediment may end up in the reservoir every year. Occasionally the capacity and lifespan of a dam is increased by raising the dam wall and spillway.

Most of the dams have no outlets, and are mainly used for groundwater re-charge in the valley downstream, although locally farmers and communities pump water directly from the dam for irrigation or village water supply.

Some projects are underway to install pressurized drip irrigation systems. In this irrigation method water is pumped from the dam and fed into a drip network, usually located downstream. More commonly farmers profit from an increased and more reliable groundwater level downstream of the dam and pump water from shallow wells which is piped towards gardens. Pumping water is a costly undertaking and an individual farmer who owns a well and a pump may rent land from other farmers to make the enterprise more cost-effective.

## 2.5. Ponds

The Ministry of Agriculture (MoA) has identified some 254 ponds with a total capacity of 4 million $m^3$. With a very few exceptions, these ponds could not be identified with the use of Google Earth. The reason may be that the available imagery is from the dry season and that most of the ponds were dry and undistinguishable from the surroundings.

Ponds are mostly for livestock and constructed by communities or by the MoA. The location of the ponds is determined by the communities, with technical advice from the MoA. A small earth wall is constructed from local material to dam a depression or small valley. A pond can be constructed by a bulldozer in a day.

## 2.6. Spate irrigation

There are two major spate irrigation schemes in Zoba Debub: Keih Kore north of Dekemhare, and Hadadme east of Mai Aini. Spate irrigation is often initiated by local farming communities. The present schemes have no control gates either at the point of take-off in the river or in the flooded fields. This makes the water diversion dams vulnerable to erosion by fast-flowing peak river flows and irrigated land liable to uneven water distribution and waterlogging.

## 3. WATER HARVESTING TECHNOLOGIES

Presently, most water for domestic purposes, livestock and irrigation is obtained from shallow wells. Shallow wells usually draw from a localized and "perched" watertable and are easily over-exploited. Groundwater levels are locally maintained or raised through upstream medium and small dams. Very small dams (ponds) locally serve as water source for domestic use and livestock in the period August – February, after the summer rains

Attempts have been made to tap underground water resources through drilling (boreholes) with varying success. Most of the geological formations in Zoba Debub have limited water storage capacity, limited to fractures and locally weathered zones.

In recent years, the Government of Eritrea has invested heavily in the rehabilitation and construction of medium-size dams. Some of these dams seem to be under-utilized. Some are also subject to silting, as not all catchments areas are protected.

A list of the most relevant water harvesting technologies is given in Attachment , including constraints and opportunities.

Some of the most promising water harvesting technologies for Zoba Debub are:

❖ Roof water harvesting for domestic purposes

Most houses have a metal roof. Water from the roof may be the only clean water available locally. The construction of cheap and reliable (underground) storage facilities has to be explored

❖ Runoff from enclosed areas (compounds, yards, woodlots), with or without roof water harvesting, to direct water to protected area of (fruit) trees

Within the farmer's compound and other enclosed (protected) areas, runoff can easily be directed towards small areas with fruit trees

❖ Protection and improvement of (shallow) groundwater table for domestic use, livestock and irrigation

Shallow groundwater provides an easily accessible and relatively clean source of water for varying purposes. Groundwater levels can be maintained or improved through the construction of small dams and catchment protection

❖ Small dams and ponds for livestock, and for groundwater re-charge

Small dams and ponds can provide water at strategic points for extended periods, but rarely last the whole year. Small dams and ponds are usually initiated and maintained by local communities.

❖ Utilization of existing medium dams for irrigation

A number of medium-size dams are not fully exploited and may have (more) potential for irrigation, piped village water supply, and fisheries.

❖ In-situ moisture conservation for rainfed cropping through contour bunding and contour bench terraces

Arguably the most importing water harvesting technique in the Zoba is the *in-situ conservation of soil moisture*. There is a long tradition of bunding and terracing in the area, but improved techniques could be introduced. These included vegetated contour strips, vegetated bunds, vegetated farm boundaries, minimum tillage, and conservation agriculture. All these techniques need long-term investments from the farmers, which may be problematic because of the rotational land tenure system prevalent in Eritrea.

# 2. ATTACHMENTS

## Attachment 1. Consultant terms of reference

**Summary:**
The GIS component of the study will deliver maps identifying areas in Debub Zoba, where water harvesting is likely to lead to substantial water and land productivity increases, and as well as the water harvesting techniques that could make best use of any potential.
To this effect an experienced land resources consultant will be fielded to produce the deliverables as specified in the section *[Role of the consultant*]. In addition the GIS Unit of ICARDA will produce the deliverables as described in the section *[Role of the ICARDA GIS Unit].*

**Role of the consultant**

In Debub Zoba (1 month):

- To undertake field work in accessible watersheds/sub-watersheds of Debub Zoba to understand relationships between agricultural systems and crop patterns and elevation, precipitation, lithology, landscape position, population, market availability and accessibility;
- To identify and describe criteria and thresholds for evaluating suitability for relevant water harvesting systems;
- To compile necessary resource datasets ( meteorology, river flow, soils, land cover/land use, lithology) on Debub Zoba to undertake the mapping of suitability for water harvesting;
- To identify and report on GIS skills and needs of the assigned Ministry staff in the Zoba and to provide training in mapping land resources in accordance with the identified needs and time available;
- To estimate annual runoff coefficients based on available meteorological and river flow data, literature data, field observations and experience from similar environments.
- To write a narrative report summarizing results from field activities, data compilation and training.

At ICARDA (2 weeks):

- To work with the ICARDA GIS Unit in creating all necessary base layers for mapping suitability for the relevant water harvesting systems

## Attachment 2. Itinerary

| Date | Activities | Overnight |
|---|---|---|
| Mon April 12 | Travel Harare – Johannesburg - Cairo | air |
| Tue April 13 | Travel Johannesburg – Cairo - Asmara | air |
| Wed April 14 | Arrival Asmara; meet Project Coordinator IFAD | Asmara |
| Thu April 15 | MOA: Policy/planning; GIS Unit, | Asmara |
| Fri April 16 | MOA: Agromet, MLWE: Lands Dept | Asmara |
| Sat April 17 | Data analysis, reporting, preparing | Asmara |
| Sun April 18 | Data analysis, reporting, preparing | Asmara |
| Mon April 19 | MLWE, Asmara; travel to Halale (NARI) & Mendifera | Mendefera |
| Tue April 20 | MOA, Debub Zoba | Mendefera |
| Wed April 21 | Debub fieldwork: Emni Haili sub-Zoba | Mendefera |
| Thu April 22 | Debub fieldwork: Dbarwa sub-Zoba | Asmara |
| Fri April 23 | Data analysis | Asmara |
| Sat April 24 | Data analysis | Asmara |
| Sun April 25 | | Asmara |
| Mon April 26 | Re-visit MLWE (Lands dept, Water Dept) | Mendefera |
| Tue April 27 | Debub fieldwork: Mai-Aini & Dekemhare sub-Zobas | Asmara |
| Wed April 28 | Data analysis, reporting, preparing | Asmara |
| Thu April 29 | Debub fieldwork: Segeneiti & Adi Keih sub-Zobas | Senafe |
| Fri April 30 | Debub fieldwork: Senafe sub-Zoba | Asmara |
| Sat May 1 | Data analysis, reporting, preparing | Asmara |
| Sun May 2 | | Asmara |
| Mon May 3 | Data analysis, reporting, preparing | Asmara |
| Tue May 4 | Meet FAO Rep | Asmara |
| Wed May 5 | Min of Energy & Mines (Geological Survey) Asmara; MoA, Mendefera | Mendefera |
| Thu May 6 | Debub fieldwork: Mendefera & Adi Quala sub-Zobas | Mendefera |
| Fri May 7 | Min of Agric. Mendefera | Asmara |
| Sat May 8 | Data analysis, reporting, preparing | Asmara |
| Sun May 9 | | Asmara |
| Mon May 10 | MoA Asmara | Asmara |
| Tue May 11 | MoA Asmara (de-briefing); Geol. Dept | (Asmara) |
| Wed May 12 | Travel Asmara – Cairo | Cairo |
| Thu May 13 | Travel Cairo - Aleppo | Aleppo |
| May 14-27 | ICARDA, Aleppo | Aleppo |
| May 27 | Travel Aleppo – Cairo | air |
| May 28 | Travel Cairo - Johannesburg - Harare | |

## Attachment 3. People met

| | | | |
|---|---|---|---|
| **Ministry of Agriculture, Asmara (MOA)** | | | |
| Tedros Ukbay | IFAD PC moapcrrd@eol.com.er | | Mob: 07122129 |
| Berhane Mogos | IFAD Project Planner | | |
| Alemseghed Asghedom | | | Acting Head P&S |
| Solomon Haile | Head Planning & Statistics | | |
| Tekleab Mesghena | Head Regulatory Service Dept | | |
| Heruy Asghedom | Head Agric. Promotion & Development Dept | | |
| Amanuel Negassi | Minister's Office | | |
| Efrem Kiflu | Head Administration | | |
| Iyassu G/Tatios | Nat Agric Research Inst | | |
| Abeba Tesfay (Ms) | GIS Expert | | |
| Tekeste Weldegabrial | Agrometeorology Exp | tekeste@moa.gov.er | |
| | | | |
| **Agric. Research Station, Halhale (NARI)** | | | |
| Tsegay Berhane | Director Crop Improvement | | |
| Kifle Mariam | Soil Specialist | | |
| | | | |
| **Ministry of Agriculture, Zoba Debub, Mendefera** | | | |
| Bahta Tedros | Head MoA, Debub Zoba | | |
| Ogbazghi Kifle (Dr) | Head Animal Husbandry Zoba Debub (IFAD Coordinator) | | |
| Isak Fisehaye | Agro-Econ, Planning, IFAD | Issakf2000@yahoo.com<br>Mob:+291(0)7160651 | |
| Yonas Welday | Irrigation, GIS Expert | yonwels@yahoo.com<br>Mob: +291(0)7138176 | |
| Kifle Tedros | Agro-forestry Expert | | |
| Simon Abraha | Irrigation Engineer | | |
| | | | |
| **Ministry of Land, Water and Environment, Asmara (MLWE)** | | | |
| Beyene Ruesom | DG Land Dept | 124633, 07-144344<br>beyeneruesom@yahoo.com | |
| Mulugheta Asmelash | Technician, Land Use | | |
| Mebrahtu Iyasu | DG Water Res Dept | | |
| Asmelash Dawit | Head Meteorology | | |
| Semere Berhe | Geologist, WR Dept | | |
| | | | |
| **Ministry of Mines & Energy, Asmara** | | | |
| Asmerom Mesfin | Dir. Geological Survey | lemasm@yahoo.com | |
| Ermias Yohannes | Head Hydrogeology | 124690 | 07145773 |
| Berhe Goifom | Head Geophysics | | |
| | | | |
| **FAO +291** 188441 | | | |
| Moeketsi Mokati | FAO Representative | Moeketsi.Mokati@fao.org | |
| Matthias Lichtenberger | CTA EU FS Facility | Matthias.Lichtenberger@fao.org | |
| Martin Ager (Harare) | Water Res. Officer | Martin.Ager@fao.org | |
| | | | |

| | | |
|---|---|---|
| **Consultants, Asmara** | | |
| Bruce Cook | Tropical Forage Systems | Australia Government |
| | | |
| **ICARDA** | | |
| Eddy De Pauw (Dr) | Head GIS Unit | E.De-Pauw@cgiar.org |
| Fawaz Tulaymat | GIS Specialist | m.f.tulaymat@cgiar.org |
| Layal Atassi (Ms) | GIS Technician | l.atassi@cgiar.org |
| Wafa Jumaa (Ms) | Secretary GIS | W.Jumaa@cgiar.org |
| M.H. Maatougui | Agronomist (Consultant) | M.Maatougui@cgiar.org |

**Attachment 4: Data Collected in Eritrea**

| Theme | Detail | Author, date | Available | Soft copy | Hard-copy | Comment |
|---|---|---|---|---|---|---|
| **Soils** | Small-scale, FAO Soil Units, Eritrea | FAO, 1998, NFSP | MOA, GIS | | GIS unit MOA | No legend |
| | Soil Map IGAD area | | FAO | CD | | No field obs? |
| | Soil Survey Halhale Research Station | Soil Science Unit | NARI | | With map | With field data |
| | Soil Units (FAO) on AEZ map | FAO, MLWE, 1997 | FAO | | Photo-copy | With Map 1:1 mln |
| **Climate** | AEZ | FAO, MLWE, 1997 | MOA | ArcView 3.2 | A3 | No legend |
| | AEZ | FAO, MLWE, 1997 | FAO | | Photo-copy | With Map 1:1 mln |
| | AEZ | A Summary of the Agricultural Ecology of Ethiopia. Main Report E. de Pauw (FAO), 1988. With Map 1:2 000 000.(digitized, ICARDA) | | | | |
| | Climate data | **See Table 8** | | | | |
| **Topography** | Contours | MoA | MOA, GIS | ArcView 3.2 | | |
| | Contours (50 m) | Debub MOA | Debub | Bitmap | | Incl drainage |
| | Towns, roads, sub-zoba admin | MoA | MOA, GIS | ArcView 3.2 | A3 | Admin boundaries vary maps |
| | Roads, settlements, drainage | | Debub | Bitmap | | |
| | DEM, 90 m interval | | Debub | Bitmap | print | |
| **Physiography** | Watersheds, catchments | | Debub | Bitmap | | |
| | Productive Plains | Debub MOA | Debub | Bitmap & JPEG | | Also names |
| **Geology** | Geological Map | Dept of Mines, 2008 | MoME | JPEG | | |
| **Hydrology** | Drainage pattern | | MOA, GIS | ArcView 3.2 | A3 | |
| | Drainage pattern | Debub, MOA | Debub | Bitmap | | detailed |
| | Mereb_Dbarwa Mean Daily Flow 1997-2009 | | MLWE (W) | Excel | | |
| | Mereb_Kinafina (brg) Mean Daily Flow 2002-2010 | | MLWE (W) | Excel | | |
| | Mereb_Kisad-Ika Mean Daily Flow 1997-1999 | | MLWE (W) | Excel | | |
| | Dams, rivers, ponds | Debub, MoA | Debub | Bitmap; JPEG | | |
| **Land Cover** | Africover | | MOA, GIS | ArcView 3.2 | A3 | |
| **Land Use** | Some data at Lands Dept (MLWE) | | MLWE | | *Info requested but not received* | |

**Attachment 5: Climatic Data files**

| Name of file | Format | Data | Period | Place |
|---|---|---|---|---|
| **Daily climatic data Halale 1999-2010** | **Excel** | **Daily climatic data** | **1/7/99 – 14/03/10** | **Halhale (NARI)** |
| **Monthly Total Rainfall Debub** | **Excel** | **Monthly total rainfall** | **1992 - 2009** | **Debub, 13 stations** |
| **Annual Rainfall Zoba Debub** | **print** | **Annual rainfall** | **1997-2008** | **12 stations Debub** |
| Monthly climatic data Debub March-May 2009 | Excel | Monthly rainfall | March – May 2009 | 16 stations in Debub |
| | | Mean monthly min/max/mean temperatures + rel. humidity | March – May 2009 | Halhale + other Eritrea |
| Monthly Rainfall Debub (18) June-July 2009 | Excel | Monthly total rainfall<br>Number of rainy days | June – July 2008 | 18 stations in Debub + other Eritrea |
| Monthly Total Rainfall Debub (12) 2007-2008 | Excel | Monthly total rainfall | May 07 – April 08 | 12 stations in Debub |
| WR Dept rainfall Upper Mereb | Excel | | | |

## Attachment 6: Coordinates of major observation sites, Zoba Debub

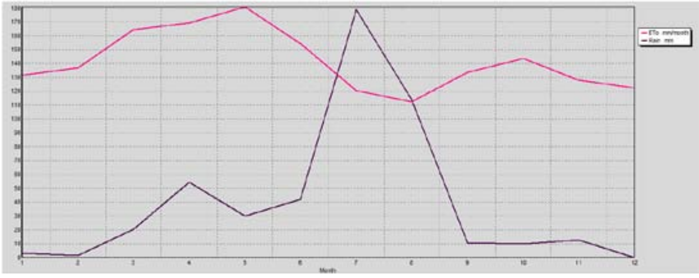
| Site no. | UTM 37 | Altitude (m) | Particulars |
|---|---|---|---|
| 1 | 0478582 1632251 | 1856 | Durco Dam, Durco Village |
| 2 | | | Adiyakulu (Adishimale) Dam |
| 3 | | | Stone bunds on steep slopes |
| 4 | 0470718 1635634 | 1635 | Stony fields |
| 5 | 0470293 1635002 | 1615 | Crusting soils |
| 6 | 0471176 1633673 | 1665 | Dam, future drip irrigation |
| 7 | 0472436 1634410 | 1729 | Defunct cistern (contaminated) |
| 9 | 0469108 1641581 | 1701 | Harnet Dam |
| 10 | 0477277 1659131 | 2054 | Warsay Dam |
| 12 | 0478842 1668982 | 1967 | Adihogo |
| 13 | 0472656 1669452 | 2059 | Amedr |
| 14 | | | Tsilima Plain |
| 15 | | | Shiketi Enclosure |
| 16 | | | road Mendefera – Mai Aini |
| 17 | 0484750 1626192 | 1941 | Depression |
| 18 | 0488415 1625626 | 1949 | protected woodlots, haystacks |
| 19b | 0491839 1626011 | 1654 | cultivated fields |
| 19c | 0503073 1629786 | 1513 | Mai-Aini |
| 20 | | | Mereb River crossing |
| 21 | | | Footslopes near Hadadme |
| 22 | 0521788 1629771 | 1576 | Hadadme Spate Irrigation |
| 22a | 0504604 1649526 | 1757 | Kertse Kemfe plain |
| 23 | | | North of Dekemhare town |
| 24 | 0506856 1672330 | 1687 | Keih Kore Spate irrigation (Alla Plain) |
| 25 | 0511684 1664446 | 2140 | Afelba Pond |
| 25b | | | Segeneiti town; MOAgriculture |
| 25c | | | Roof water harvesting, Segeneiti |
| 27 | 0525218 1657836 | 2192 | Pond |
| 28 | 0535761 1658623 | 2558 | Halay dam |
| 29 | 0535166 1654656 | 2549 | Pond (remote); early barley |
| 29a | 0537189 1655475 | 2506 | Derra Dam |
| 30 | | | Adi Keih town |
| 39 | | | North-west of Adi Keih (main road) |
| 31 | 0542699 1618078 | 2525 | Pond |
| 32 | 0541172 1616349 | 2475 | Pond |
| 33 | | | Serha (near border) |
| 34 | | | Bunds, north of Serha |
| 35 | 0542437 1614772 | 2283 | Bihat Plain |
| 36 | 0544200 1613370 | 2252 | Pond |
| 37 | 0544249 1612405 | 2242 | Bihat Dam |
| 38 | 0547722 1619160 | 2373 | Smejana Plain; forage seed production |
| 40 | 0483682 1638724 | 1900 | Commercial farmer (Tesfay) |
| 41 | 0479495 1641295 | 1955 | Water supply Hotel |
| 46 | 0477848 1646427 | 2002 | Old reservoir |
| 47 | 0475768 1650606 | 2040 | Small dam |
| 42 | 0484101 1622454 | 1926 | Adi Baharro Dam |
| 43 | 0485006 1619585 | 2001 | Sememo Dam |
| 44 | | | Adi Quala market (see photos). |
| 45 | | | badlands |
| Note: These sites have been described in a separate document, photographed and mapped | | | |

*

## Attachment 7: P and ETo graphs of 13 stations in and around Zoba Debub

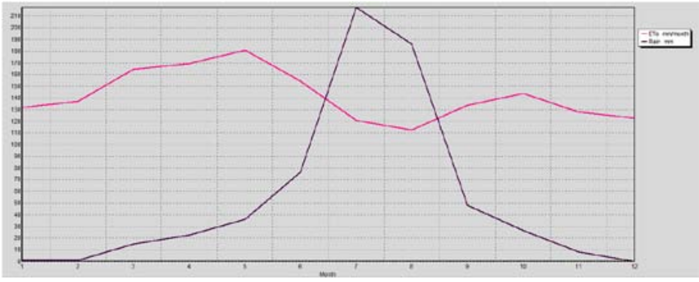
Mean monthly Precipitation (P) and Evapo-transpiration (ETo)[16]

**Figure 17**. Adi Keih (1992-2009)



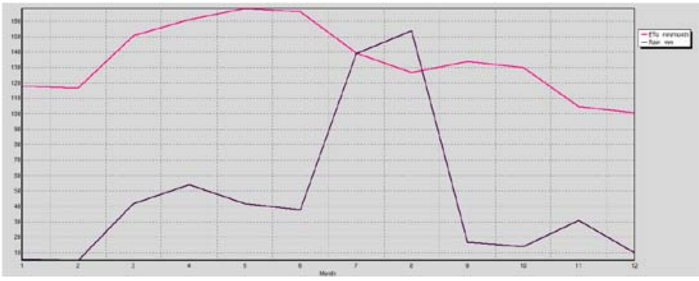
14.84° N, 39.37°4 E
Alt 2419 m
Total P = 473 mm (162-890mm)
Cv = 42%
P>ET = 40 days
P>0.5ET = 70 days

**Figure 18.** Adi Quala (1992-2009)



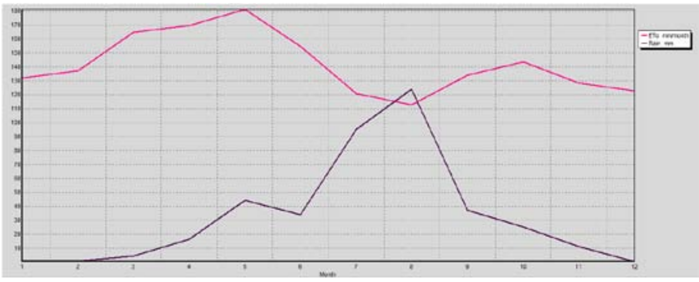
14.63 N, 38.83° E
Alt 2049 m
Total P = 637 mm (404-830mm)
Cv = 22%
P>ET = 60 days
P>0.5ET = 80 days

**Figure 19.** Adigrat, Ethiopia



14.63 N, 38.83 E
Alt 2449 m
Total P = ... mm (.......mm)
Cv = ..%
P>ET = 35 days
P>0.5ET = 67 days

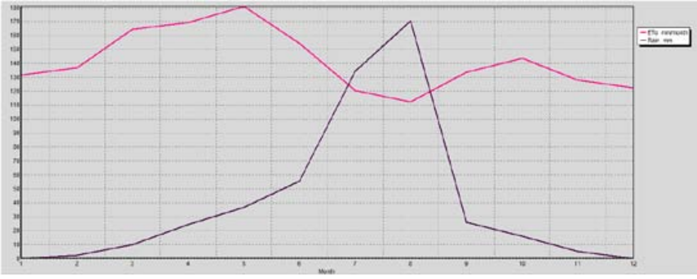
**Figure 20.** Areza (1992-2009)



14.93° N, 38.56° E
Alt 2001 m
Total P = 389 mm (181-618mm)
Cv = 27%
P>ET = 12 days
P>0.5ET = 65 days

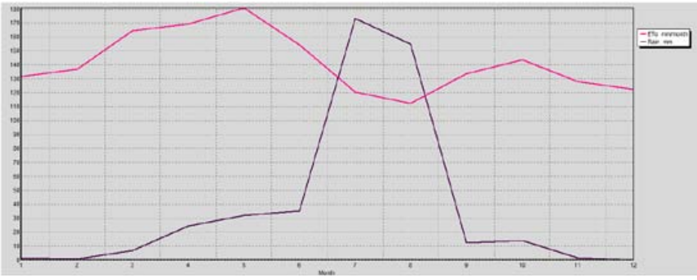
[16] ETo calculated from climatic data of Halale Agricultural Research Station through Penman-Monteith method (FAO, CROPWAT)

**Figure 21.** Dbarwa (1992-2009)



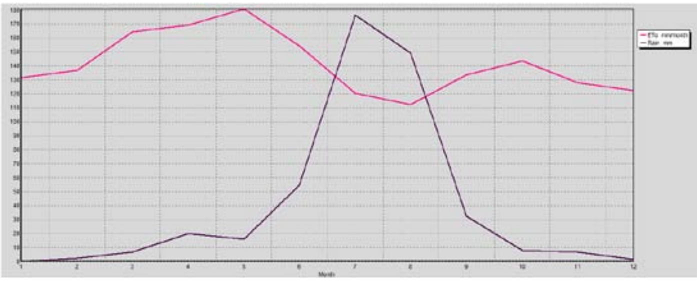
15.09° N, 38.83° E
Alt 1914 m
Total P = 479 mm (267-858mm)
Cv = 30%
P>ET = 45 days
P>0.5ET = 75 days

**Figure 22.** Dekemhare (1992-2009)



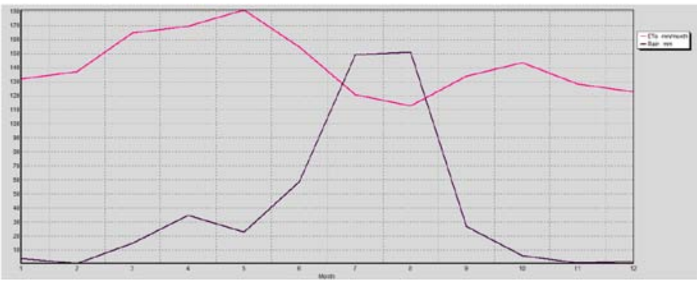
15.07° N, 39.04° E
Alt 2035 m
Total P = 456 mm (240-795mm)
Cv = 27%
P>ET = 48 days
P>0.5ET = 72 days

**Figure 23.** Emni Haili (1999-2009)



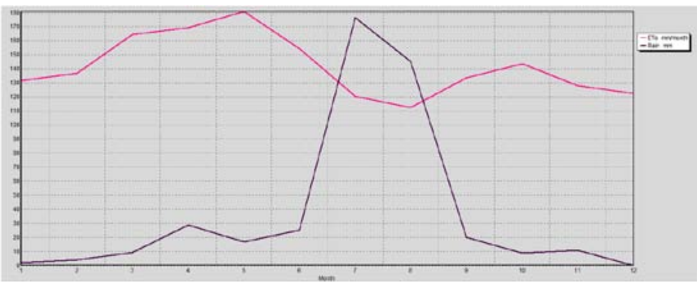
14.72° N, 38.68° E
Alt 2025 m
Total P = 472 mm (277-768mm)
Cv = 34%
P>ET = 48 days
P>0.5ET = 72 days

**Figure 24.** Halhale (2000-2009)



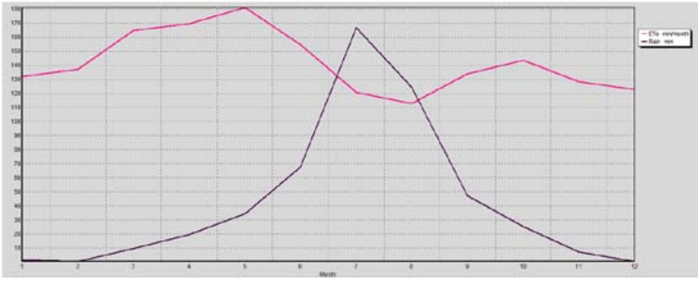
15.06° N, 38.82° E
Alt 1910 m
Total P = 470 mm (300-689mm)
Cv = 23%
P>ET = 40 days
P>0.5ET = 75 days

**Figure 25.** Mai Aini (1996-2009)



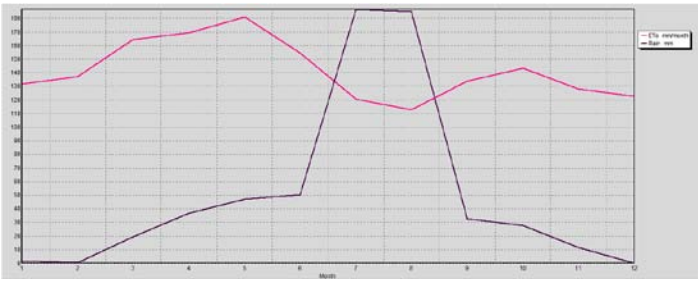
14.78° N, 39.12° E
Alt 1803 m
Total P = 443 mm (153-754mm)
Cv = 34%
P>ET = 48 days
P>0.5ET = 71 days

**Figure 26.** Mai Mine (1994-2009)



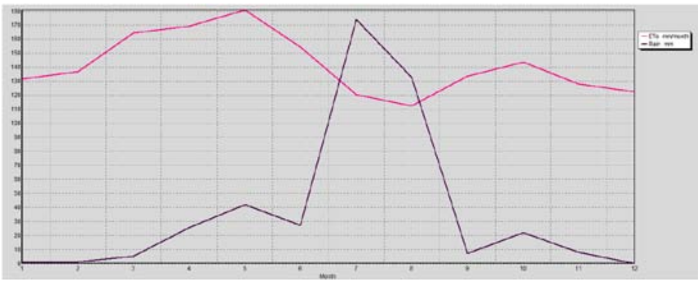
14.53° N, 38.55° E
Alt 1854 m
Total P = 497 mm (175-772mm)
Cv = 34%
P>ET = 42 days
P>0.5ET = 82 days

**Figure 27.** Mendefera (Adi Ugri) (1992-2009)



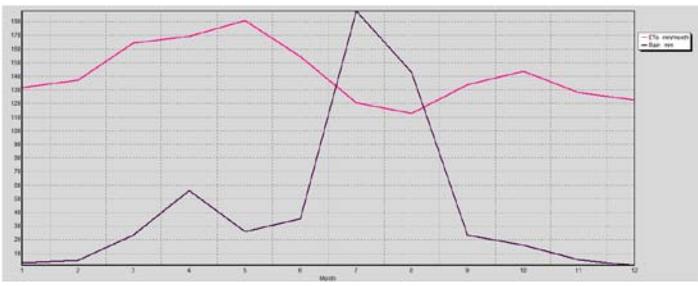
14.88° N, 38.81° E
Alt 1964 m
Total P = 596 mm (352-1158mm)
Cv = 33%
P>ET = 55 days
P>0.5ET = 79 days

**Figure 28.** Segeneiti (1993-2009)



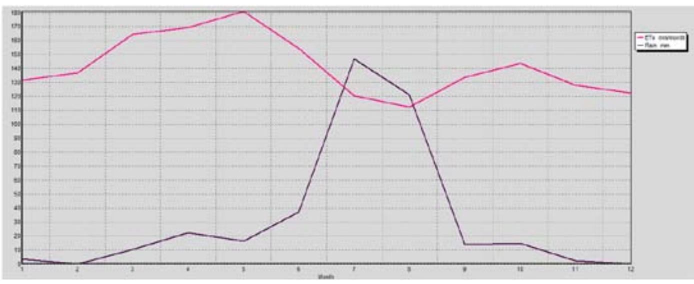
15.02° N, 39.21° E
Alt 2193 m
Total P = 445 mm (291-857mm)
Cv = 32%
P>ET = 44 days
P>0.5ET = 66 days

**Figure 29.** Senafe (1992-2009)



14.70° N, 39.42° E
Alt 2433 m
Total P = 523 mm (102-961mm)
Cv = 41%
P>ET = 47 days
P>0.5ET = 72 days

**Figure 30.** Tsorona (1997-2009)



14.63° N, 39.20° E
Alt 1553 m
Total P = 390 mm (118-595mm)
Cv = 33%
P>ET = 40 days
P>0.5ET = 65 days

## Attachment 8: Historical rainfall data

Table 16. Historical rainfall data selected stations in and around Zoba Debub

| Station | No.of years | main period* | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean Annual Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADI KEYIH | 41 | 1923-59 | 2 | 8 | 24 | 57 | 38 | 33 | 157 | 121 | 24 | 8 | 18 | 7 | 496 |
| ADI KWALA | 20 | 1933-53 | 0 | 1 | 7 | 28 | 40 | 77 | 254 | 211 | 61 | 9 | 7 | 2 | 697 |
| ADI UGRI (Mendefera) | 46 | 1923-65 | 1 | 3 | 11 | 34 | 45 | 58 | 192 | 197 | 53 | 10 | 18 | 2 | 625 |
| ADIGRAT | 22 | 1954-83 | 8 | 7 | 48 | 59 | 42 | 37 | 146 | 142 | 19 | 28 | 23 | 14 | 575 |
| DECAMERE | 21 | 1931-53 | 3 | 4 | 10 | 24 | 40 | 49 | 201 | 167 | 29 | 2 | 9 | 3 | 543 |
| SEGENEYTI | 20 | 1923-37 | 4 | 3 | 5 | 43 | 58 | 34 | 171 | 139 | 17 | 13 | 9 | 1 | 498 |

* data are mainly from period as indicated, but some extra years were used in some stations

Table 17. Comparison of mean annual rainfall over various periods

| Station | Mean annual total precipitation (mm) | | | | Change (%) |
|---|---|---|---|---|---|
| | 1923-1959 | 1954-1983 | 1971-2000 | 1993-2009 | |
| Adi Keih | 496 | | | 473 | **- 5** |
| Adi Quala | 697 | | | 637 | **- 9** |
| Mendefera | 625 | | 535 | 596 | |
| Adigrat | | 575 | 540 | | **- 6** |
| Dekamhere | 543 | | | 456 | **- 16** |
| Segeneiti | 498 | | | 445 | **- 11** |
| *source* | *FAO* | | *FAO, CLIMWAT* | *Min of Agric.* | |

## Attachment 9: Fieldwork in Eritrea (Zoba Debub): General remarks

1. The Consultant received full support from the Ministry of Agriculture (MOA) both at HQ (Asmara) and Zoba (Mendefera) level.
2. An exploratory field survey of Zoba Debub was completed successfully, although not all sub-zobas could be visited because of travel restrictions. A total of nine sub-zobas were visited, out of a total of 12. Because of a system of strict travel permits, only eight days were spent in the field, rather than the twelve originally planned.
3. During field work the Consultant was always accompanied by two to four Technical staff from the MOA of Zoba Debub, who proved to be knowledgeable and informative.
4. Farmers and rural dwellers approached by the surveying team were invariable cooperative and informative
5. The Consultant was received well by all Departments and Institutions who were visited by appointment. However, it was not always easy to extract available information from Government Departments outside the Ministry of Agriculture. Subsequent written requests from the MOA were required for every piece of information and even after those requests were made, the information has not always been forthcoming.
6. Geographical information in the form of maps was often given in a format which is not easily processed in a GIS system (e.g. pictures in JPEG or BMP format, rather than Shape or Raster files). It was not always clear whether the piecemeal data exchange was deliberate or not.
7. There is a general lack of soil information in Zoba Debub and in the country as a whole. Except for a few detailed surveys covering small areas, soil characterization and classification seems to be based on the interpretation of satellite imagery without field verification.
8. Land cover has been systematically mapped through the Africover programme and the relevant SHP files were made available by the MoA
9. No inventories of Present Land Use of Zoba Debub or parts thereof were identified. Land Use Planning exercises are carried out by the Department of Lands (MLWE), but promised information on the LUP process and land use data have not yet made been available.
10. There are sufficient rainfall data for Zoba Debub to make an agro-ecological zoning (AEZ) of the regions possible, even though there is only on 1$^{st}$ class meteorological station (Halhale) in the study area with sufficient other climatic records.

## Attachment 10: GIS Training requirements

Training is recommended at two levels:

1. Explanation of methodology and results; distribution of hardcopy maps. Selective installation of soft copies (Min. of Agriculture Asmara and Zoba Debub). Possible involvement of the Department of Water of the Ministry of Land Water and Environment (MLWE) and GIS unit of Planning Department Zoba Debub Administration.
2. More technical GIS training of Irrigation/GIS expert at Zoba Debub (Mr Yonas Welday) and possible one or two staff from Department of Water (Asmara)?

Presently GIS Unit Zoba Debub uses ArcView 3.2. Computer equipment at Zoba Debub is fairly new and has sufficient memory.

## Attachment 11: Water Harvesting Technologies

| Technology | | Uses | | Bio-physical conditions | | | Constraints | Other |
|---|---|---|---|---|---|---|---|---|
| | | Main | Opportunities | Physiography | Soil | Climate | | |
| **Spate irrigation** | Controlled Uncontrol -led | Field crops, vegetables, (tree crops) | Two crops/yr | Large hilly area with almost flat footslopes or floodplains | Medium – fine texture; not saline | Semi-arid < 400 mm | Unreliable (drought, floods) unless control structures are built | Needs catchment treatment Needs farmer organization |
| **Medium dams** | Drip Well re-charge Pump & channel | Field crops, vegetables, (tree crops) | Continuous cropping Aquaculture | Large catchment Suitable dam site Irrigable land nearby | Medium – fine texture; not saline | > 300 mm ??? | Large investment; needs econ. feasibility Liable to silting | Needs catchment treatment Needs farmer organization and training |
| **Small dams, ponds** | Well re-charge Direct use | Livestock, domestic | Tree crops | Gently sloping depressions, | Not too coarse | > 250 mm ??? | Contamination Usually dry out February/March Public area | Needs catchment treatment Needs farmer organization |
| **Small check dams** | SWC GW recharge | Grazing Reforestation | Tree crops Opuntia | General slopes 5 - 30 % and dissected | Not too coarse | > 200 mm | Usually public area | Needs maintenance and care |
| **Conservation Agriculture** | Minimum tillage | Field crops | Fodder | Arable land | Not poorly drained | Any | Needs research Land tenure | |
| **Micro catchments (stone)** | direct WH | Forestation | Tree crops Field crops (coarse cereals?) | General slopes 5 – 30% | Not on solid rock | 200 – 500 mm | Damage by livestock in communal areas | |
| **Level Bunds, terraces (earth, stone)** | SWC | Field crops | Fodder, tree crops on bunds, boundaries | Slopes < 30% | | > 300 mm | May cause erosion if not well constructed and maintained | Various techniques |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sloping bunds, terraces with drainage** | Soil Conserva--tion | Field crops<br>Tree crops | Valuable tree crops<br>Double cropping | Slopes 2 – 30% (field crops)<br>Slopes 2 – 60% (tree crops) | Not too coarse | > 600 mm | Labour intensive and needs expertise and supervision | |
| **Re-directed road/gully runoff without storage** | WH | Field crops<br>Fodder | | Gently sloping arable land | | > 250 mm | Un-reliable and not always sustainable. May cause flooding, erosion or sedimentation | Needs close monitoring and good management |
| **Yard or enclosure RWH** | Targeted flow | Fodder, trees | Fruit trees; high value shrubs | > 2% slope of catchment | Some soil below catchmen t | > 300 mm | None | Water receiving land and use within enclosure |
| **Reservoir (tank) near well or river** | Pump during summer | | Vegetables<br>Field crops? | Near (seasonal) water courses | Not too coarse | any | Cost of tank<br>Land tenure | As suppl. irrigation after main rains??<br>Cost effective ????? |
| **Roof RWH** | Under-ground tank | Domestic, Public | Include in large building designs | n/a | Not in solid rock | > 250 mm | Reservoirs expensive | Need good management |
| **Roof RWH** | Container | Domestic | Tree crops (overflow) | n/a | | > 200 mm | Containers expensive<br>Low storage | |
| **Roof RWH** | Targeted flow | Fodder, trees, ornamental | Fruit trees | | | | None | |

Notes:
GW: groundwater
RWH: rainwater harvesting
SWC: soil and water conservation
WH: water harvesting

## ANNEX 4. SUITABILITY FOR DIFFERENT WATER HARVESTING SYSTEMS IN THE SELECTED WATERSHEDS

Table 18. Areas (hectare) of different suitability classes for watershed Tselema (Priority 1)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 12,221 | 12,221 | 22,805 | 8,312 | 8,312 | 23,932 | 8,312 | 23,932 | 8,312 | 23,932 | 8,312 | 23,932 | 45,332 | 23,651 | 13,110 | 13,110 |
| 10-20 | 724 | 724 | 1,183 | 2,902 | 2,902 | 3,420 | 2,902 | 3,420 | 2,902 | 3,420 | 2,902 | 3,420 | 703 | 1,059 | 1,732 | 1,732 |
| 20-30 | 976 | 976 | 633 | 3,468 | 3,468 | 2,652 | 3,468 | 2,652 | 3,468 | 2,652 | 3,468 | 2,652 | 619 | 1,118 | 1,942 | 1,942 |
| 30-40 | 1,366 | 1,366 | 1,981 | 3,289 | 3,289 | 3,579 | 3,289 | 3,579 | 3,289 | 3,579 | 3,289 | 3,579 | 526 | 1,041 | 2,279 | 2,279 |
| 40-50 | 1,449 | 10,746 | 1,052 | 2,852 | 15,370 | 1,877 | 15,370 | 1,877 | 15,370 | 1,877 | 15,370 | 1,877 | 484 | 1,121 | 9,287 | 8,936 |
| 50-60 | 1,537 | 1,814 | 23,259 | 2,847 | 2,753 | 15,911 | 2,753 | 15,911 | 2,753 | 15,911 | 2,753 | 15,911 | 823 | 1,024 | 2,481 | 2,361 |
| 60-70 | 2,091 | 2,559 | 110 | 2,784 | 2,651 | 11 | 2,651 | 11 | 2,651 | 11 | 2,651 | 11 | 347 | 975 | 2,929 | 3,400 |
| 70-80 | 2,048 | 20,690 | 72 | 3,327 | 12,645 | 9 | 12,645 | 9 | 12,645 | 9 | 12,645 | 9 | 2,588 | 948 | 16,892 | 16,892 |
| 80-90 | 29,009 | 325 | 325 | 21,640 | 31 | 31 | 31 | 31 | 31 | 31 | 31 | 31 | 0 | 861 | 770 | 770 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19,623 | 0 | 0 |
| >60 | 33,147 | 23,574 | 508 | 27,751 | 15,326 | 51 | 15,326 | 51 | 15,326 | 51 | 15,326 | 51 | 2,935 | 22,407 | 20,590 | 21,061 |

Table 19. Areas (hectare) of different suitability classes for watershed Hazemo (Priority 2)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 21,920 | 21,920 | 29,485 | 19,713 | 19,713 | 32,582 | 19,713 | 32,582 | 19,713 | 32,582 | 19,713 | 32,582 | 47,311 | 17,785 | 22,615 | 22,615 |
| 10-20 | 1,075 | 1,075 | 5,503 | 3,875 | 3,875 | 8,990 | 3,875 | 8,990 | 3,875 | 8,990 | 3,875 | 8,990 | 744 | 941 | 1,620 | 1,620 |
| 20-30 | 1,668 | 1,668 | 1,200 | 3,788 | 3,788 | 2,358 | 3,788 | 2,358 | 3,788 | 2,358 | 3,788 | 2,358 | 649 | 1,101 | 1,714 | 1,714 |
| 30-40 | 2,189 | 2,189 | 5,450 | 3,380 | 3,380 | 5,886 | 3,380 | 5,886 | 3,380 | 5,886 | 3,380 | 5,886 | 615 | 1,216 | 1,734 | 1,734 |
| 40-50 | 2,240 | 8,548 | 1,500 | 2,737 | 11,992 | 1,016 | 11,992 | 1,016 | 11,992 | 1,016 | 11,992 | 1,016 | 513 | 1,108 | 9,289 | 6,006 |
| 50-60 | 2,040 | 5,684 | 9,214 | 2,699 | 5,714 | 5,342 | 5,714 | 5,342 | 5,714 | 5,342 | 5,714 | 5,342 | 3,439 | 984 | 3,482 | 4,162 |
| 60-70 | 2,754 | 5,200 | 1,041 | 2,385 | 3,939 | 139 | 3,939 | 139 | 3,939 | 139 | 3,939 | 139 | 357 | 861 | 928 | 3,530 |
| 70-80 | 4,285 | 7,690 | 582 | 5,843 | 4,025 | 114 | 4,025 | 114 | 4,025 | 114 | 4,025 | 114 | 3,397 | 722 | 7,846 | 7,846 |
| 80-90 | 18,853 | 3,049 | 3,049 | 12,603 | 598 | 598 | 598 | 598 | 598 | 598 | 598 | 598 | 0 | 713 | 7,797 | 7,797 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31,592 | 0 | 0 |
| >60 | 25,892 | 15,939 | 4,671 | 20,832 | 8,562 | 851 | 8,562 | 851 | 8,562 | 851 | 8,562 | 851 | 3,754 | 33,889 | 16,571 | 19,173 |

Table 20. Areas (hectare) of different suitability classes for watershed Maitekela (Priority 3)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 4,407 | 4,407 | 10,097 | 5,945 | 5,945 | 12,960 | 5,945 | 12,960 | 5,945 | 12,960 | 5,945 | 12,960 | 32,057 | 18,881 | 4,721 | 4,721 |
| 10-20 | 456 | 456 | 1,545 | 2,244 | 2,244 | 3,463 | 2,244 | 3,463 | 2,244 | 3,463 | 2,244 | 3,463 | 473 | 748 | 786 | 786 |
| 20-30 | 689 | 689 | 551 | 2,706 | 2,706 | 2,239 | 2,706 | 2,239 | 2,706 | 2,239 | 2,706 | 2,239 | 320 | 787 | 1,084 | 1,084 |
| 30-40 | 1,048 | 1,048 | 3,468 | 2,461 | 2,461 | 4,577 | 2,461 | 4,577 | 2,461 | 4,577 | 2,461 | 4,577 | 297 | 917 | 1,309 | 1,309 |
| 40-50 | 1,202 | 6,395 | 935 | 2,136 | 7,662 | 1,438 | 7,662 | 1,438 | 7,662 | 1,438 | 7,662 | 1,438 | 270 | 968 | 6,589 | 5,829 |
| 50-60 | 1,172 | 2,052 | 16,714 | 2,130 | 2,814 | 10,278 | 2,814 | 10,278 | 2,814 | 10,278 | 2,814 | 10,278 | 603 | 877 | 3,423 | 2,457 |
| 60-70 | 1,693 | 3,772 | 377 | 1,821 | 3,224 | 55 | 3,224 | 55 | 3,224 | 55 | 3,224 | 55 | 146 | 779 | 2,267 | 3,993 |
| 70-80 | 1,760 | 15,089 | 221 | 1,914 | 7,995 | 41 | 7,995 | 41 | 7,995 | 41 | 7,995 | 41 | 1,031 | 699 | 12,268 | 12,268 |
| 80-90 | 22,771 | 1,291 | 1,291 | 13,841 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 147 | 0 | 707 | 2,751 | 2,751 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,835 | 0 | 0 |
| >60 | 26,224 | 20,151 | 1,889 | 17,575 | 11,366 | 242 | 11,366 | 242 | 11,366 | 242 | 11,366 | 242 | 1,177 | 12,021 | 17,286 | 19,012 |

Table 21. Areas (hectare) of different suitability classes for watershed Tsaedakelay, section 4a (Priority 4)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3,699 | 3,699 | 5,713 | 2,921 | 2,921 | 6,189 | 2,921 | 6,189 | 2,921 | 6,189 | 2,921 | 6,189 | 14,987 | 8,534 | 3,878 | 3,878 |
| 10-20 | 141 | 141 | 345 | 939 | 939 | 1,018 | 939 | 1,018 | 939 | 1,018 | 939 | 1,018 | 116 | 250 | 340 | 340 |
| 20-30 | 180 | 180 | 123 | 1,397 | 1,397 | 1,142 | 1,397 | 1,142 | 1,397 | 1,142 | 1,397 | 1,142 | 122 | 284 | 358 | 358 |
| 30-40 | 256 | 256 | 1,312 | 1,524 | 1,524 | 1,838 | 1,524 | 1,838 | 1,524 | 1,838 | 1,524 | 1,838 | 100 | 286 | 399 | 399 |
| 40-50 | 309 | 2,068 | 214 | 1,359 | 3,645 | 947 | 3,645 | 947 | 3,645 | 947 | 3,645 | 947 | 71 | 266 | 1,935 | 1,670 |
| 50-60 | 336 | 534 | 8,229 | 1,297 | 1,287 | 5,011 | 1,287 | 5,011 | 1,287 | 5,011 | 1,287 | 5,011 | 61 | 262 | 1,582 | 710 |
| 60-70 | 518 | 1,454 | 21 | 990 | 953 | 12 | 953 | 12 | 953 | 12 | 953 | 12 | 57 | 245 | 996 | 2,132 |
| 70-80 | 3,661 | 7,640 | 15 | 2,664 | 3,502 | 11 | 3,502 | 11 | 3,502 | 11 | 3,502 | 11 | 690 | 242 | 6,484 | 6,484 |
| 80-90 | 7,105 | 233 | 233 | 3,114 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 0 | 243 | 234 | 234 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,593 | 0 | 0 |
| >60 | 11,284 | 9,327 | 269 | 6,769 | 4,492 | 60 | 4,492 | 60 | 4,492 | 60 | 4,492 | 60 | 747 | 6,323 | 7,713 | 8,850 |

Table 22  Areas (hectare) of different suitability classes for watershed Tsaedakelay, section 4b (Priority 4)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 26,739 | 26,739 | 38,862 | 13,381 | 13,381 | 36,807 | 13,381 | 36,807 | 13,381 | 36,807 | 13,381 | 36,807 | 14,987 | 16,881 | 28,274 | 28,274 |
| 10-20 | 867 | 867 | 1,755 | 2,415 | 2,415 | 3,032 | 2,415 | 3,032 | 2,415 | 3,032 | 2,415 | 3,032 | 116 | 970 | 2,378 | 2,378 |
| 20-30 | 936 | 936 | 403 | 3,072 | 3,072 | 1,766 | 3,072 | 1,766 | 3,072 | 1,766 | 3,072 | 1,766 | 122 | 1,033 | 2,685 | 2,685 |
| 30-40 | 1,047 | 1,047 | 8,242 | 3,203 | 3,203 | 9,757 | 3,203 | 9,757 | 3,203 | 9,757 | 3,203 | 9,757 | 100 | 1,082 | 2,780 | 2,780 |
| 40-50 | 1,134 | 11,141 | 358 | 3,374 | 21,644 | 1,045 | 21,644 | 1,045 | 21,644 | 1,045 | 21,644 | 1,045 | 71 | 1,094 | 8,926 | 7,987 |
| 50-60 | 1,218 | 1,986 | 11,877 | 3,437 | 3,292 | 9,092 | 3,292 | 9,092 | 3,292 | 9,092 | 3,292 | 9,092 | 61 | 1,034 | 6,940 | 2,642 |
| 60-70 | 1,608 | 7,978 | 0 | 3,394 | 7,415 | 0 | 7,415 | 0 | 7,415 | 0 | 7,415 | 0 | 57 | 918 | 1,785 | 7,023 |
| 70-80 | 14,819 | 10,804 | 0 | 19,109 | 7,075 | 0 | 7,075 | 0 | 7,075 | 0 | 7,075 | 0 | 690 | 916 | 7,730 | 7,730 |
| 80-90 | 13,131 | 0 | 0 | 10,112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 983 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36,588 | 0 | 0 |
| >60 | 29,558 | 18,783 | 0 | 32,615 | 14,490 | 0 | 14,490 | 0 | 14,490 | 0 | 14,490 | 0 | 747 | 39,406 | 9,515 | 14,753 |

Table 23.  Areas (hectare) of different suitability classes for watershed Oubel (Priority 5)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 19,317 | 19,317 | 29,548 | 10,953 | 10,953 | 28,064 | 10,953 | 28,064 | 10,953 | 28,064 | 10,953 | 28,064 | 36,383 | 10,265 | 20,132 | 20,132 |
| 10-20 | 444 | 444 | 3,383 | 1,616 | 1,616 | 3,601 | 1,616 | 3,601 | 1,616 | 3,601 | 1,616 | 3,601 | 414 | 1,061 | 1,304 | 1,304 |
| 20-30 | 517 | 517 | 184 | 2,106 | 2,106 | 601 | 2,106 | 601 | 2,106 | 601 | 2,106 | 601 | 331 | 1,084 | 1,394 | 1,394 |
| 30-40 | 556 | 556 | 4,075 | 2,208 | 2,208 | 4,880 | 2,208 | 4,880 | 2,208 | 4,880 | 2,208 | 4,880 | 313 | 999 | 1,438 | 1,438 |
| 40-50 | 651 | 9,613 | 108 | 2,202 | 14,839 | 291 | 14,839 | 291 | 14,839 | 291 | 14,839 | 291 | 273 | 875 | 10,876 | 7,930 |
| 50-60 | 649 | 3,328 | 3,353 | 2,327 | 2,450 | 3,214 | 2,450 | 3,214 | 2,450 | 3,214 | 2,450 | 3,214 | 448 | 758 | 3,142 | 3,676 |
| 60-70 | 821 | 3,790 | 0 | 2,143 | 3,875 | 0 | 3,875 | 0 | 3,875 | 0 | 3,875 | 0 | 224 | 651 | 458 | 2,871 |
| 70-80 | 2,864 | 3,087 | 0 | 5,461 | 2,604 | 0 | 2,604 | 0 | 2,604 | 0 | 2,604 | 0 | 2,265 | 610 | 1,906 | 1,906 |
| 80-90 | 14,831 | 0 | 0 | 11,635 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 557 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23,791 | 0 | 0 |
| >60 | 18,517 | 6,877 | 0 | 19,239 | 6,480 | 0 | 6,480 | 0 | 6,480 | 0 | 6,480 | 0 | 2,489 | 25,609 | 2,364 | 4,777 |

Table 24. Areas (hectare) of different suitability classes for watershed Megerba, section 6a (Priority 6)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2,958 | 2,958 | 4,254 | 1,851 | 1,851 | 3,802 | 1,851 | 3,802 | 1,851 | 3,802 | 1,851 | 3,802 | 5,371 | 2,135 | 3,092 | 3,092 |
| 10-20 | 77 | 77 | 158 | 422 | 422 | 462 | 422 | 462 | 422 | 462 | 422 | 462 | 92 | 81 | 215 | 215 |
| 20-30 | 96 | 96 | 59 | 548 | 548 | 333 | 548 | 333 | 548 | 333 | 548 | 333 | 88 | 74 | 201 | 201 |
| 30-40 | 127 | 127 | 538 | 552 | 552 | 1,207 | 552 | 1,207 | 552 | 1,207 | 552 | 1,207 | 81 | 69 | 220 | 220 |
| 40-50 | 148 | 1,297 | 72 | 449 | 1,628 | 174 | 1,628 | 174 | 1,628 | 174 | 1,628 | 174 | 83 | 74 | 1,230 | 1,174 |
| 50-60 | 173 | 206 | 1,776 | 379 | 350 | 879 | 350 | 879 | 350 | 879 | 350 | 879 | 191 | 73 | 273 | 200 |
| 60-70 | 218 | 537 | 0 | 344 | 865 | 0 | 865 | 0 | 865 | 0 | 865 | 0 | 71 | 75 | 122 | 252 |
| 70-80 | 694 | 1,558 | 0 | 1,155 | 641 | 0 | 641 | 0 | 641 | 0 | 641 | 0 | 880 | 70 | 1,504 | 1,504 |
| 80-90 | 2,365 | 0 | 0 | 1,157 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 78 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,127 | 0 | 0 |
| >60 | 3,278 | 2,095 | 0 | 2,657 | 1,506 | 0 | 1,506 | 0 | 1,506 | 0 | 1,506 | 0 | 951 | 4,350 | 1,626 | 1,757 |

Table 25. Areas (hectare) of different suitability classes for watershed Megerba, section 6b (Priority 6)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3,692 | 3,692 | 5,200 | 2,037 | 2,037 | 4,400 | 2,037 | 4,400 | 2,037 | 4,400 | 2,037 | 4,400 | 6,392 | 2,441 | 3,841 | 3,841 |
| 10-20 | 74 | 74 | 49 | 307 | 307 | 161 | 307 | 161 | 307 | 161 | 307 | 161 | 121 | 198 | 225 | 225 |
| 20-30 | 87 | 87 | 52 | 401 | 401 | 199 | 401 | 199 | 401 | 199 | 401 | 199 | 104 | 159 | 253 | 253 |
| 30-40 | 92 | 92 | 796 | 508 | 508 | 1,433 | 508 | 1,433 | 508 | 1,433 | 508 | 1,433 | 95 | 124 | 261 | 261 |
| 40-50 | 93 | 1,480 | 39 | 486 | 2,034 | 197 | 2,034 | 197 | 2,034 | 197 | 2,034 | 197 | 100 | 107 | 1,468 | 1,468 |
| 50-60 | 114 | 71 | 1,840 | 534 | 302 | 1,586 | 302 | 1,586 | 302 | 1,586 | 302 | 1,586 | 85 | 102 | 507 | 268 |
| 60-70 | 146 | 751 | 0 | 485 | 1,229 | 0 | 1,229 | 0 | 1,229 | 0 | 1,229 | 0 | 88 | 99 | 243 | 481 |
| 70-80 | 1,089 | 1,729 | 0 | 1,960 | 1,158 | 0 | 1,158 | 0 | 1,158 | 0 | 1,158 | 0 | 992 | 95 | 1,179 | 1,179 |
| 80-90 | 2,589 | 0 | 0 | 1,258 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 97 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,552 | 0 | 0 |
| >60 | 3,824 | 2,480 | 0 | 3,702 | 2,387 | 0 | 2,387 | 0 | 2,387 | 0 | 2,387 | 0 | 1,080 | 4,843 | 1,422 | 1,661 |

Table 26. Areas (hectare) of different suitability classes for watershed Megerba, section 6c (Priority 6)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 6,079 | 6,079 | 7,597 | 3,208 | 3,208 | 6,501 | 3,208 | 6,501 | 3,208 | 6,501 | 3,208 | 6,501 | 7,754 | 757 | 6,288 | 6,288 |
| 10-20 | 110 | 110 | 1,102 | 348 | 348 | 1,352 | 348 | 1,352 | 348 | 1,352 | 348 | 1,352 | 158 | 157 | 335 | 335 |
| 20-30 | 110 | 110 | 42 | 391 | 391 | 120 | 391 | 120 | 391 | 120 | 391 | 120 | 122 | 157 | 353 | 353 |
| 30-40 | 124 | 124 | 548 | 419 | 419 | 1,104 | 419 | 1,104 | 419 | 1,104 | 419 | 1,104 | 120 | 172 | 343 | 343 |
| 40-50 | 134 | 1,424 | 23 | 475 | 2,803 | 61 | 2,803 | 61 | 2,803 | 61 | 2,803 | 61 | 113 | 164 | 1,979 | 1,255 |
| 50-60 | 116 | 1,022 | 790 | 495 | 1,267 | 965 | 1,267 | 965 | 1,267 | 965 | 1,267 | 965 | 347 | 183 | 383 | 897 |
| 60-70 | 129 | 487 | 0 | 477 | 855 | 0 | 855 | 0 | 855 | 0 | 855 | 0 | 76 | 196 | 139 | 349 |
| 70-80 | 244 | 746 | 0 | 768 | 812 | 0 | 812 | 0 | 812 | 0 | 812 | 0 | 1,411 | 191 | 283 | 283 |
| 80-90 | 3,055 | 0 | 0 | 3,522 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 193 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,933 | 0 | 0 |
| >60 | 3,429 | 1,233 | 0 | 4,767 | 1,667 | 0 | 1,667 | 0 | 1,667 | 0 | 1,667 | 0 | 1,487 | 8,513 | 422 | 633 |

Table 27. Areas (hectare) of different suitability classes for watershed Alla (Priority 7)

| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 20,318 | 20,318 | 26,008 | 12,331 | 12,331 | 24,261 | 12,331 | 24,261 | 12,331 | 24,261 | 12,331 | 24,261 | 33,087 | 5,323 | 21,019 | 21,019 |
| 10-20 | 368 | 368 | 3,634 | 1,290 | 1,290 | 4,984 | 1,290 | 4,984 | 1,290 | 4,984 | 1,290 | 4,984 | 327 | 251 | 1,118 | 1,118 |
| 20-30 | 378 | 378 | 81 | 1,621 | 1,621 | 728 | 1,621 | 728 | 1,621 | 728 | 1,621 | 728 | 290 | 329 | 1,213 | 1,213 |
| 30-40 | 439 | 439 | 2,885 | 1,870 | 1,870 | 3,606 | 1,870 | 3,606 | 1,870 | 3,606 | 1,870 | 3,606 | 257 | 414 | 1,276 | 1,276 |
| 40-50 | 430 | 5,173 | 70 | 1,871 | 10,810 | 613 | 10,810 | 613 | 10,810 | 613 | 10,810 | 613 | 222 | 473 | 6,164 | 3,789 |
| 50-60 | 518 | 3,461 | 4,222 | 1,955 | 4,728 | 2,698 | 4,728 | 2,698 | 4,728 | 2,698 | 4,728 | 2,698 | 1,867 | 578 | 2,509 | 2,896 |
| 60-70 | 614 | 2,816 | 27 | 1,796 | 2,587 | 67 | 2,587 | 67 | 2,587 | 67 | 2,587 | 67 | 100 | 595 | 536 | 2,524 |
| 70-80 | 601 | 3,990 | 16 | 1,788 | 1,788 | 68 | 1,788 | 68 | 1,788 | 68 | 1,788 | 68 | 1,282 | 628 | 3,463 | 3,463 |
| 80-90 | 12,679 | 488 | 488 | 11,428 | 406 | 406 | 406 | 406 | 406 | 406 | 406 | 406 | 0 | 671 | 134 | 134 |
| 90-100 | 1,087 | 0 | 0 | 1,481 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28,167 | 0 | 0 |
| >60 | 14,981 | 7,294 | 532 | 16,494 | 4,781 | 542 | 4,781 | 542 | 4,781 | 542 | 4,781 | 542 | 1,383 | 30,062 | 4,132 | 6,120 |

Table 28. Areas (hectare) of different suitability classes for watershed Shemejana, section 8a (Priority 8)

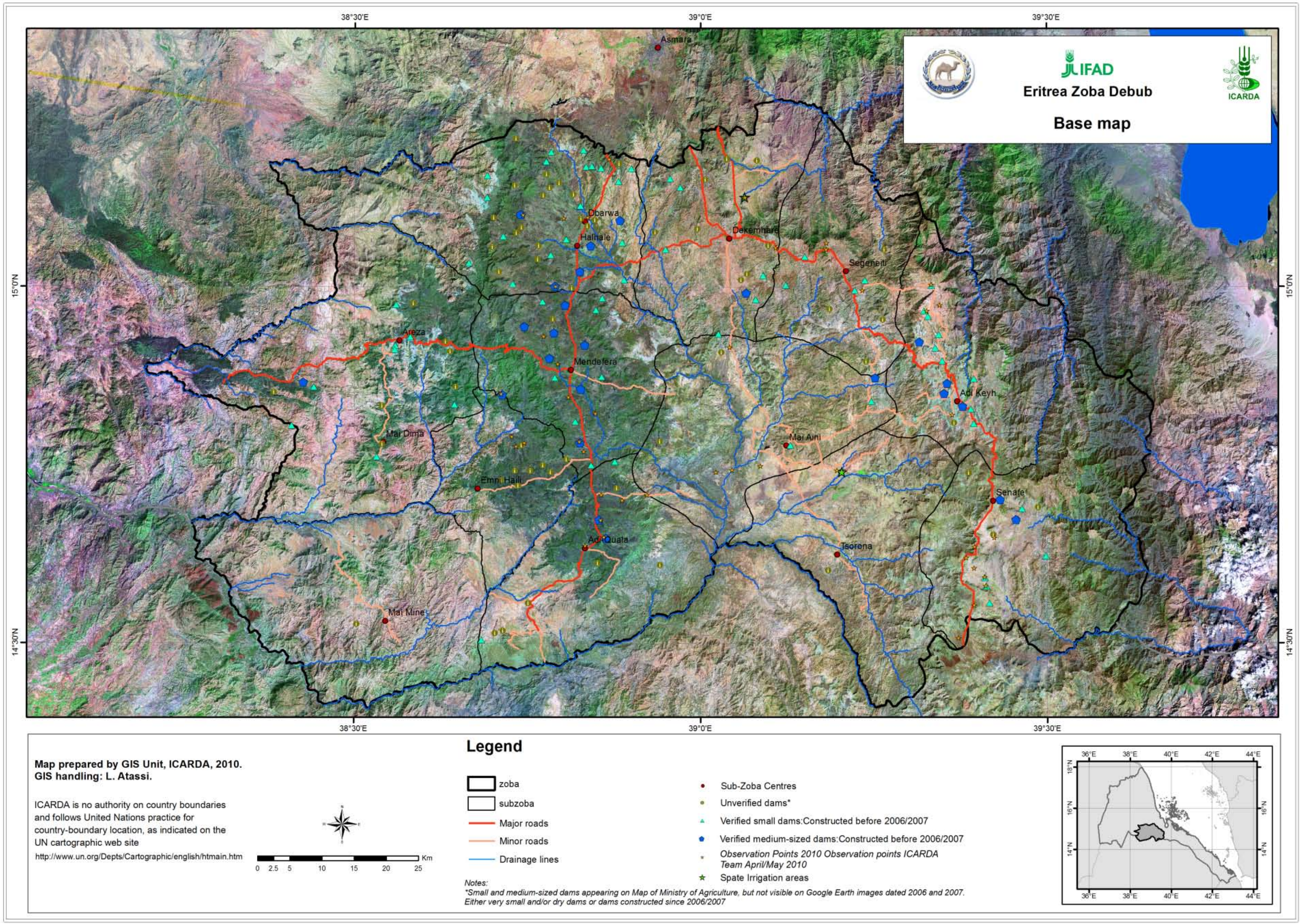
| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 8,657 | 8,657 | 9,791 | 4,702 | 4,702 | 7,609 | 4,702 | 7,609 | 4,702 | 7,609 | 4,702 | 7,609 | 11,287 | 2,637 | 9,017 | 9,017 |
| 10-20 | 188 | 188 | 1,864 | 598 | 598 | 3,854 | 598 | 3,854 | 598 | 3,854 | 598 | 3,854 | 313 | 145 | 580 | 580 |
| 20-30 | 215 | 215 | 62 | 774 | 774 | 374 | 774 | 374 | 774 | 374 | 774 | 374 | 279 | 175 | 647 | 647 |
| 30-40 | 244 | 244 | 616 | 774 | 774 | 1,091 | 774 | 1,091 | 774 | 1,091 | 774 | 1,091 | 269 | 203 | 661 | 661 |
| 40-50 | 258 | 1,148 | 89 | 736 | 2,813 | 298 | 2,813 | 298 | 2,813 | 298 | 2,813 | 298 | 225 | 217 | 1,626 | 1,044 |
| 50-60 | 253 | 1,566 | 3,451 | 800 | 3,267 | 2,791 | 3,267 | 2,791 | 3,267 | 2,791 | 3,267 | 2,791 | 2,767 | 253 | 705 | 1,056 |
| 60-70 | 819 | 949 | 27 | 1,545 | 1,270 | 13 | 1,270 | 13 | 1,270 | 13 | 1,270 | 13 | 471 | 277 | 715 | 946 |
| 70-80 | 5,497 | 3,164 | 231 | 6,203 | 1,934 | 102 | 1,934 | 102 | 1,934 | 102 | 1,934 | 102 | 519 | 262 | 2,180 | 2,180 |
| 80-90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 290 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11,671 | 0 | 0 |
| >60 | 6,316 | 4,113 | 258 | 7,748 | 3,204 | 115 | 3,204 | 115 | 3,204 | 115 | 3,204 | 115 | 990 | 12,501 | 2,895 | 3,126 |

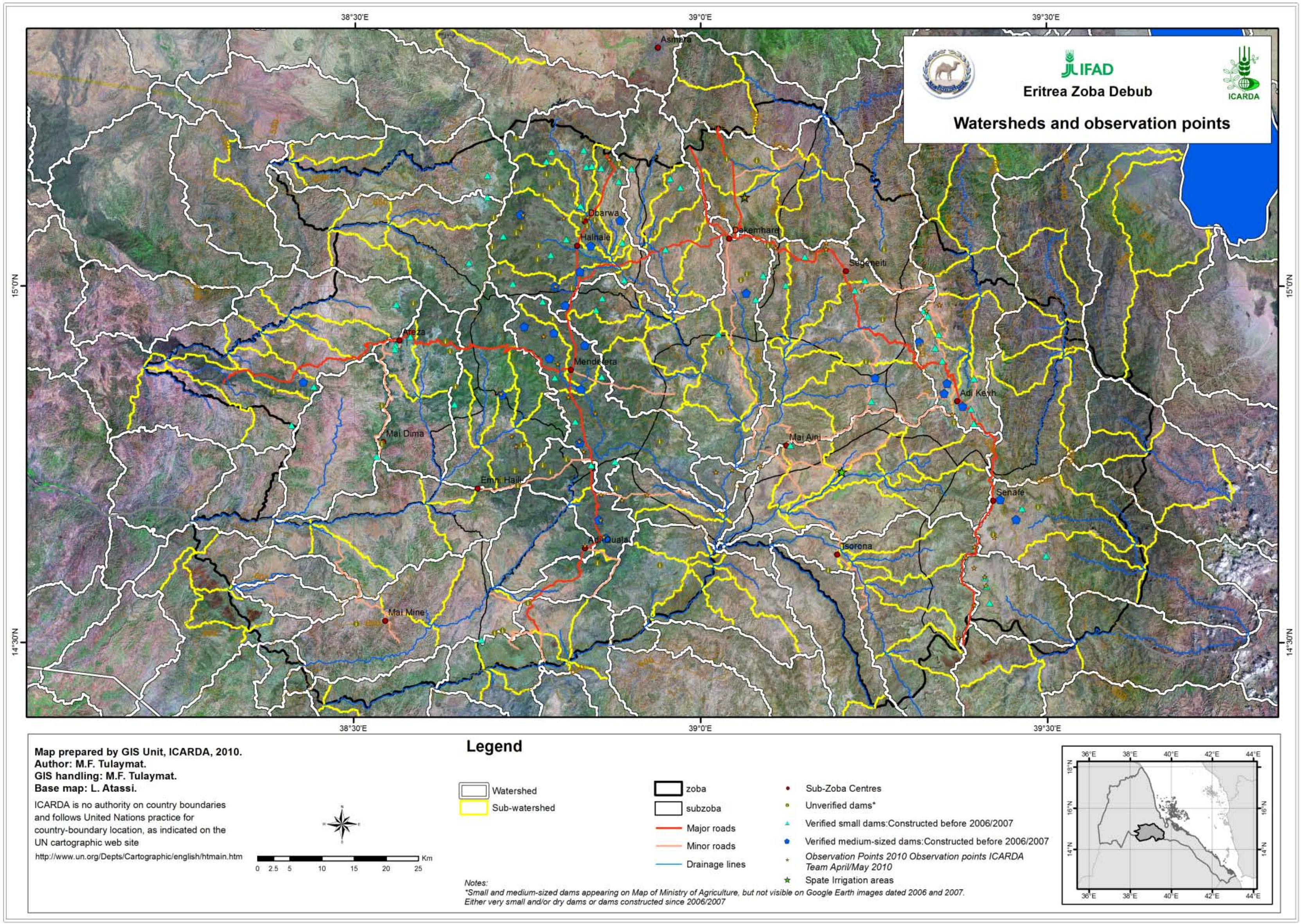
Table 29. Areas (hectare) of different suitability classes for watershed Shemejana, section 8b (Priority 8)

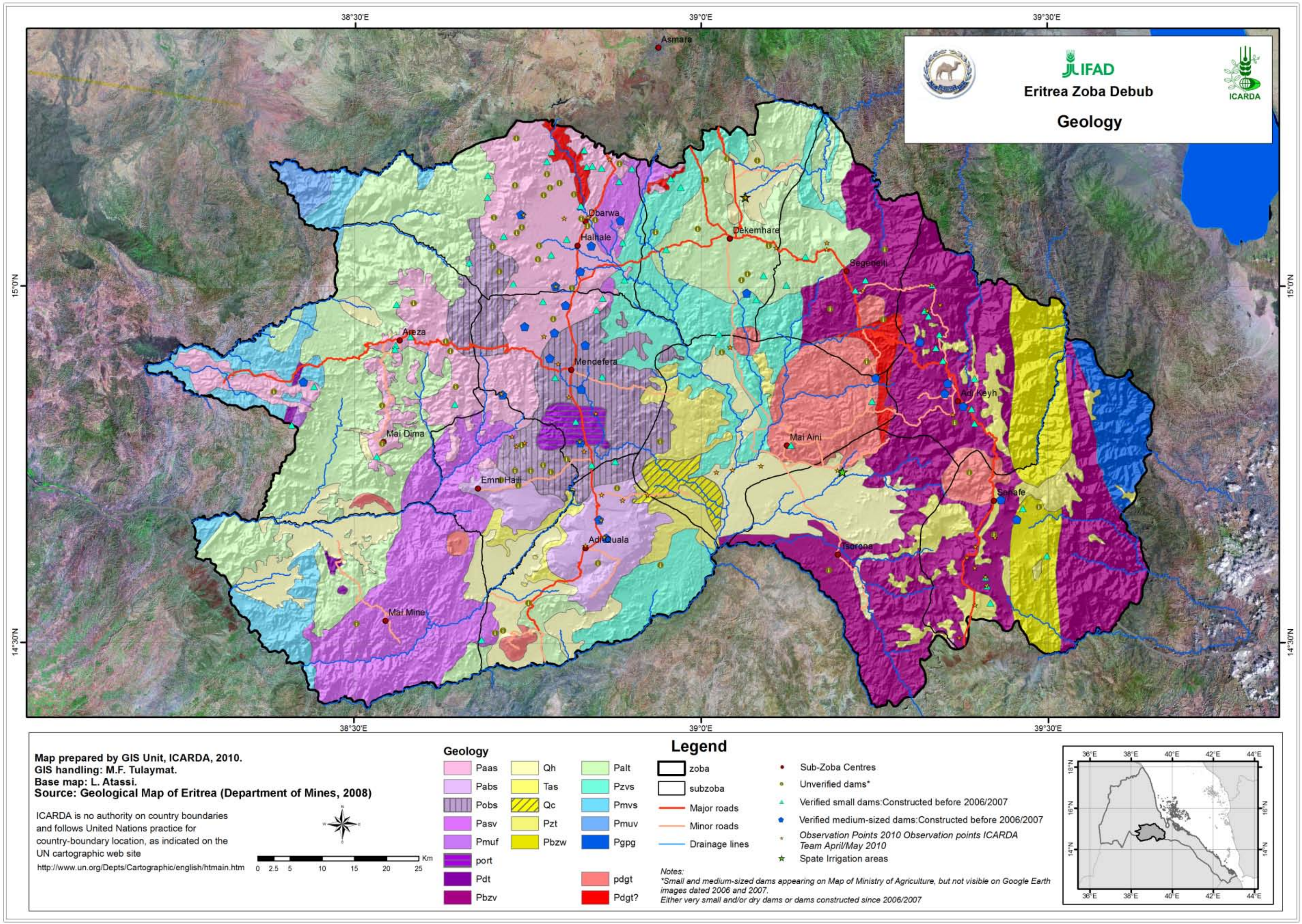
| Suitability scores | S11 | S12 | S13 | S21 | S22 | S23 | S31 | S33 | S41 | S43 | S51 | S52 | S6 | Cat | Tree | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 4,534 | 4,534 | 5,158 | 2,982 | 2,982 | 4,659 | 2,982 | 4,659 | 2,982 | 4,659 | 2,982 | 4,659 | 4,223 | 39 | 4,647 | 4,647 |
| 10-20 | 56 | 56 | 256 | 196 | 196 | 702 | 196 | 702 | 196 | 702 | 196 | 702 | 108 | 29 | 163 | 163 |
| 20-30 | 64 | 64 | 9 | 181 | 181 | 19 | 181 | 19 | 181 | 19 | 181 | 19 | 85 | 18 | 159 | 159 |
| 30-40 | 57 | 57 | 24 | 179 | 179 | 65 | 179 | 65 | 179 | 65 | 179 | 65 | 53 | 39 | 158 | 158 |
| 40-50 | 57 | 534 | 7 | 204 | 1,393 | 14 | 1,393 | 14 | 1,393 | 14 | 1,393 | 14 | 43 | 24 | 352 | 292 |
| 50-60 | 71 | 209 | 129 | 186 | 491 | 125 | 491 | 125 | 491 | 125 | 491 | 125 | 890 | 36 | 18 | 75 |
| 60-70 | 212 | 131 | 0 | 414 | 161 | 0 | 161 | 0 | 161 | 0 | 161 | 0 | 106 | 33 | 87 | 89 |
| 70-80 | 459 | 0 | 0 | 1,111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 42 | 0 | 2,180 |
| 80-90 | 74 | 0 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 0 |
| 90-100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,289 | 0 | 0 |
| >60 | 745 | 131 | 0 | 1,656 | 161 | 0 | 161 | 0 | 161 | 0 | 161 | 0 | 180 | 5,398 | 87 | 2,269 |

Notes:
1. The location of the watersheds is shown in Map 11. ‘Selected watersheds’.
2. S11, S12, S13, S21, S22, S23, S31, S33, S41, S43, S51, S52, S6: symbols for micro-catchment systems explained in section 2.3.1. , step 2.
3. Cat: suitability for catchment use; Tree: suitability for use as target area (tree crops); Field: suitability for use as target area (field crops)

**ANNEX 5. MAPS**

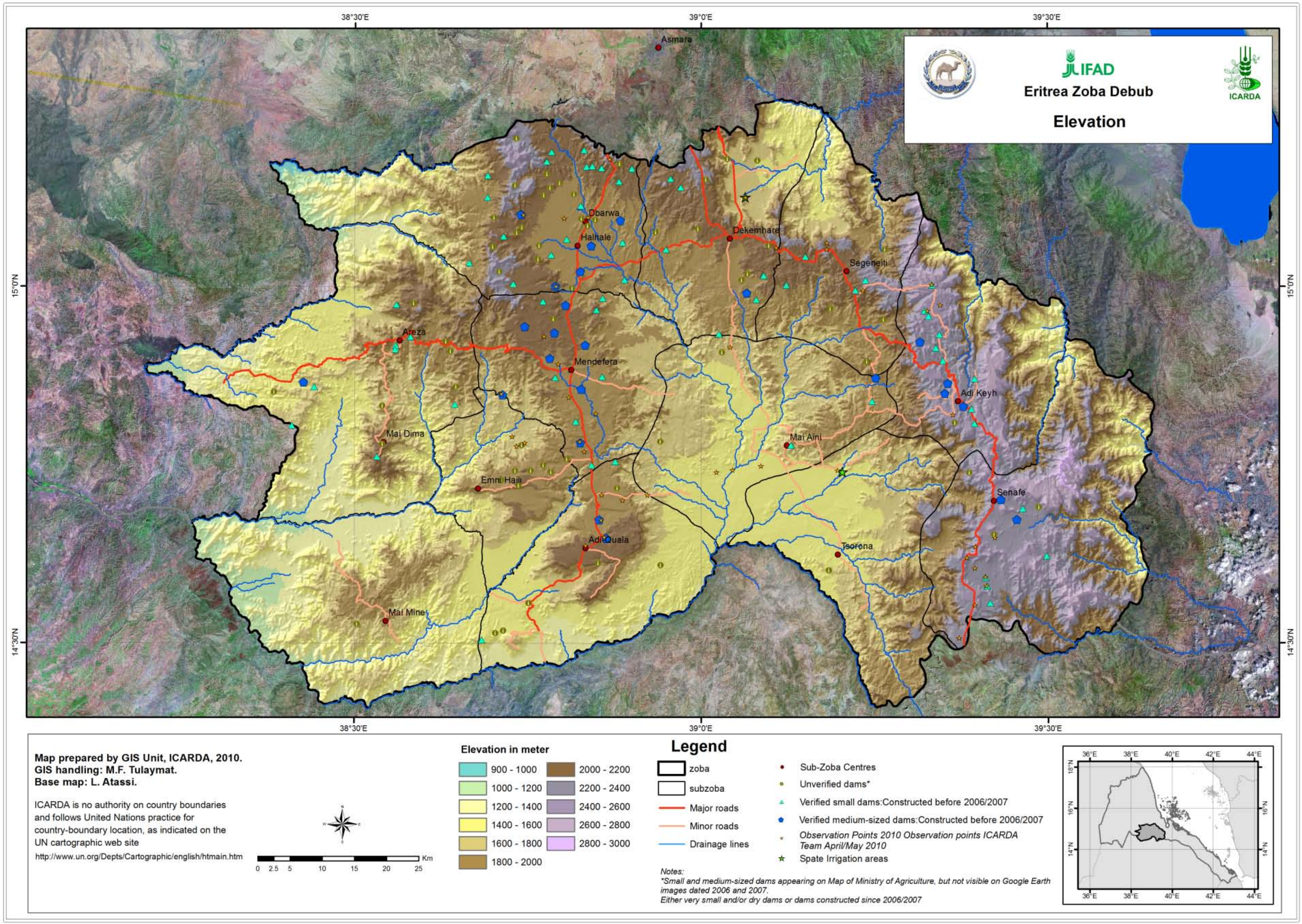

IFAD
Eritrea Zoba Debub
ICARDA
Base map
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi Quala
Tsorona
Mai Mine
Legend
Map prepared by GIS Unit, ICARDA, 2010.
GIS handling: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N
16°N
14°N


Eritrea Zoba Debub
Watersheds and observation points
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: M.F. Tulaymat.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Watershed
Sub-watershed
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N
16°N
14°N

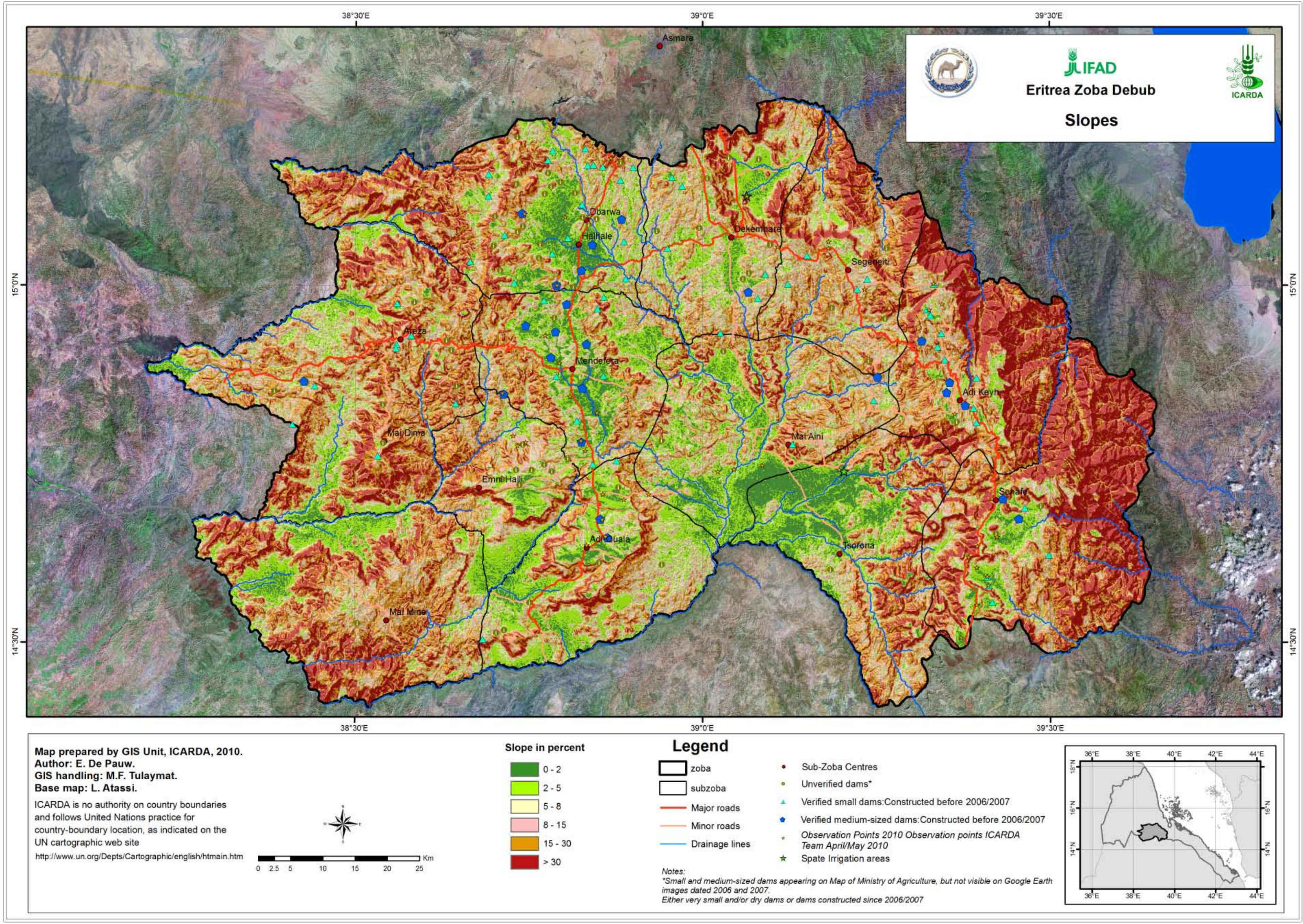

Eritrea Zoba Debub
Geology
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
Source: Geological Map of Eritrea (Department of Mines, 2008)
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Geology
Paas
Pabs
Pobs
Pasv
Pmuf
port
Pdt
Pbzv
Qh
Tas
Qc
Pzt
Pbzw
Palt
Pzvs
Pmvs
Pmuv
Pgpg
pdgt
Pdgt?
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
14°N
16°N
18°N

# Eritrea Zoba Debub: Geology
## Legend

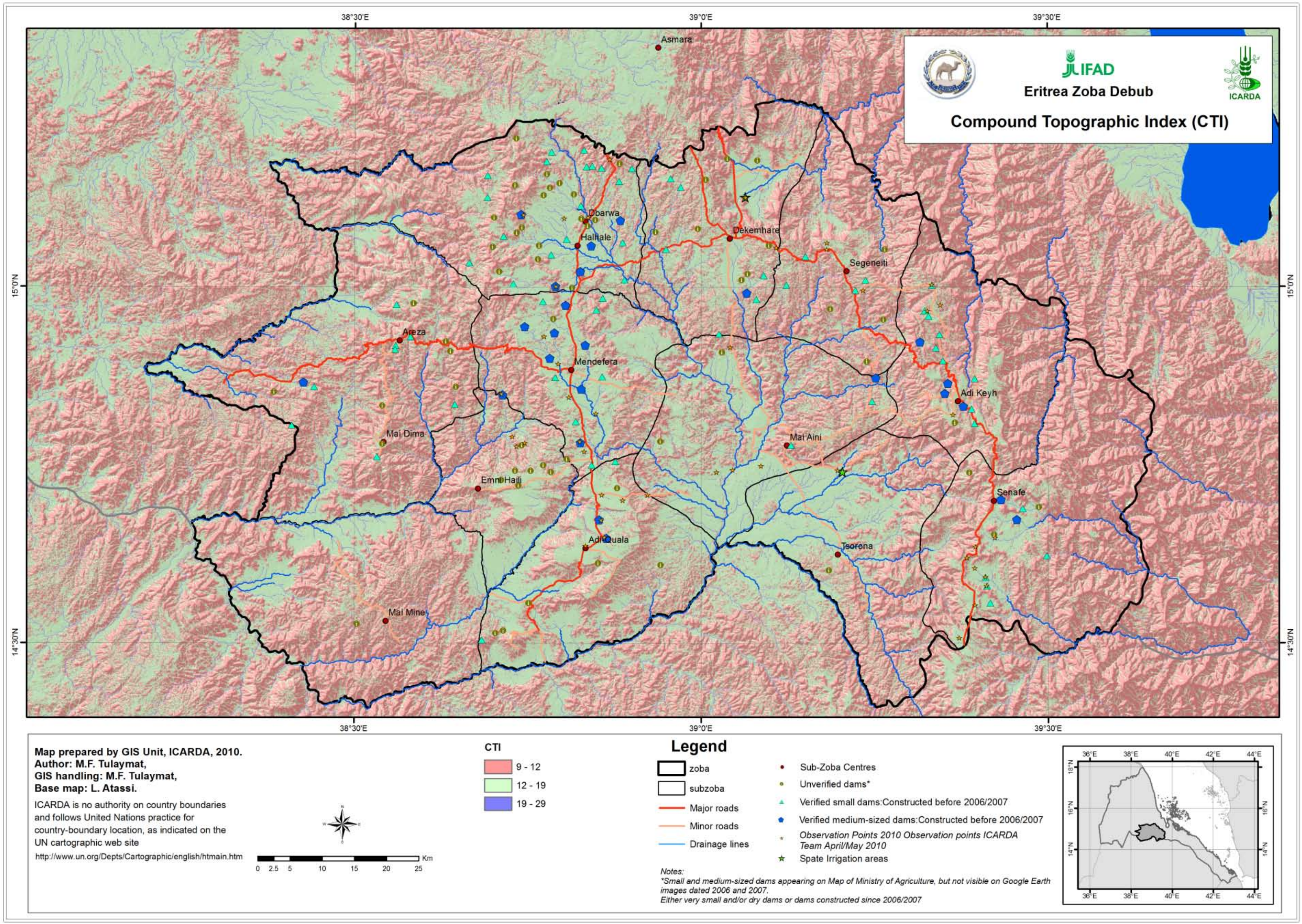
| Color | Class | Description |
|---|---|---|
| | Paas | Asmara Basalt includes undifferentiated flood basalts |
| | Pabs | Adi Quala basalt aphyric to weakly porphyric flood basalt |
| | Pobs | Adi Ugri Basalt |
| | Pasv | Lower Volcanics (Asmara Group of Mafic flows, mafic to intermediate tuffs and felsic flows and associated tuffs |
| | Pmuf | Mafic- ultramafic rocks sheared |
| | Port | Seraye rhyolite |
| | Pdt | Meta-diorites |
| | Pbzv | Intermediate and basic lavas, greywack, tuffaceous slate, phyllite, agglomerate rhyolite |
| | Qh | Recent sediments undifferentiated, conglomerates, sands, silt clays, coral reef, alluvium and aolian sediments |
| | Tas | Adi Grat (Lower variagated quartzose) sandstone of fluviatile and/or littoral origin |
| | Qc | Collvium scree or talus with finer sediment |
| | Pzt | Enticho sandstone and Edaga Arbi Glacials not divided. Sandstone, conglomerates shale, erratic boulders, tillite |
| | Pbzw | Black slate, calcareous intercalations of slate |
| | Palt | Laterite which is commonly found at the upper laterized part of basement rocks |
| | Pzvs | Undifferentiated metavolcanic rocks and metasediments |
| | Pmvs | Meta-volcanic of intermediate composition |
| | Pmuv | Undifferentiated metavolcanic and/or volcanic pyroclasti rocks |
| | Pgpg | Pelitic (staurolite, Kyanite and garnet-bearing) schists and gneisses |
| | Pdgt | Late- to post-tectonic granite |
| | Pdgt? | |



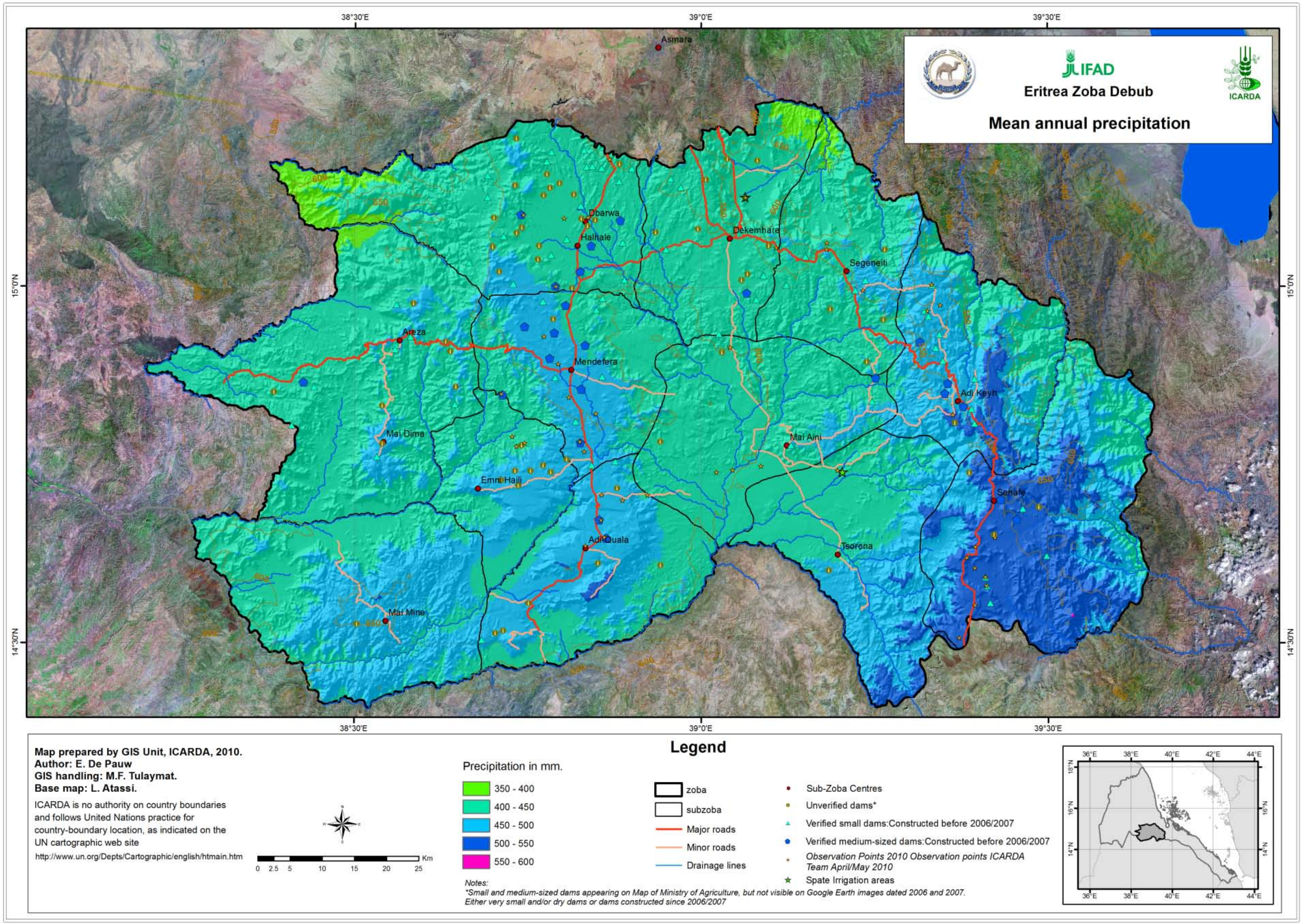
Eritrea Zoba Debub
Elevation
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Elevation in meter
900 - 1000
1000 - 1200
1200 - 1400
1400 - 1600
1600 - 1800
1800 - 2000
2000 - 2200
2200 - 2400
2400 - 2600
2600 - 2800
2800 - 3000
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N 16°N 14°N

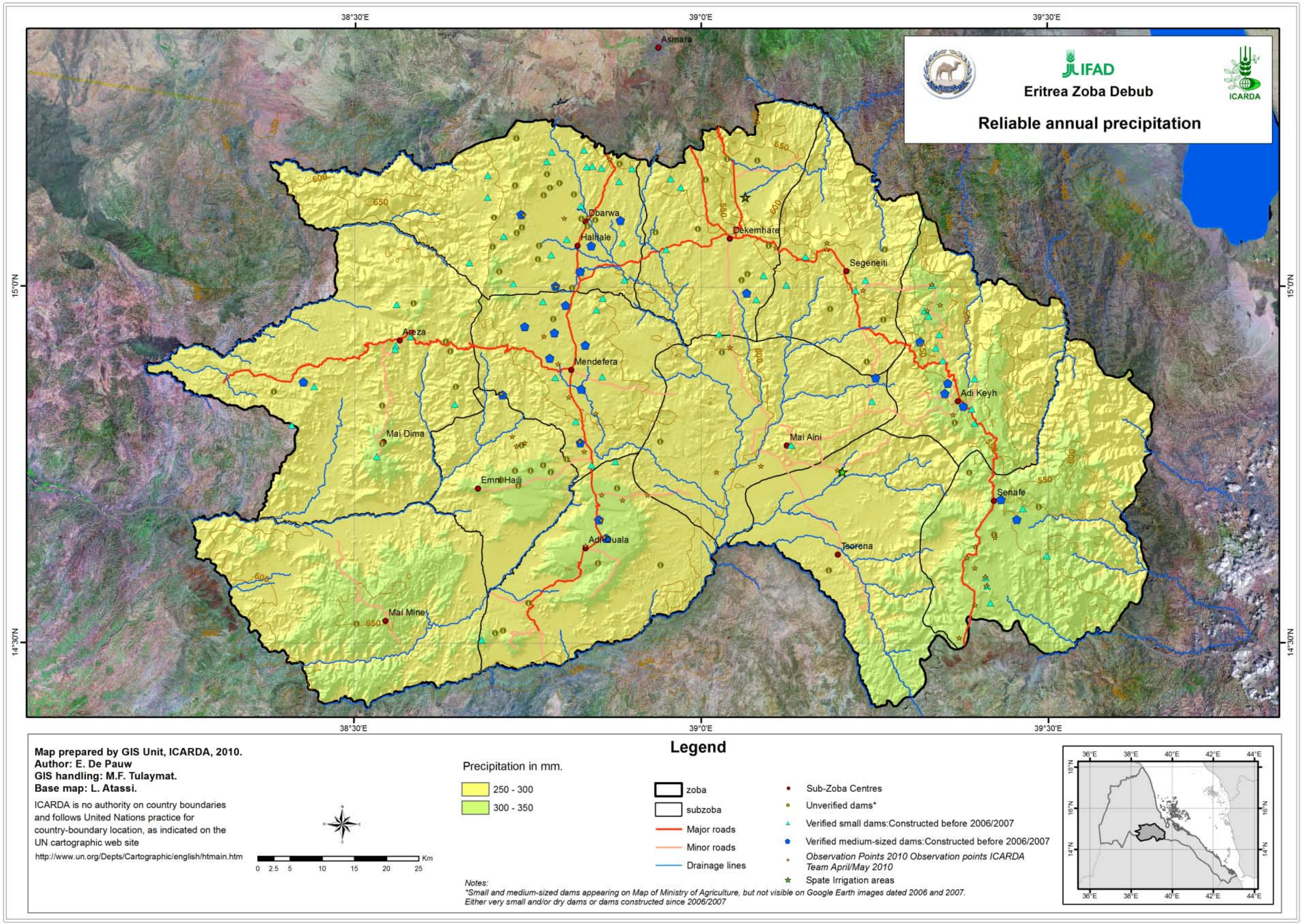


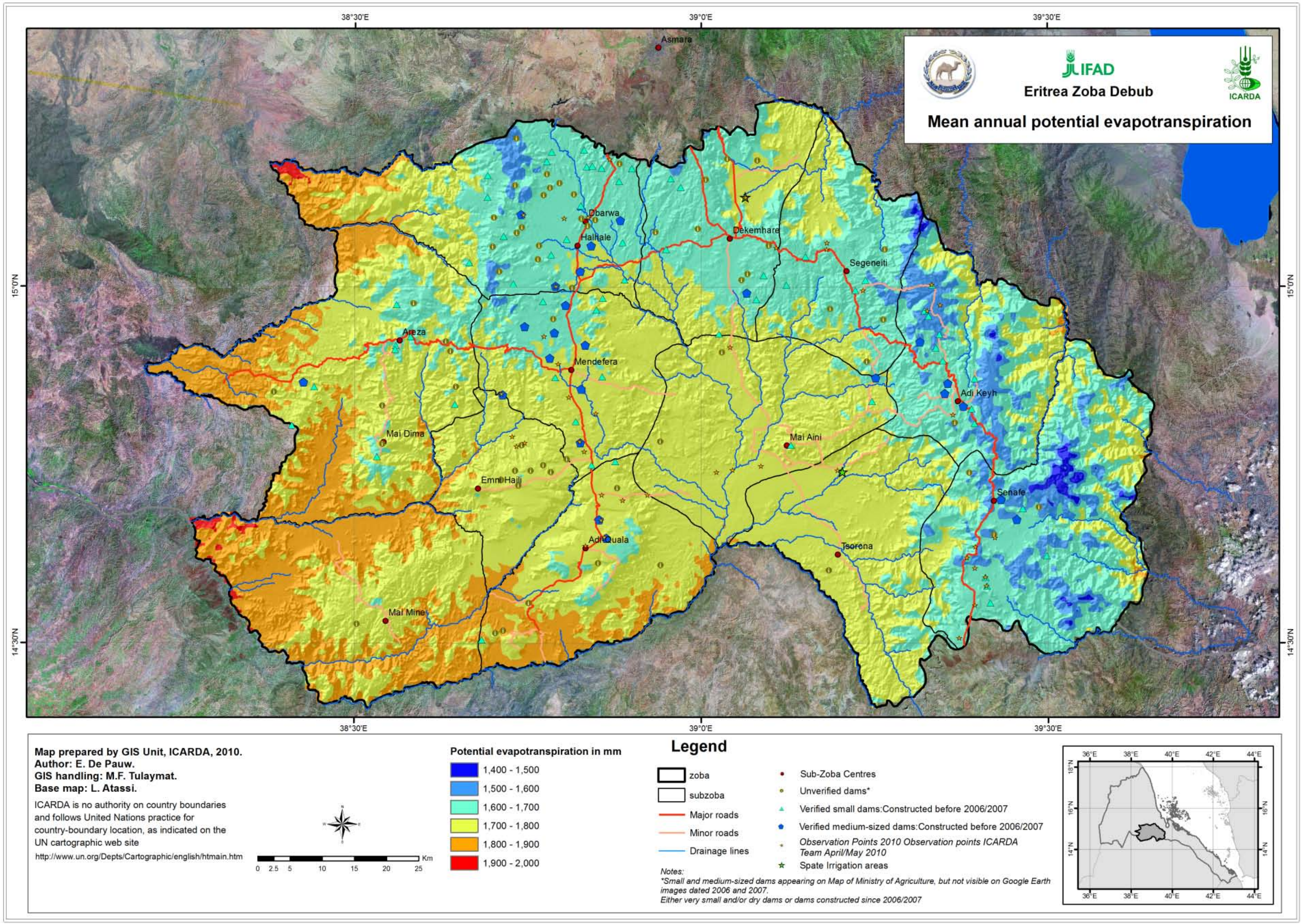
Eritrea Zoba Debub
Slopes
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Slope in percent
0 - 2
2 - 5
5 - 8
8 - 15
15 - 30
> 30
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
18°N
16°N
14°N



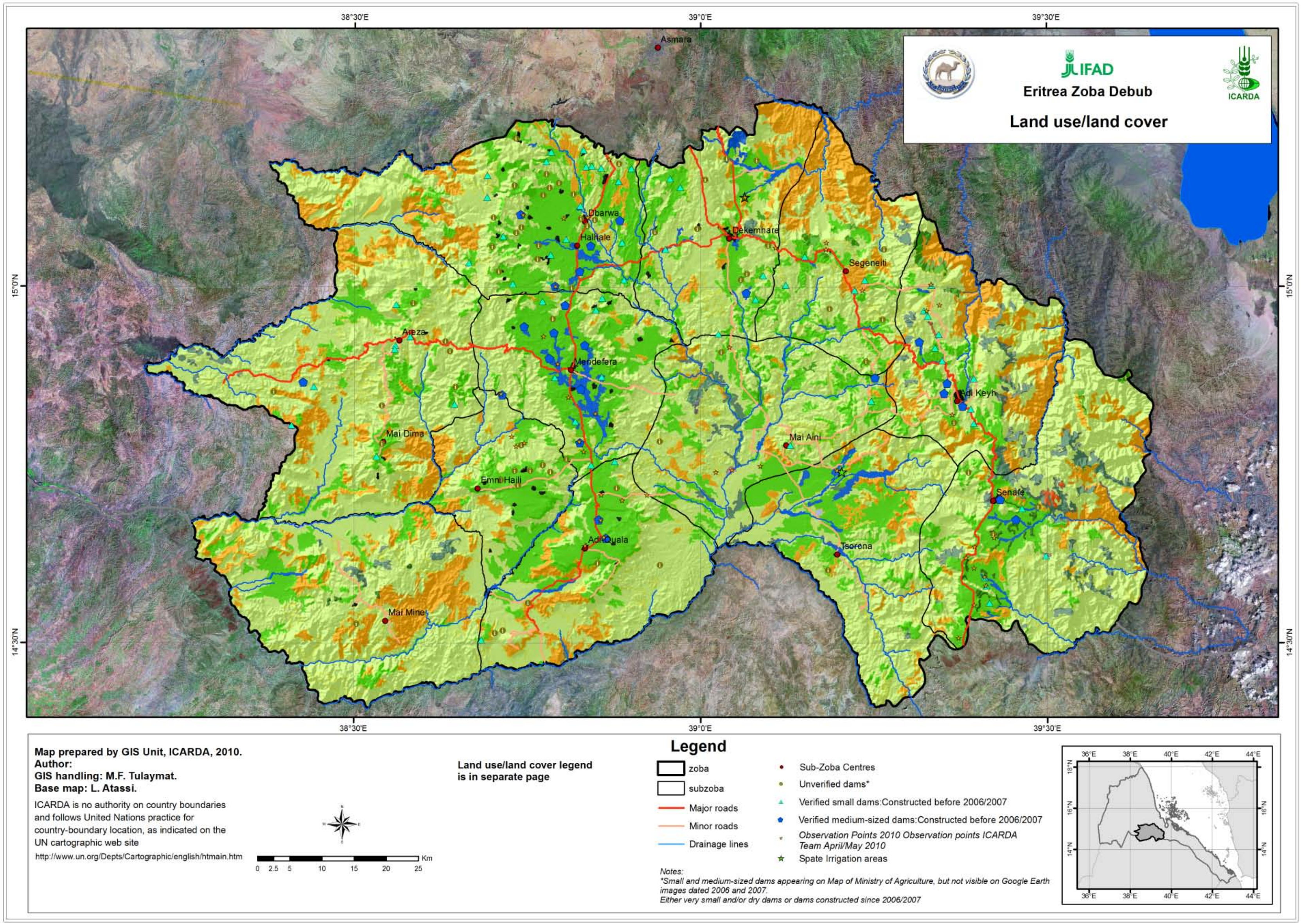
Eritrea Zoba Debub
Compound Topographic Index (CTI)
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: M.F. Tulaymat,
GIS handling: M.F. Tulaymat,
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
CTI
9 - 12
12 - 19
19 - 29
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N
16°N
14°N


Eritrea Zoba Debub
Mean annual precipitation
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Precipitation in mm.
350 - 400
400 - 450
450 - 500
500 - 550
550 - 600
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N 16°N 14°N


IFAD
Eritrea Zoba Debub
ICARDA
Reliable annual precipitation
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
550
600
650
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Precipitation in mm.
250 - 300
300 - 350
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
14°N
16°N
18°N



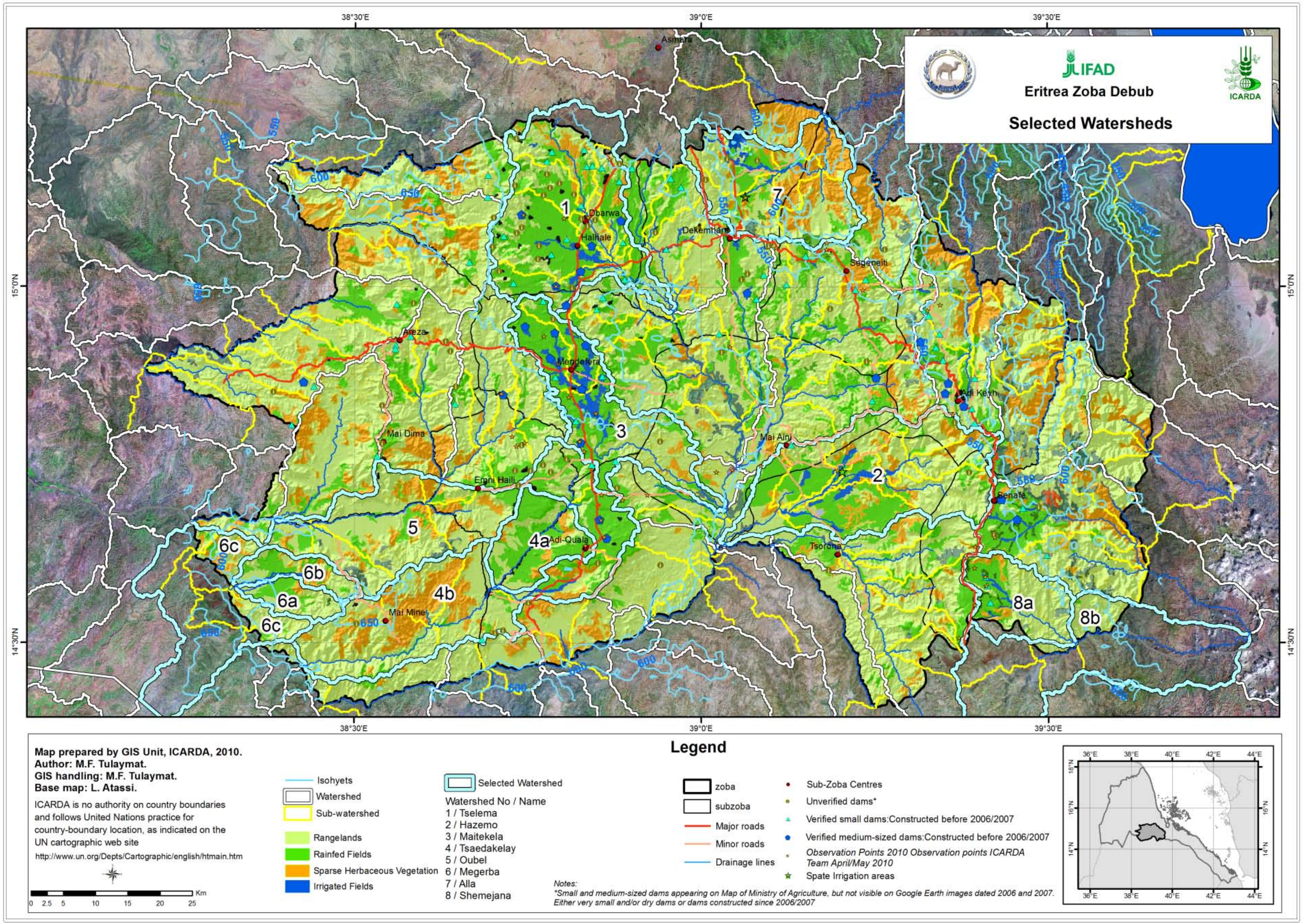
Eritrea Zoba Debub
Mean annual potential evapotranspiration
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Potential evapotranspiration in mm
1,400 - 1,500
1,500 - 1,600
1,600 - 1,700
1,700 - 1,800
1,800 - 1,900
1,900 - 2,000
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
0 2.5 5 10 15 20 25 Km



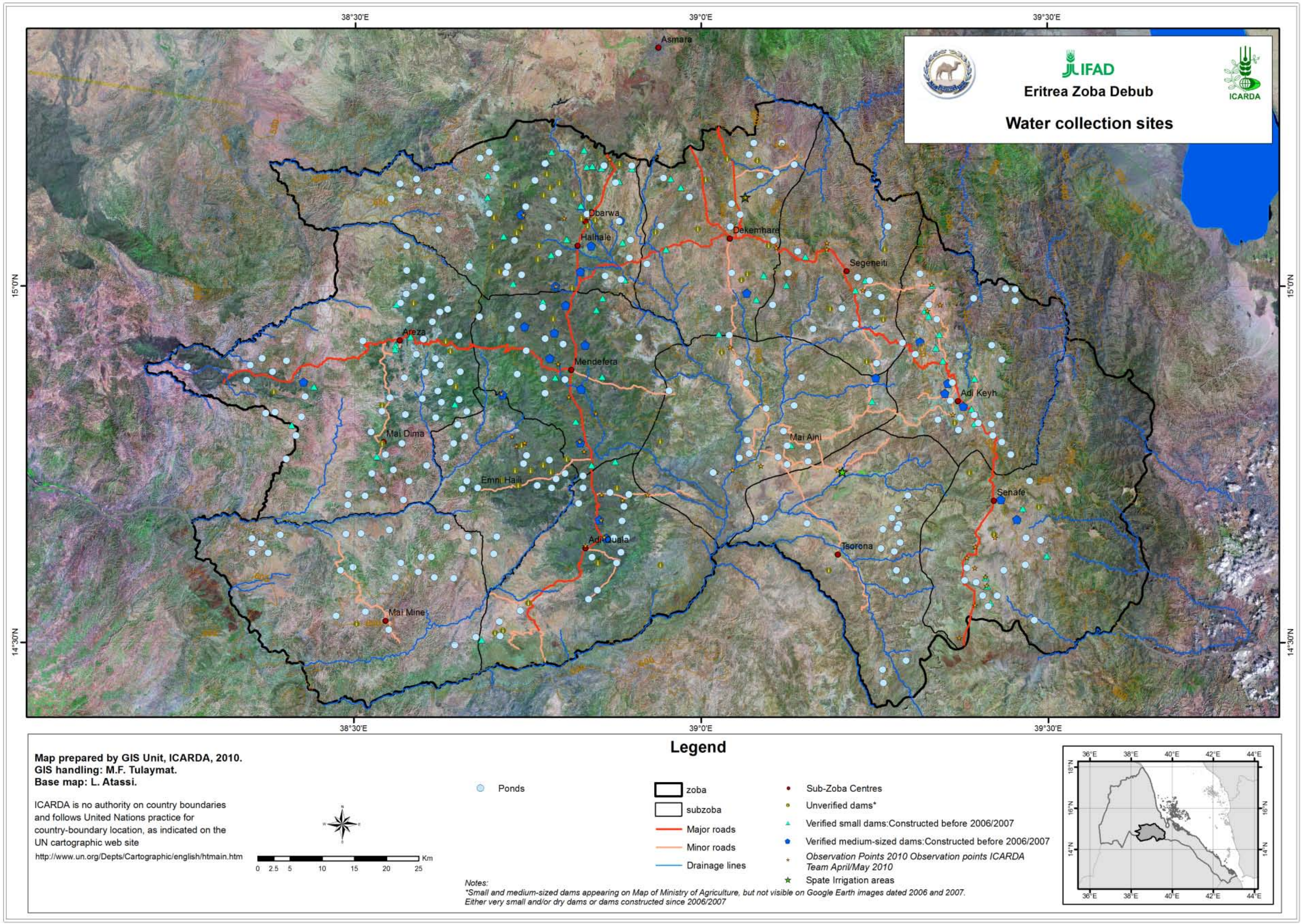
IFAD
Eritrea Zoba Debub
ICARDA
Land use/land cover
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author:
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Land use/land cover legend is in separate page
Legend
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N
16°N
14°N

## Eritrea Zoba Debub: Land use/land cover
## Legend

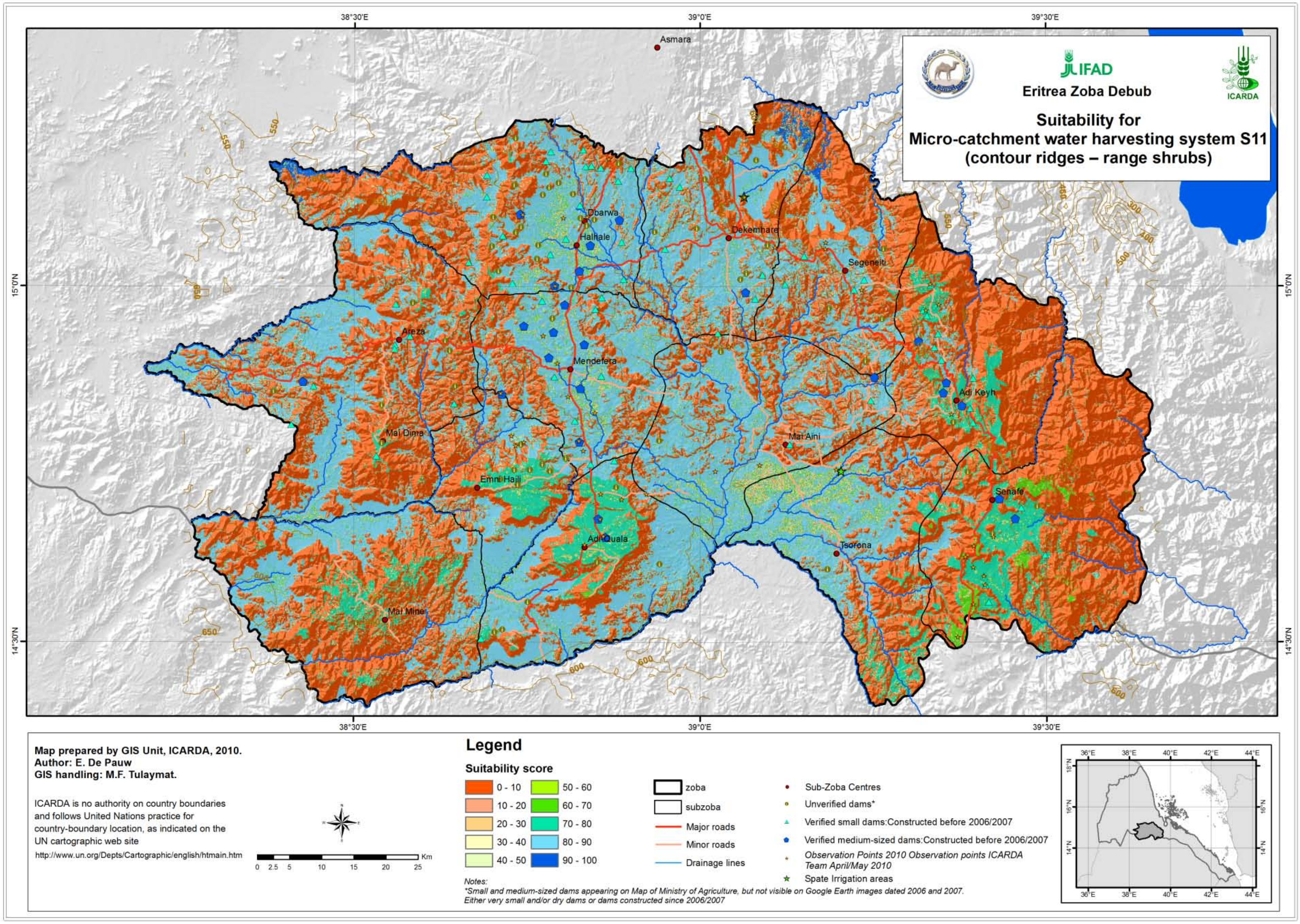
- Artificial Waterbodies
- Bare rocks and river banks
- Bare soil
- Closed Herbacous Vegetation (Seasonally Flooded)
- Closed Shrubs
- Closed Trees (Broadleaved Evergreen)
- Closed Trees (Needle leaved Evergreen)
- Closed Woody Vegetation Thickets
- Closed to Open Herbaceous Vegetation
- Irrigated Herbaceous Fields
- Irrigated Herbaceous Fields (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
- Irrigated Shrub Crop - Banana
- Irrigated Tree Crop - Citrus
- Irrigated Tree Crop - Citrus (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
- Isolated (in natural vegetation or other) Rainfed Small Herbaceous Fields (field frequency 10-20% polygon area)
- Open Shrubs
- Open Trees
- Rainfed Large to Medium Herbaceous Fields
- Rainfed Small Herbaceous Fields
- Rainfed Small Herbaceous Fields (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
- Savannah (Shrub or Tree and Shrub)
- Scattered (in natural vegetation or other) Irrigated Herbaceous Fields (field frequency 20-40% polygon area)
- Scattered (in natural vegetation or other) Rainfed Small Herbaceous Fields (field frequency 20-40% polygon area)
- Scattered (in natural vegetation or other) Tree Plantation - Eucalyptus (field frequency 20-40% polygon area)
- Sparse Herbaceous Vegetation
- Sparse Shrubs
- Sparse Trees
- Tree Plantation - Eucalyptus
- Tree Plantation - Eucalyptus (mixed unit with natural vegetation or other) (field area approx. 60% polygon area)
- Urban and Associated Areas

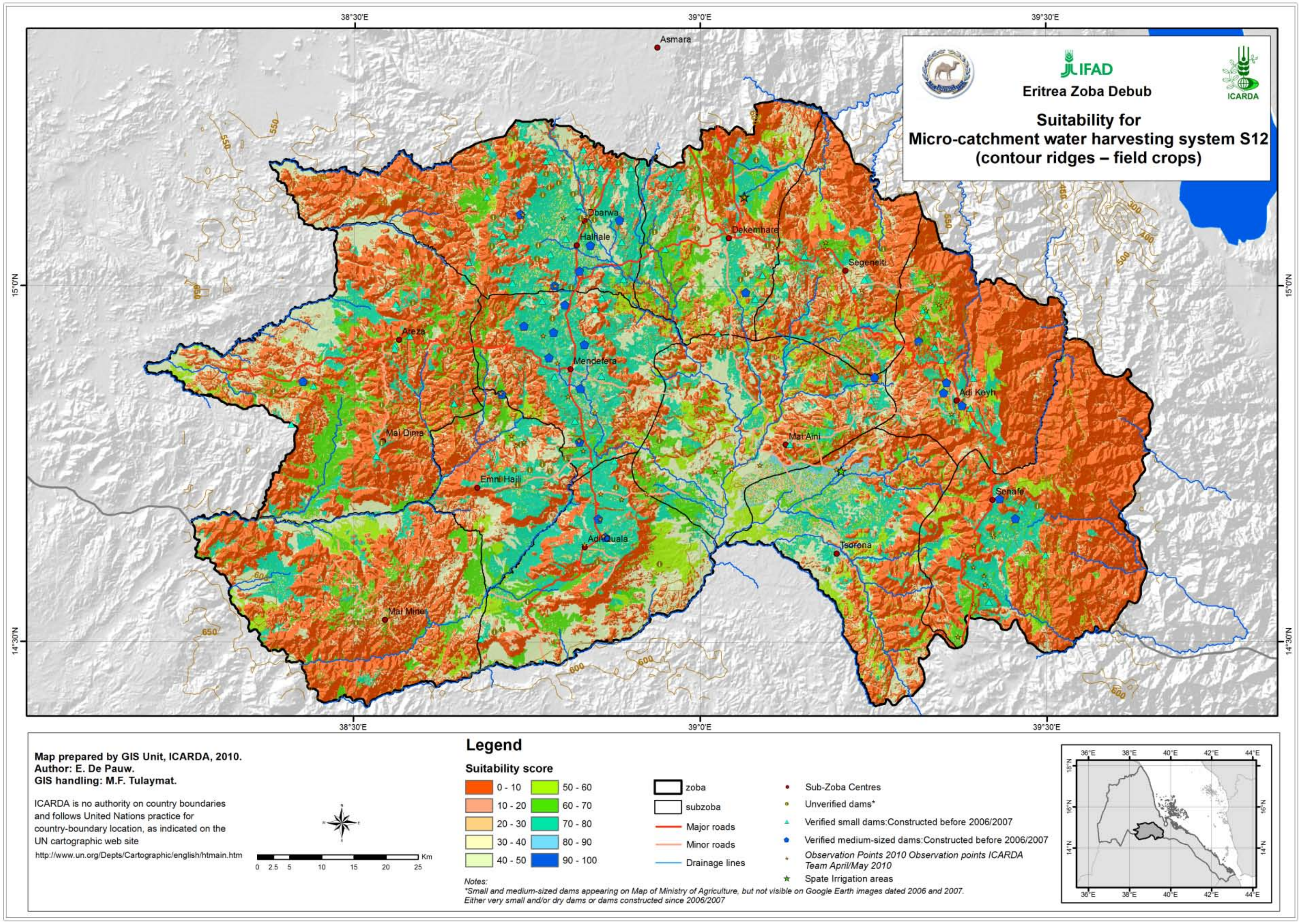


IFAD
Eritrea Zoba Debub
ICARDA
Selected Watersheds
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi-Quala
Tsorona
Mai Mine
1
2
3
4a
4b
5
6a
6b
6c
7
8a
8b
Map prepared by GIS Unit, ICARDA, 2010.
Author: M.F. Tulaymat.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Isohyets
Watershed
Sub-watershed
Rangelands
Rainfed Fields
Sparse Herbaceous Vegetation
Irrigated Fields
Selected Watershed
Watershed No / Name
1 / Tselema
2 / Hazemo
3 / Maitekela
4 / Tsaedakelay
5 / Oubel
6 / Megerba
7 / Alla
8 / Shemejana
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007

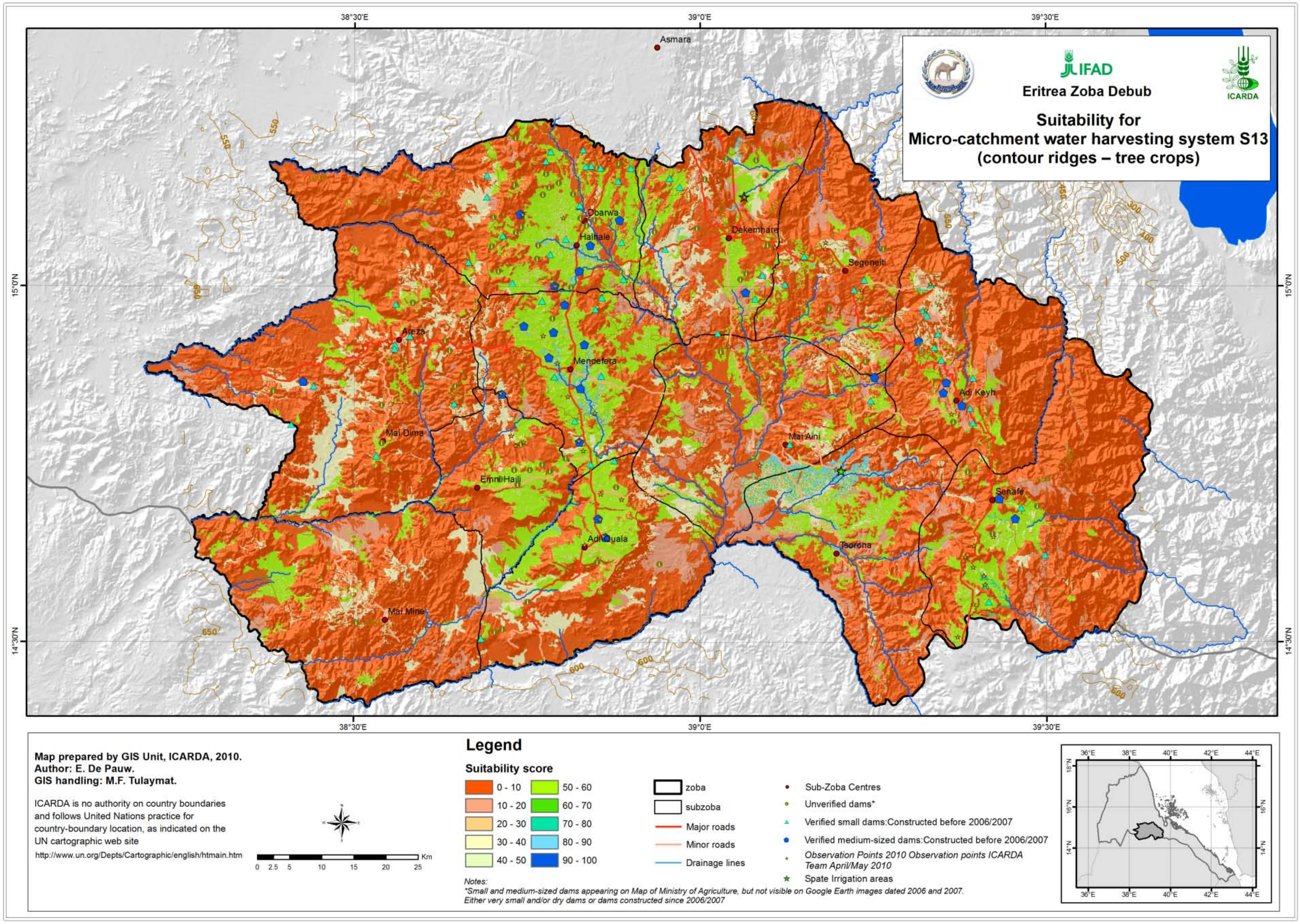


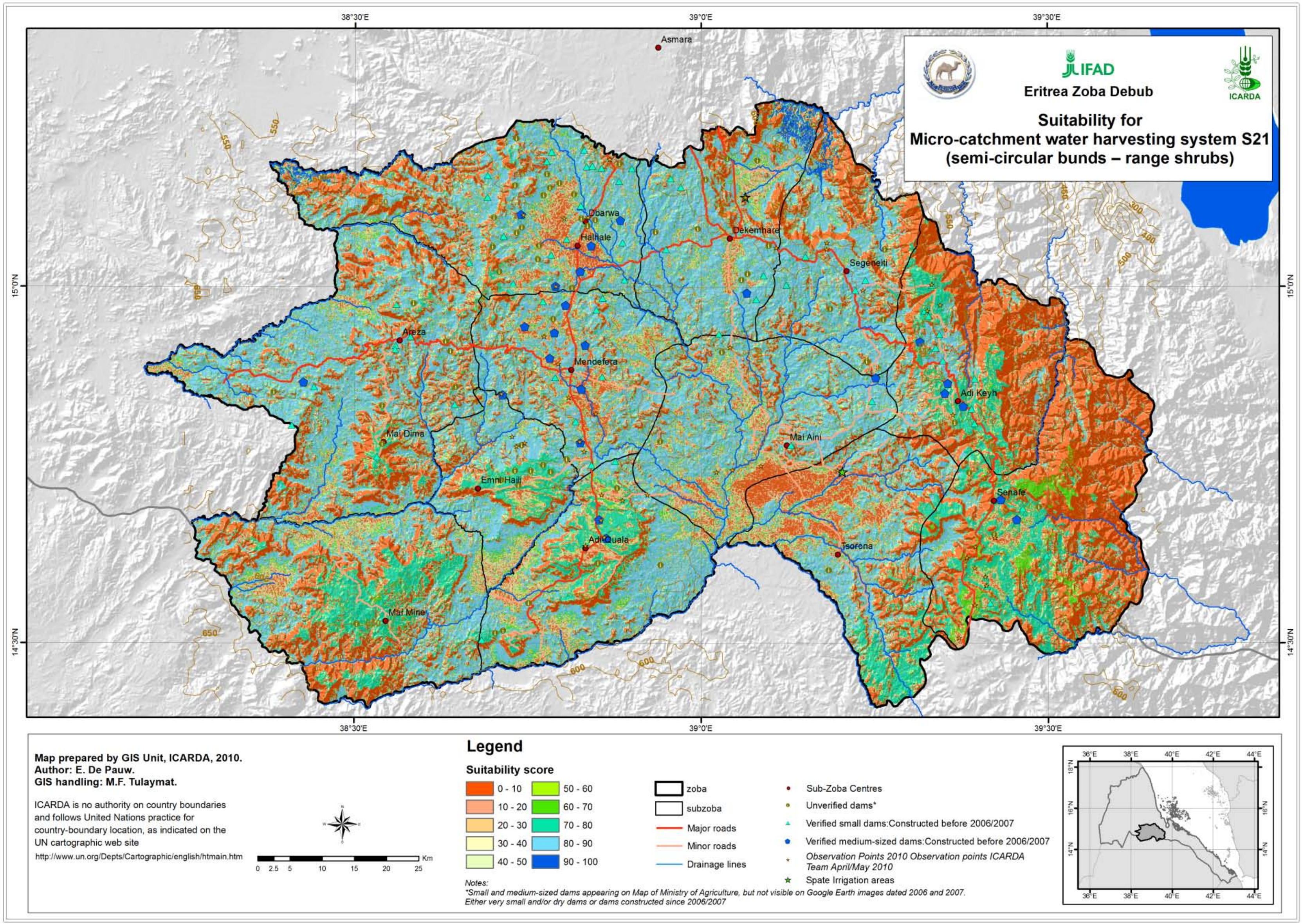
IFAD
Eritrea Zoba Debub
Water collection sites
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi Quala
Tsorona
Mai Mine
Legend
Map prepared by GIS Unit, ICARDA, 2010.
GIS handling: M.F. Tulaymat.
Base map: L. Atassi.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Ponds
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N 16°N 14°N

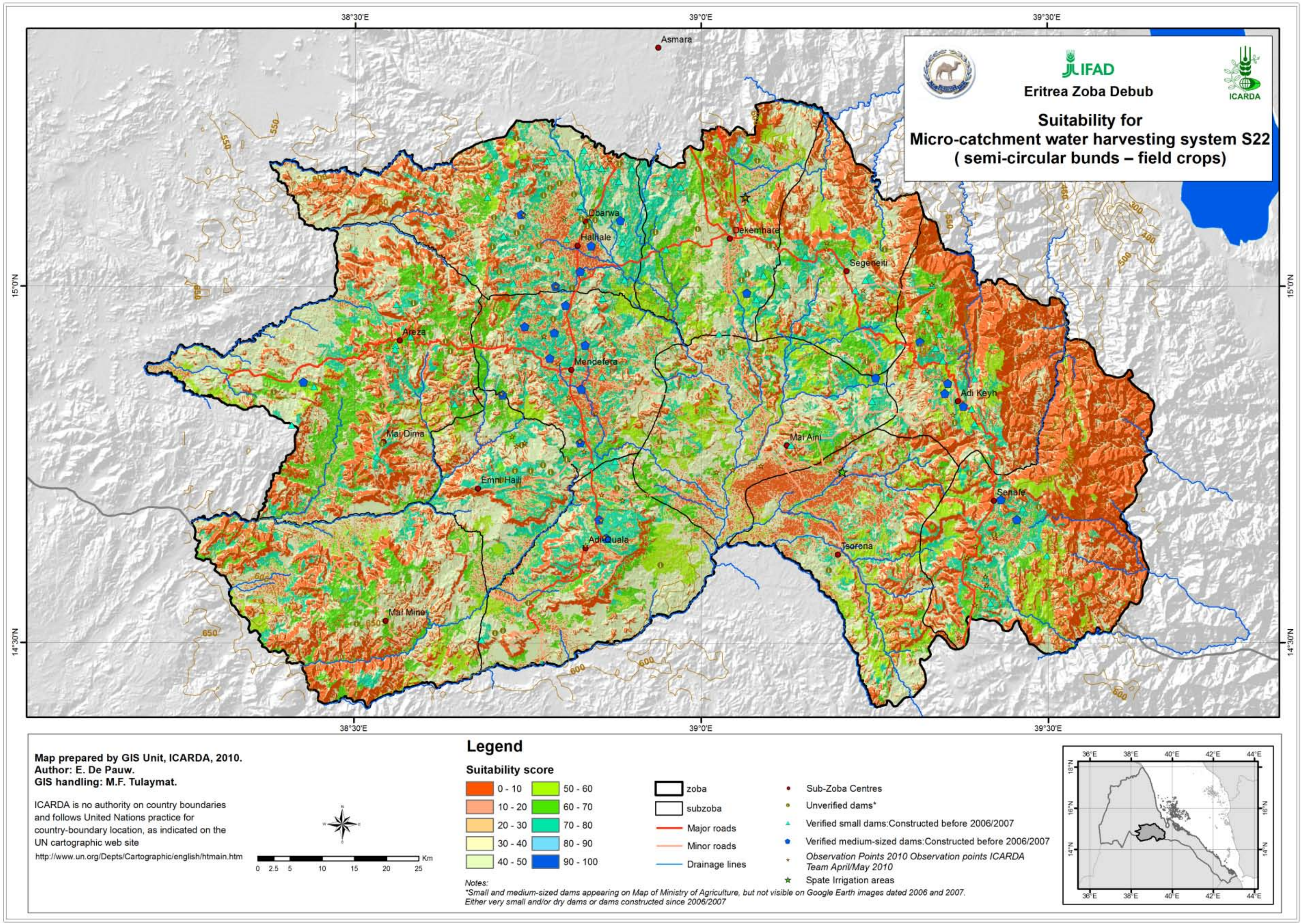

Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S11
(contour ridges – range shrubs)
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajil
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E 38°E 40°E 42°E 44°E
18°N
16°N
14°N

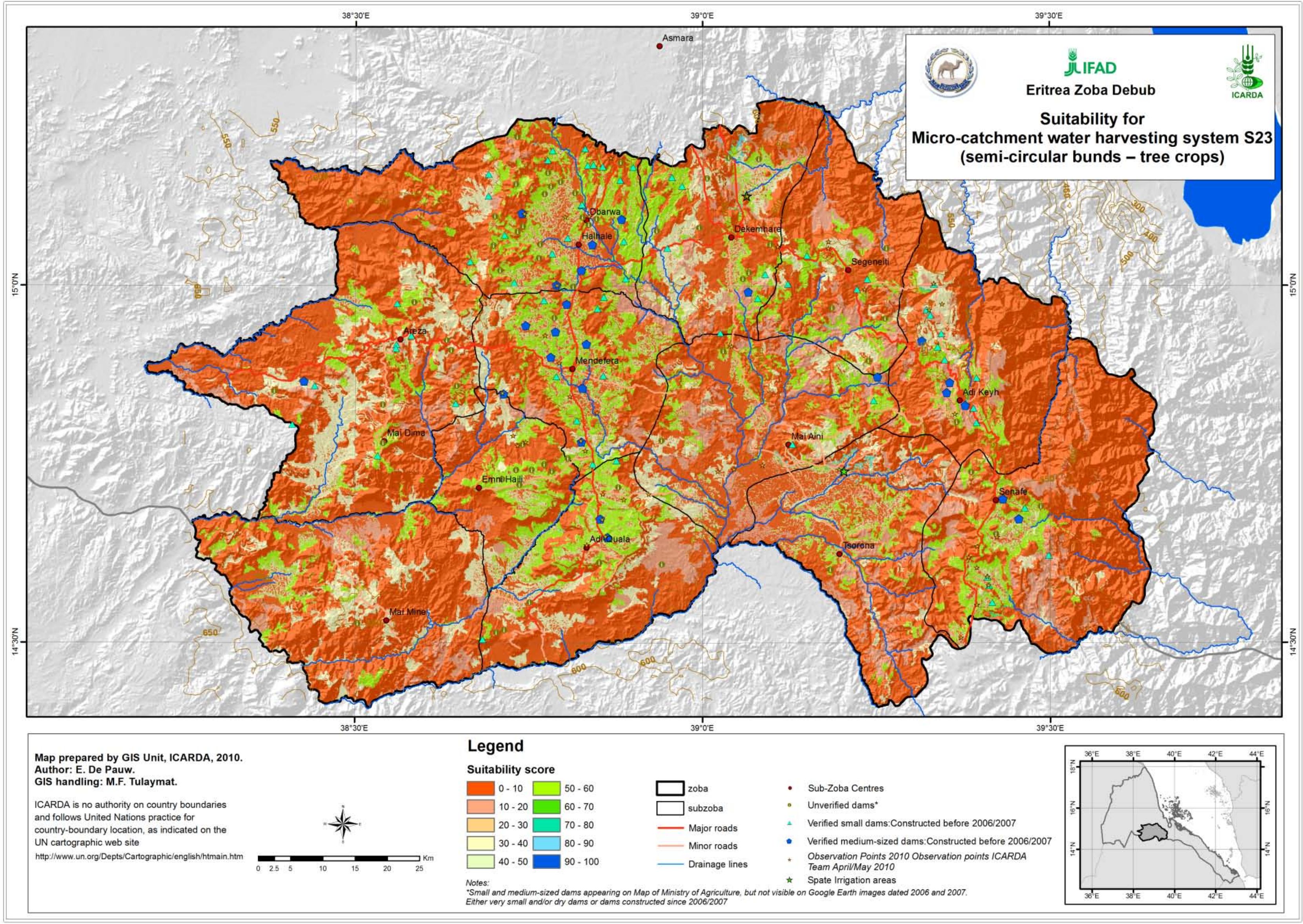


Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S12
(contour ridges – field crops)
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Aini
Mai Dima
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007

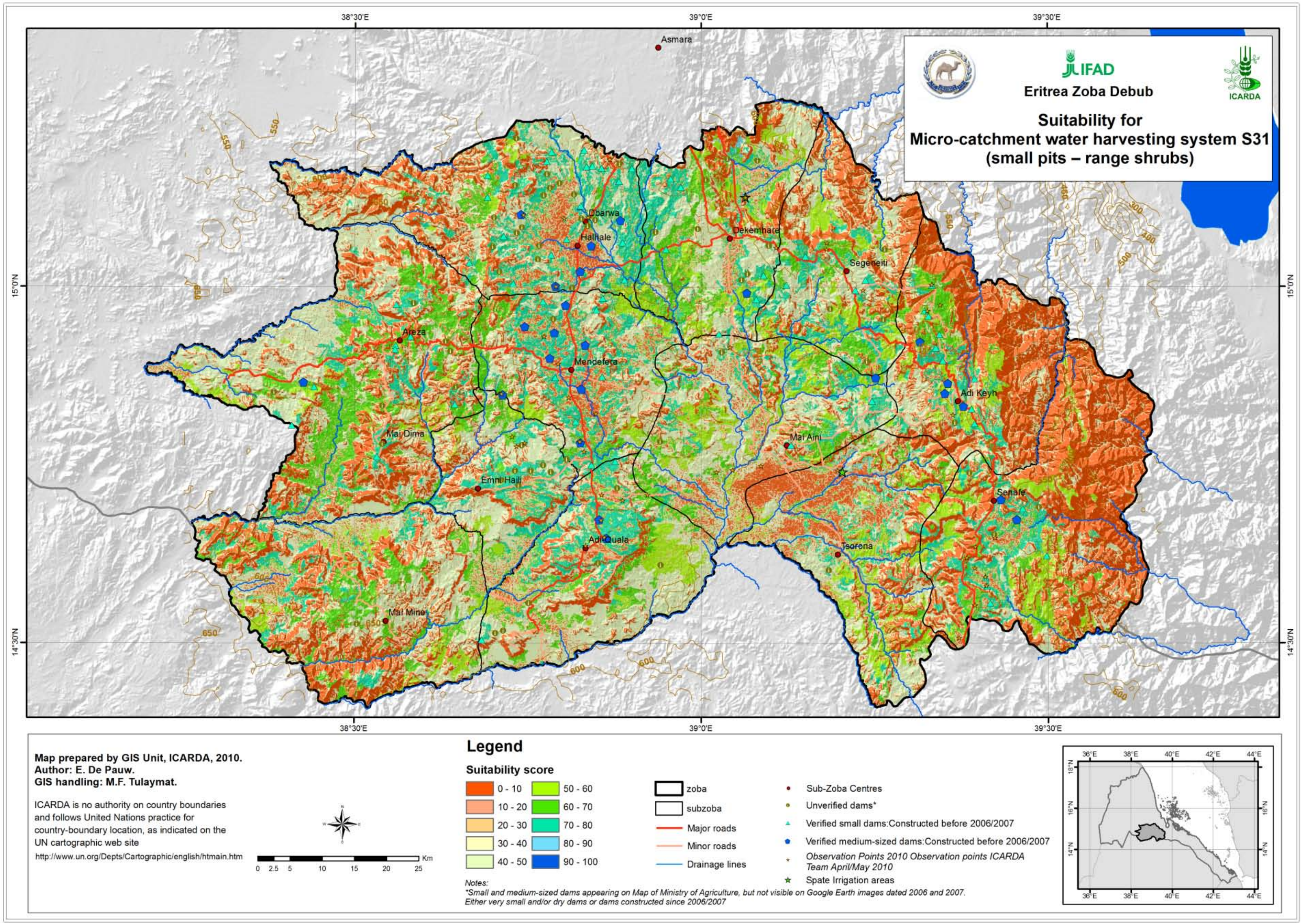

Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S13
(contour ridges – tree crops)
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007


Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S21
(semi-circular bunds – range shrubs)
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007

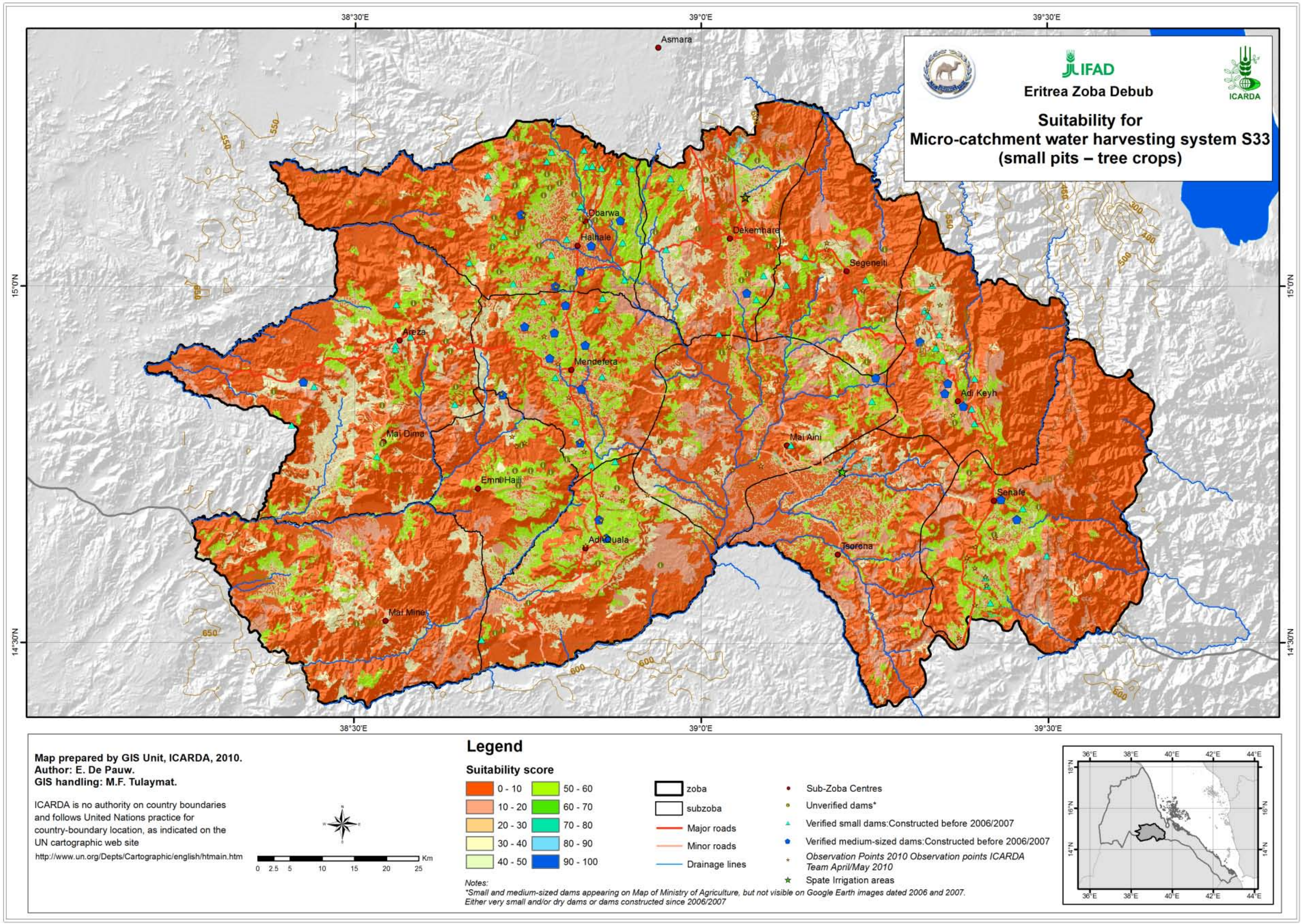

Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S22
( semi-circular bunds – field crops)
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
18°N
16°N
14°N

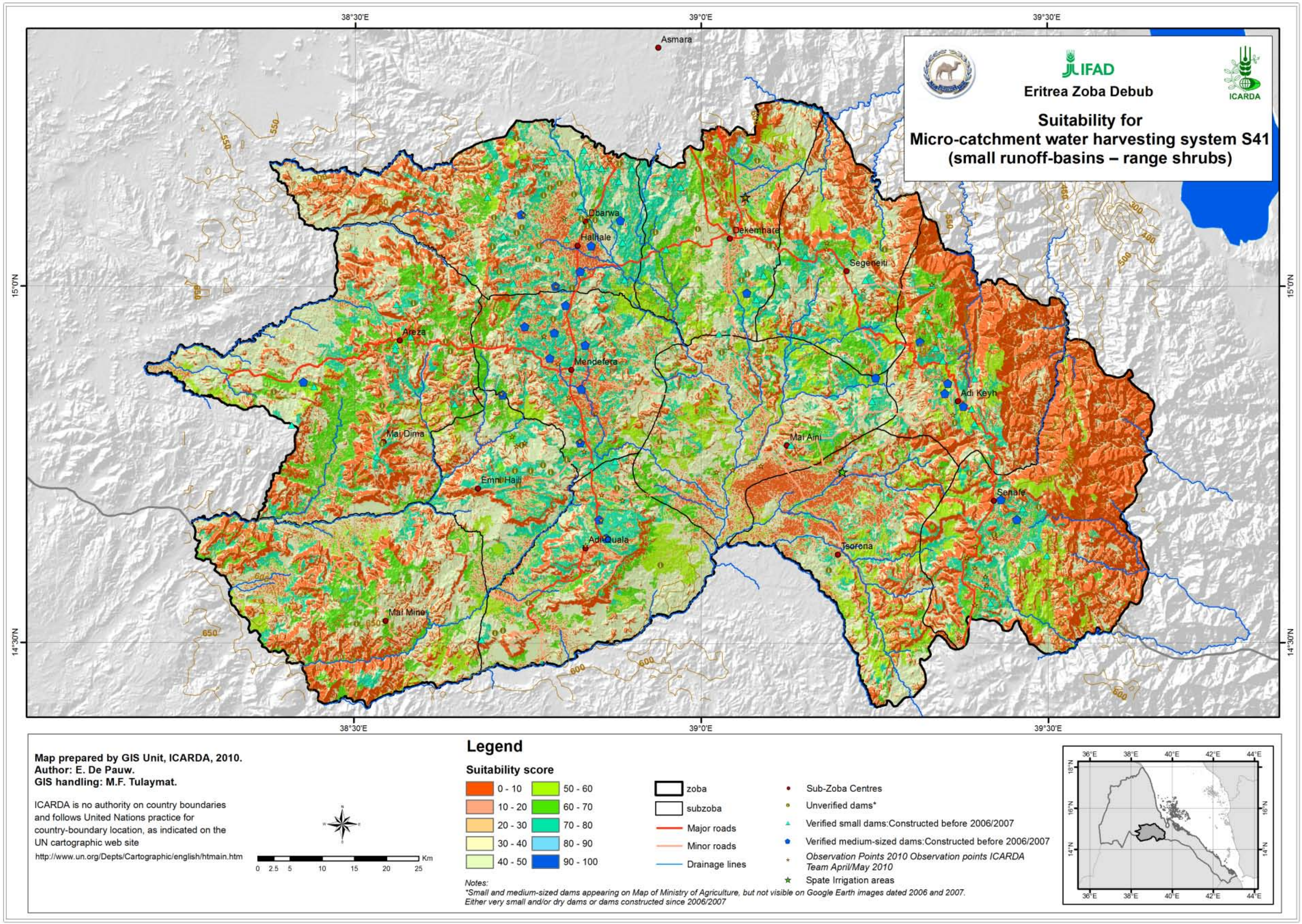


Eritrea Zoba Debub
IFAD
ICARDA
Suitability for
Micro-catchment water harvesting system S23
(semi-circular bunds – tree crops)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007

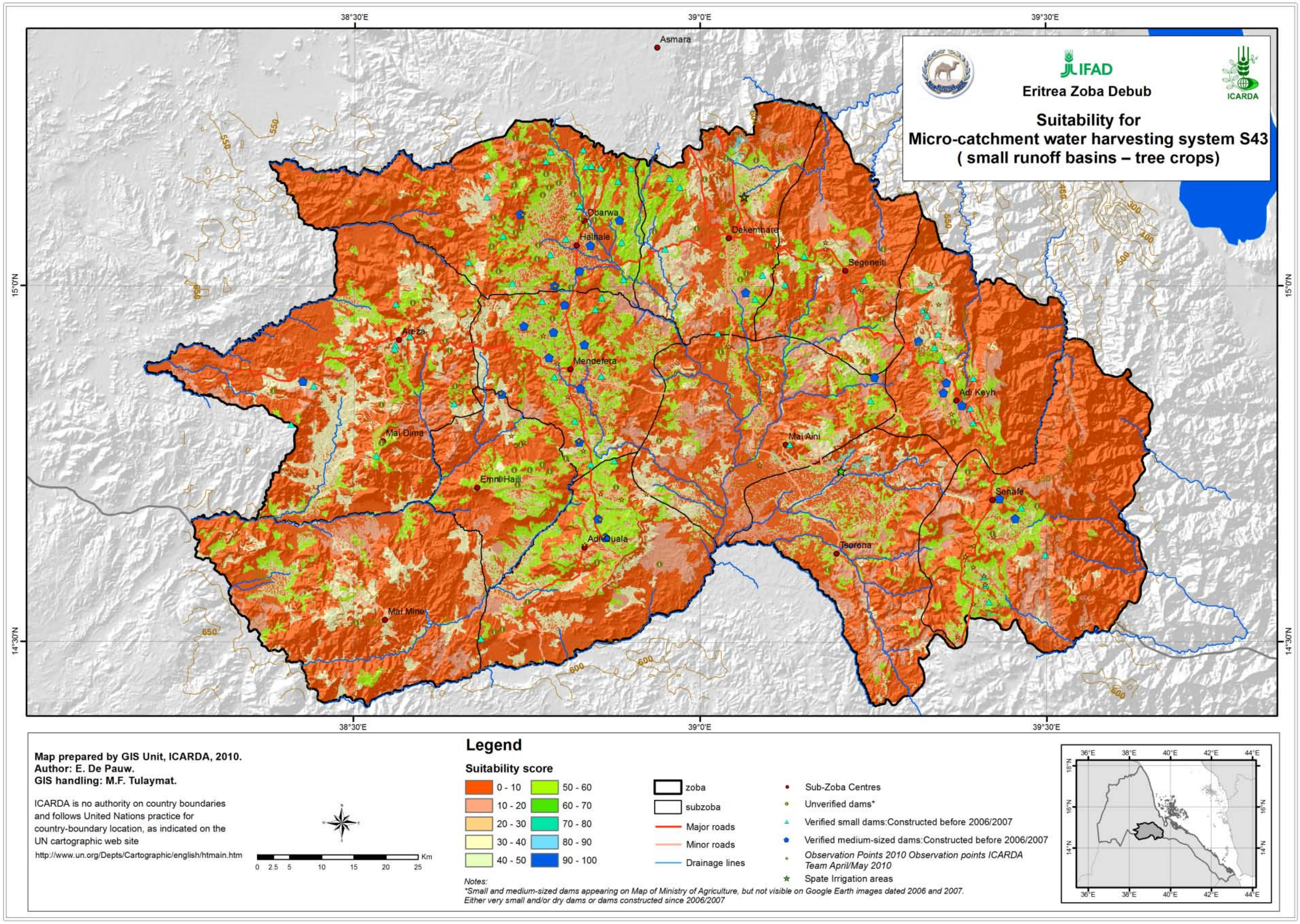


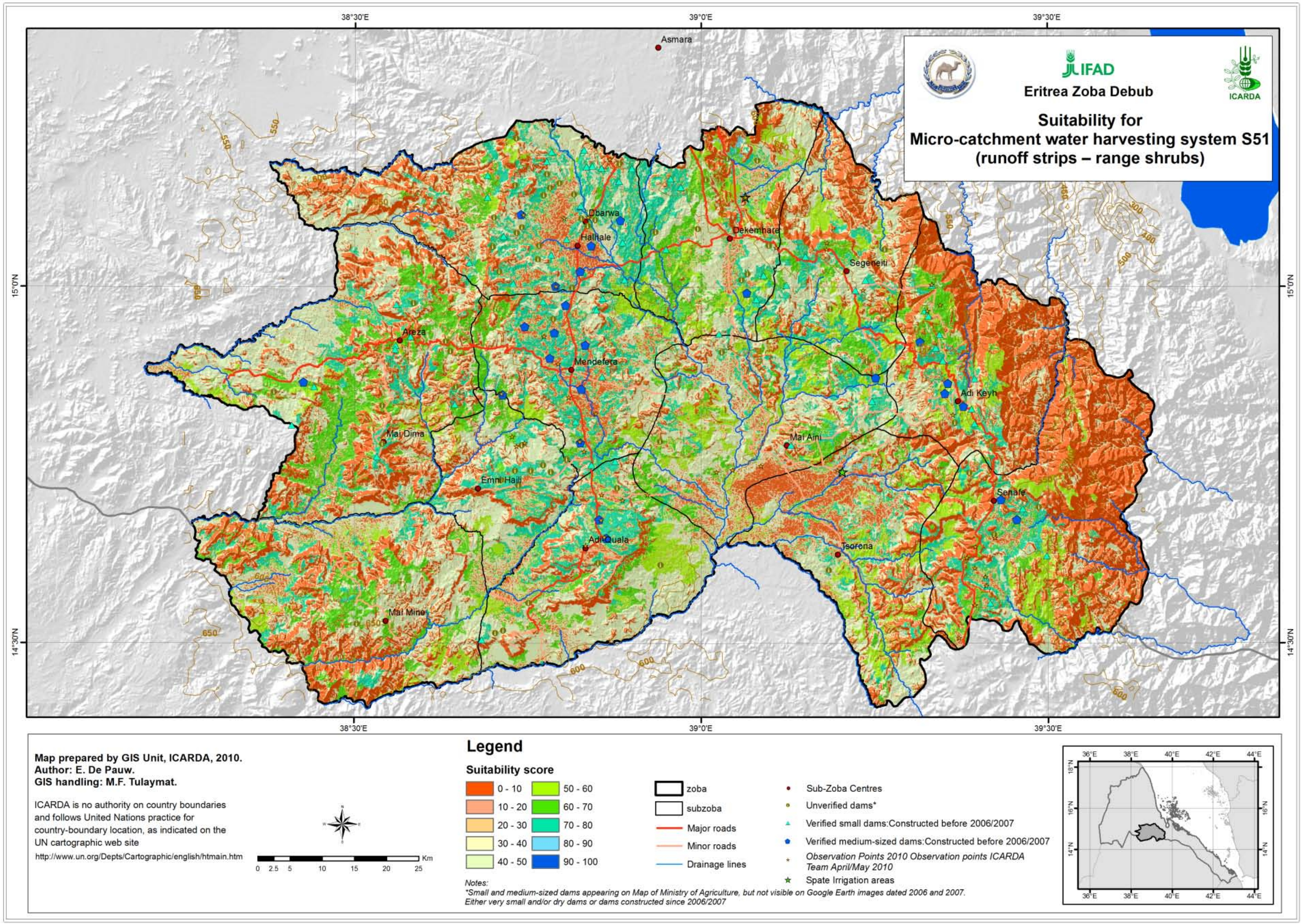
Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S31
(small pits – range shrubs)
IFAD
ICARDA
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
18°N
16°N
14°N

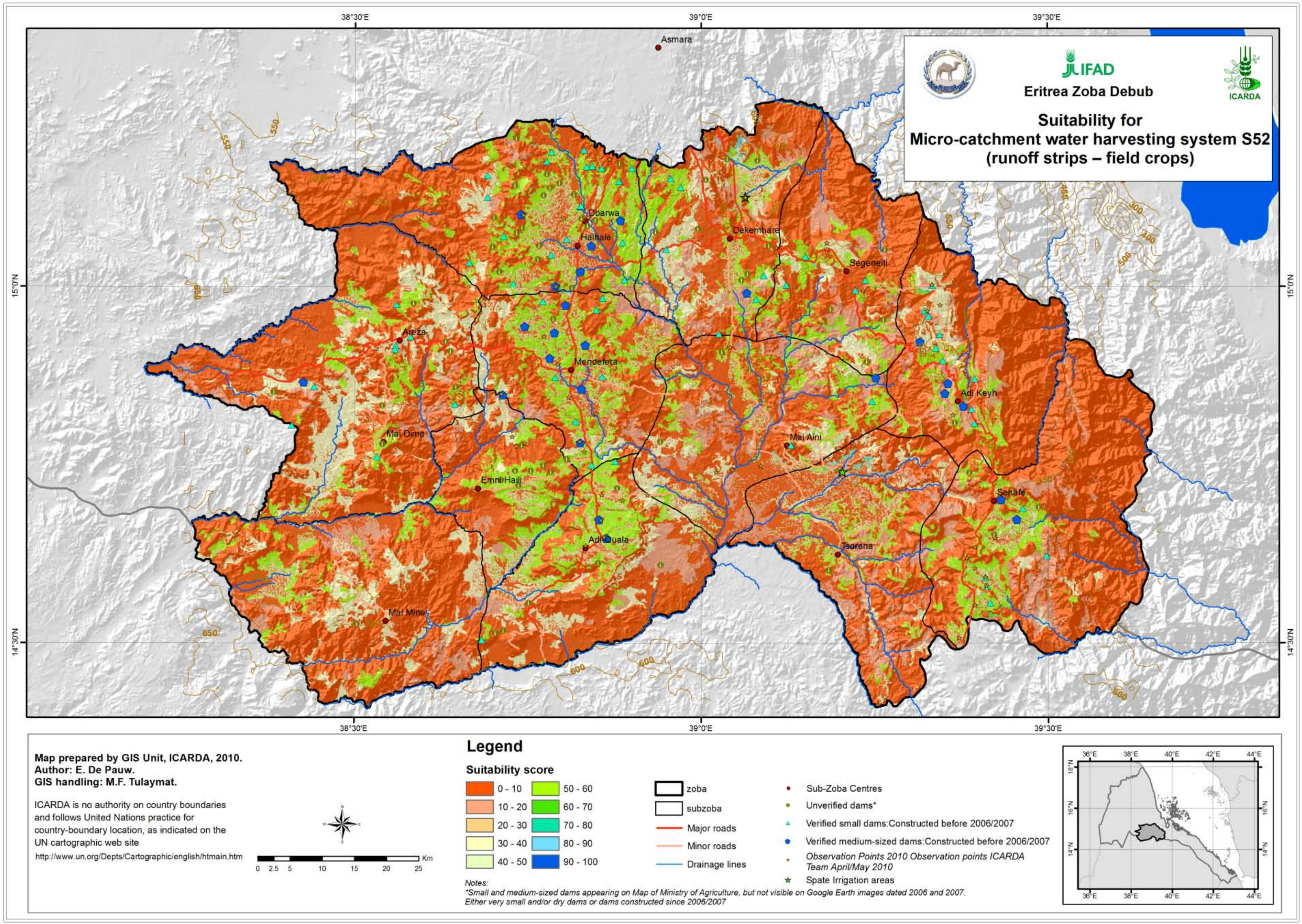

Eritrea Zoba Debub
IFAD
ICARDA
Suitability for
Micro-catchment water harvesting system S33
(small pits – tree crops)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007



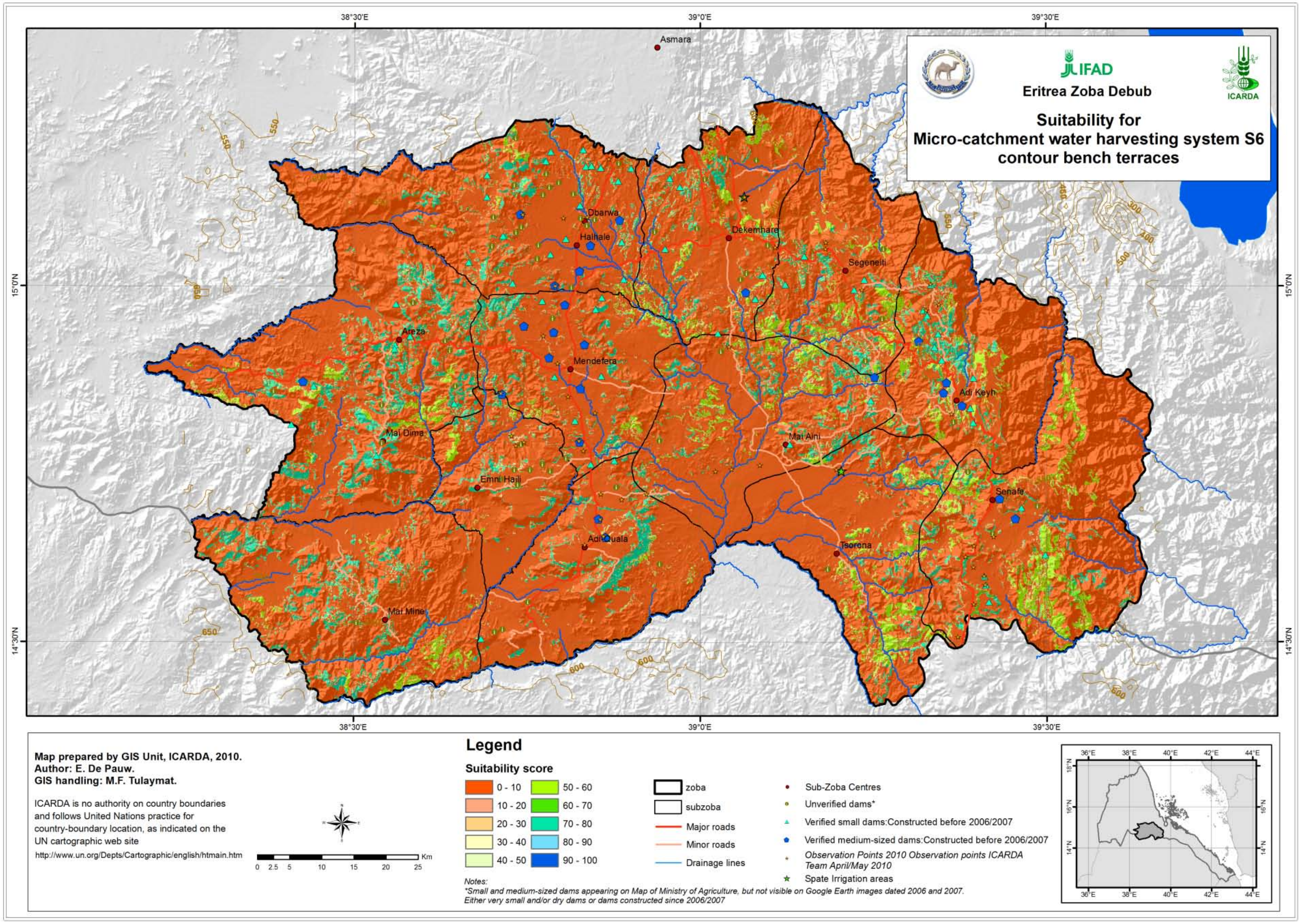
IFAD
Eritrea Zoba Debub
ICARDA
Suitability for
Micro-catchment water harvesting system S41
(small runoff-basins – range shrubs)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007


Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S43
( small runoff basins – tree crops)
IFAD
ICARDA
Asmara
Dbarwa
Hadhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007

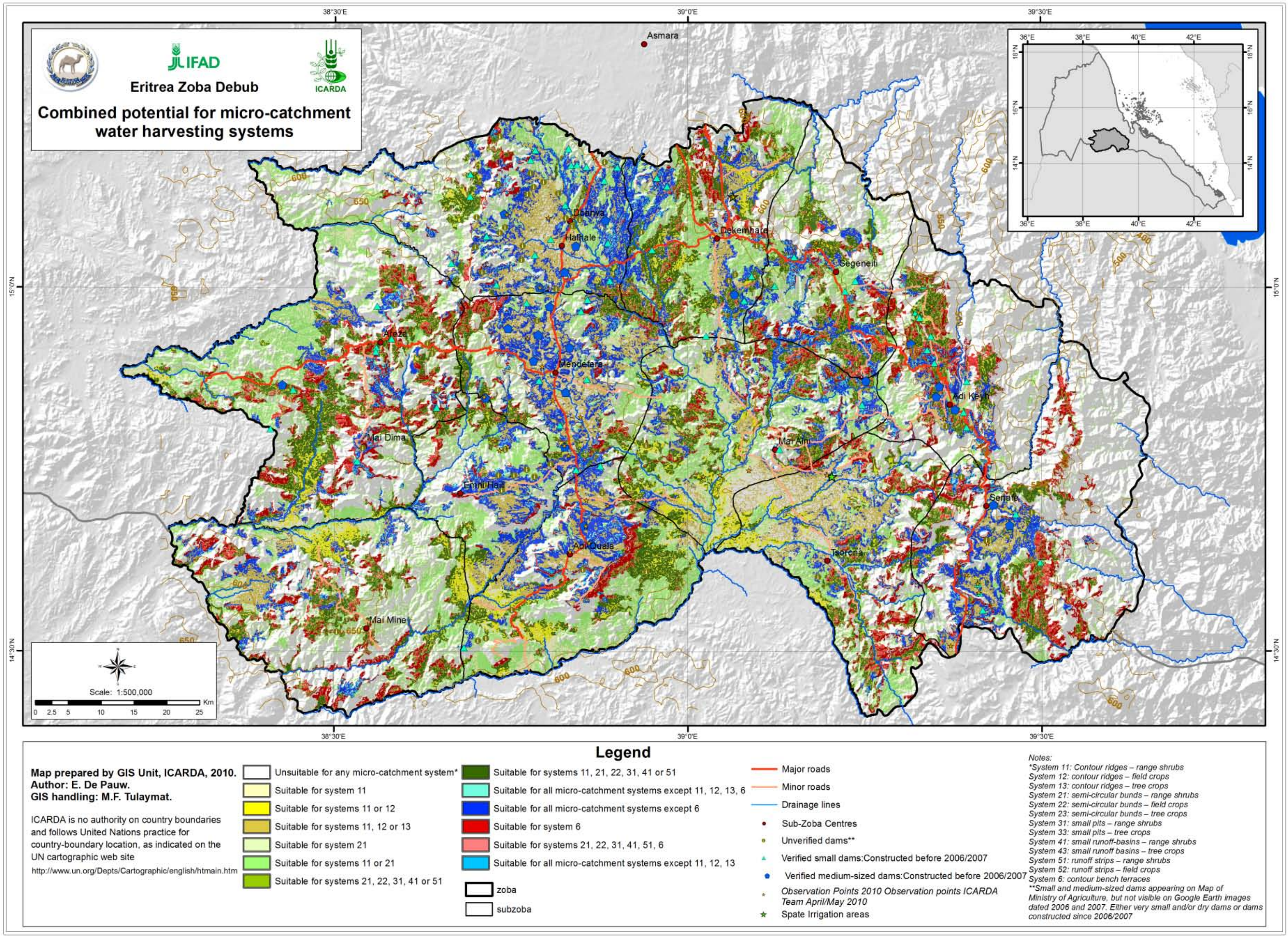

Eritrea Zoba Debub
IFAD
ICARDA
Suitability for
Micro-catchment water harvesting system S51
(runoff strips – range shrubs)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007

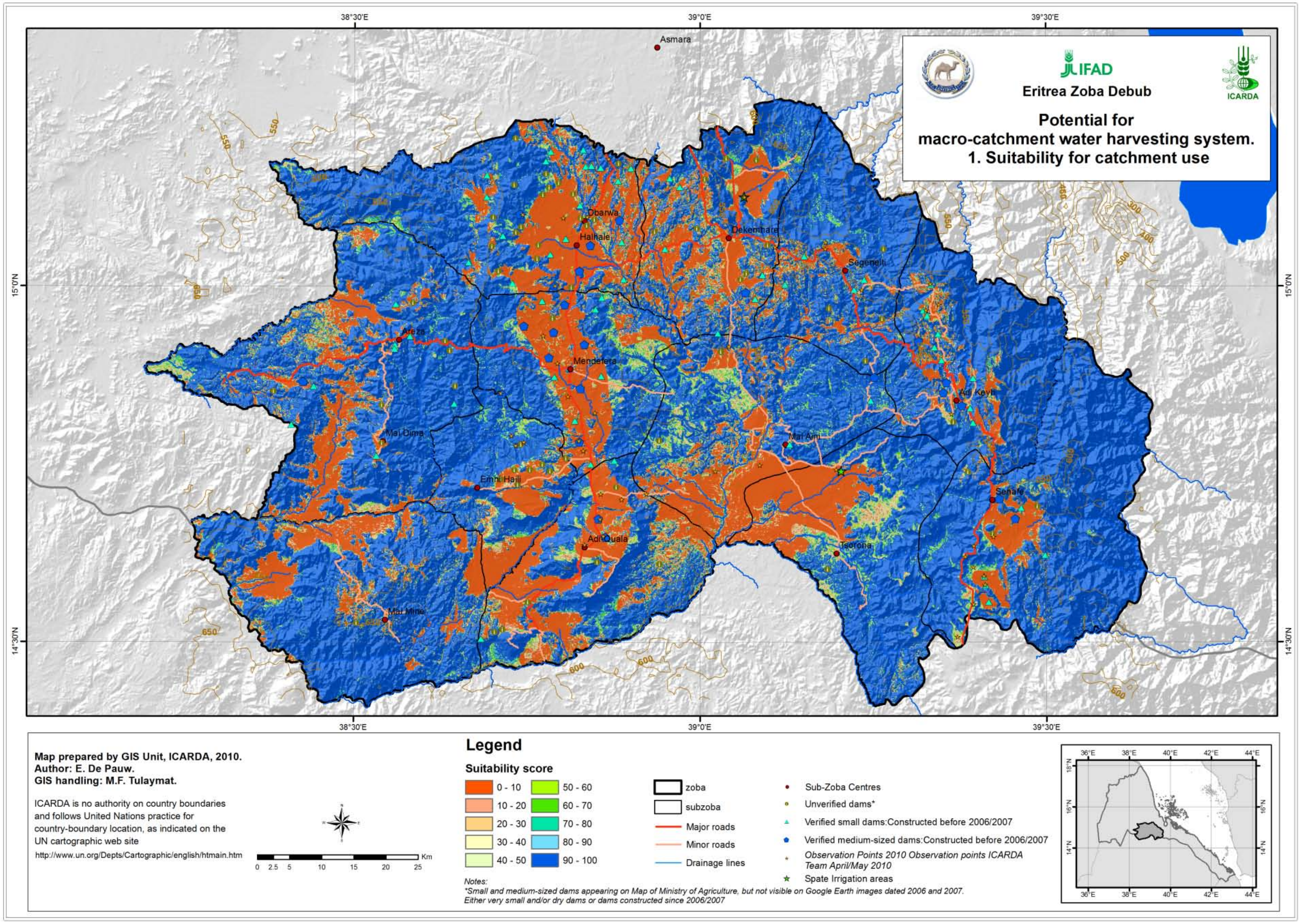


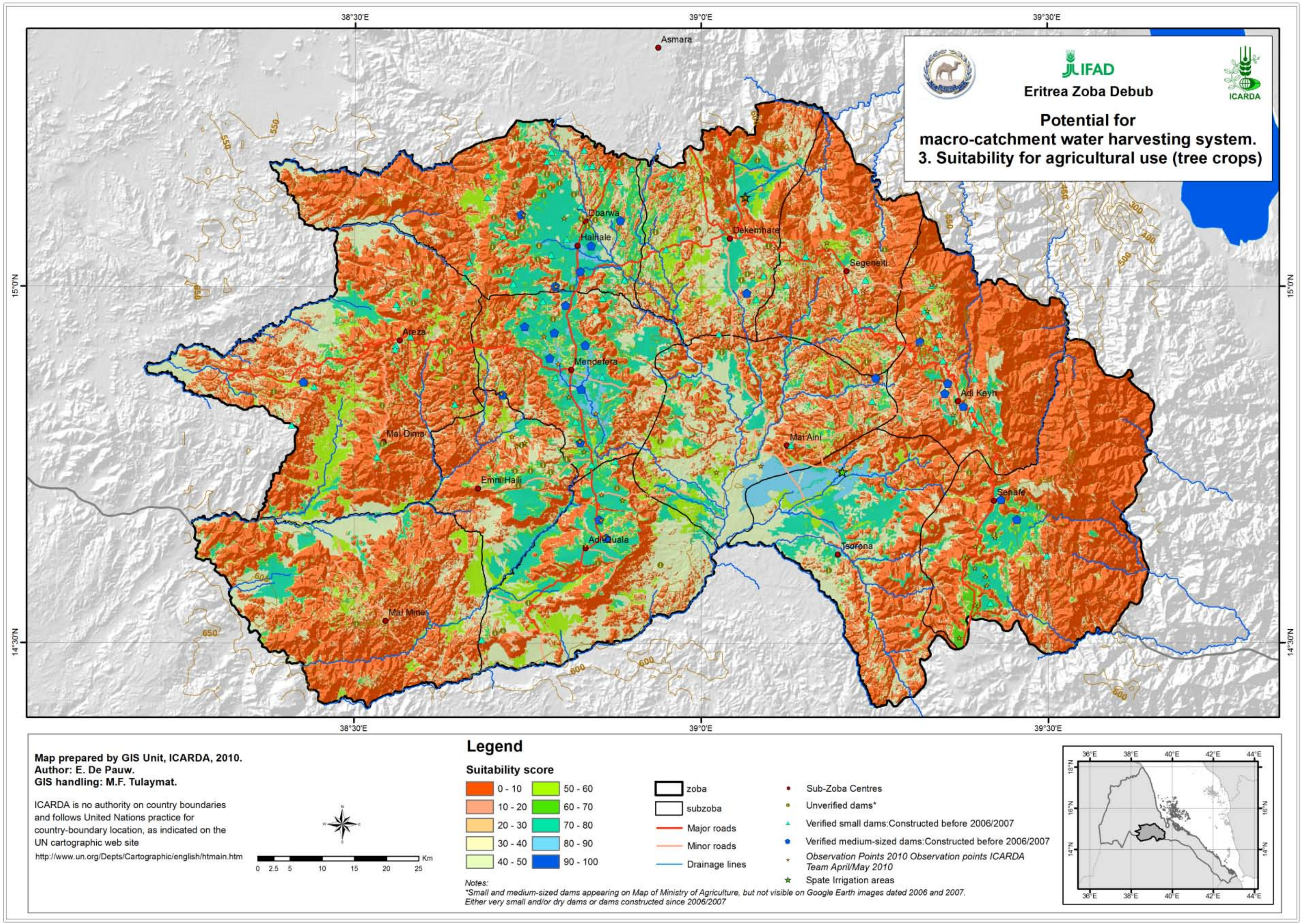
IFAD
Eritrea Zoba Debub
ICARDA
Suitability for
Micro-catchment water harvesting system S52
(runoff strips – field crops)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
14°N
16°N
18°N



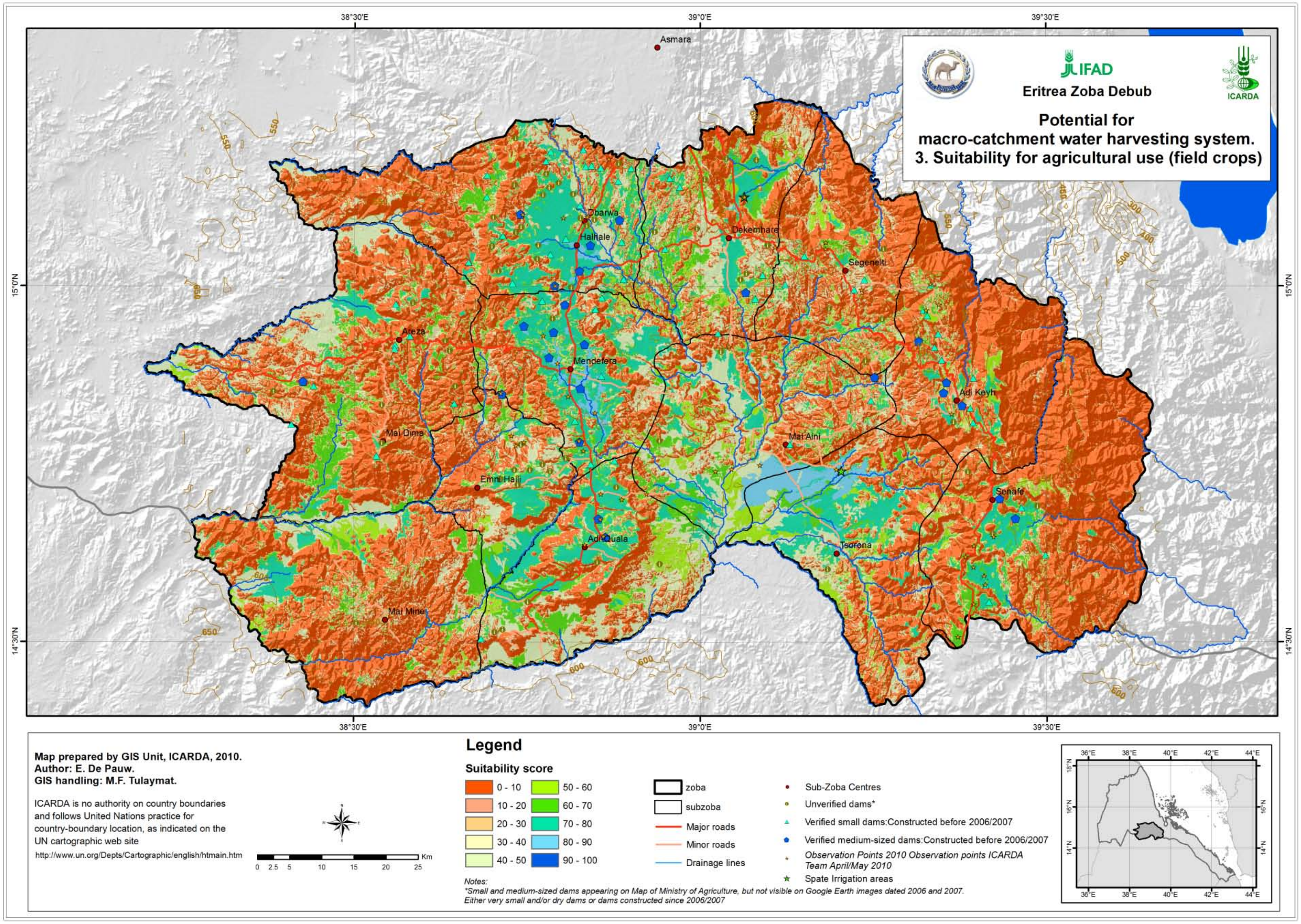
Eritrea Zoba Debub
Suitability for
Micro-catchment water harvesting system S6
contour bench terraces
IFAD
ICARDA
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007


IFAD
ICARDA
Eritrea Zoba Debub
Combined potential for micro-catchment water harvesting systems
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Haili
Senafe
Adi Quala
Tsorona
Mai Mine
Scale: 1:500,000
Km
0 2.5 5 10 15 20 25
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Legend
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Unsuitable for any micro-catchment system*
Suitable for system 11
Suitable for systems 11 or 12
Suitable for systems 11, 12 or 13
Suitable for system 21
Suitable for systems 11 or 21
Suitable for systems 21, 22, 31, 41 or 51
Suitable for systems 11, 21, 22, 31, 41 or 51
Suitable for all micro-catchment systems except 11, 12, 13, 6
Suitable for all micro-catchment systems except 6
Suitable for system 6
Suitable for systems 21, 22, 31, 41, 51, 6
Suitable for all micro-catchment systems except 11, 12, 13
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams**
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*System 11: Contour ridges – range shrubs
System 12: contour ridges – field crops
System 13: contour ridges – tree crops
System 21: semi-circular bunds – range shrubs
System 22: semi-circular bunds – field crops
System 23: semi-circular bunds – tree crops
System 31: small pits – range shrubs
System 33: small pits – tree crops
System 41: small runoff-basins – range shrubs
System 43: small runoff basins – tree crops
System 51: runoff strips – range shrubs
System 52: runoff strips – field crops
System 6: contour bench terraces
**Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007

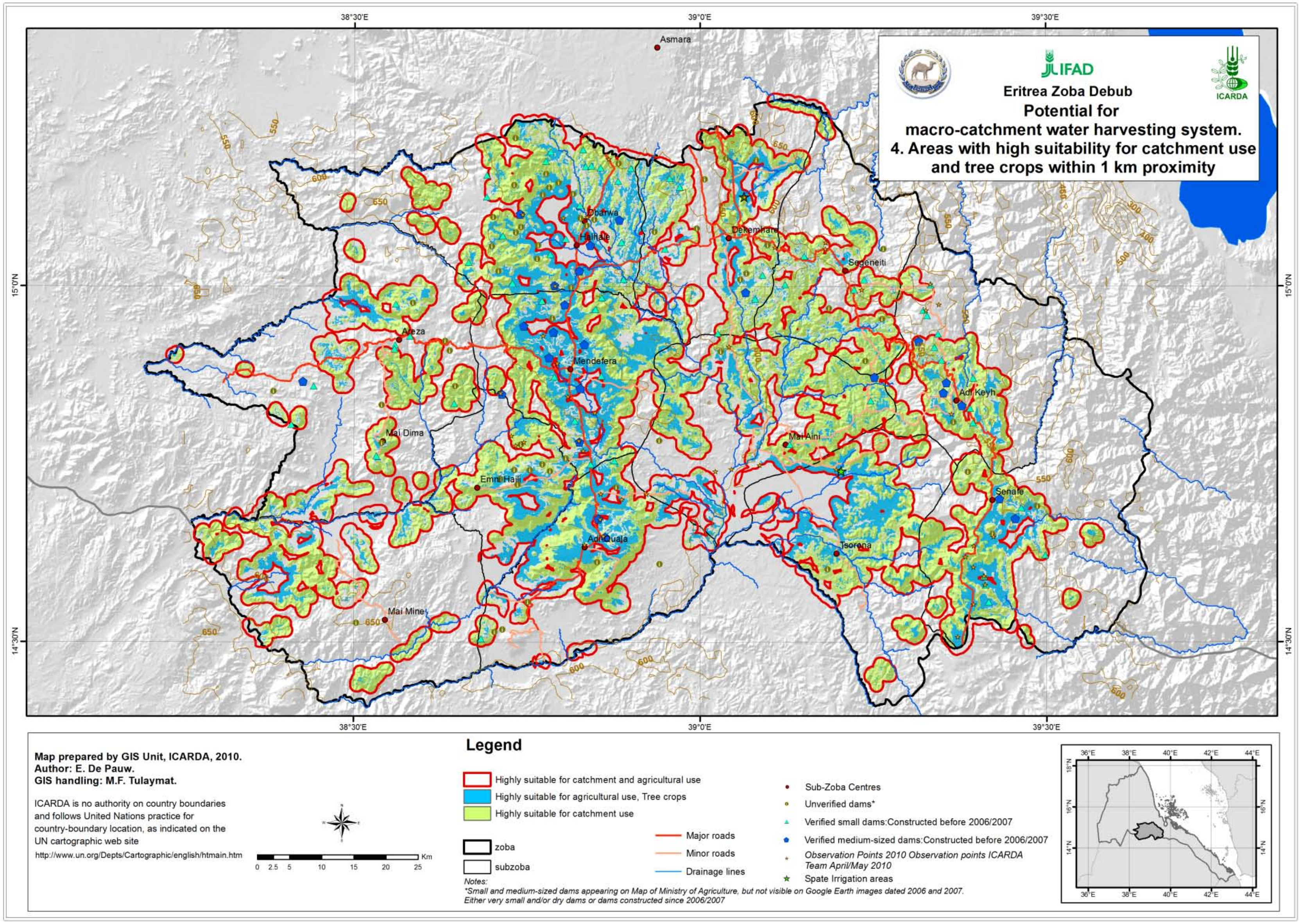

Eritrea Zoba Debub
IFAD
ICARDA
Potential for
macro-catchment water harvesting system.
1. Suitability for catchment use
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyih
Mai Dima
Mai Aini
Senafe
Emni Haili
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007



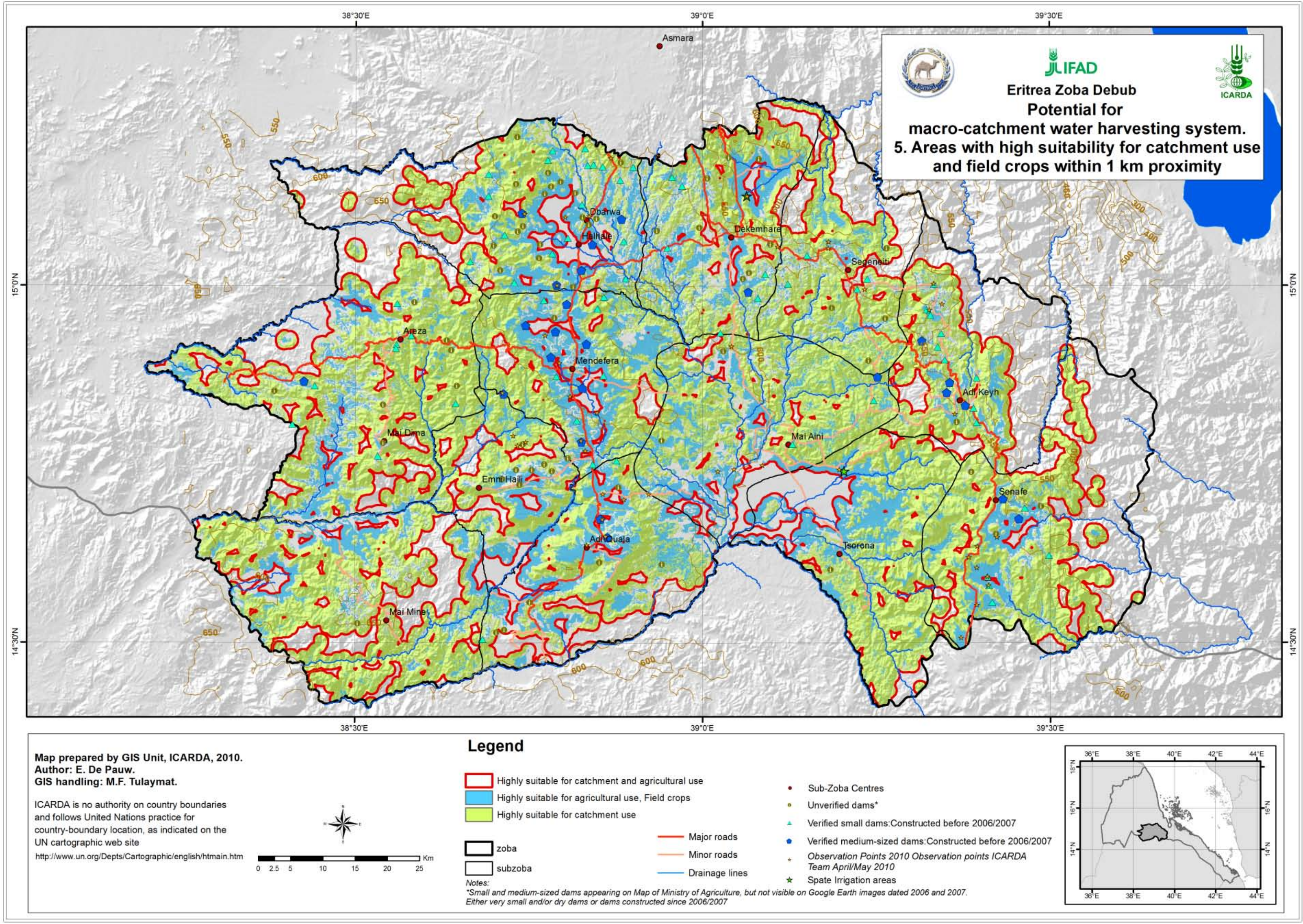
Eritrea Zoba Debub
IFAD
ICARDA
Potential for
macro-catchment water harvesting system.
3. Suitability for agricultural use (tree crops)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
0 2.5 5 10 15 20 25 Km
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
36°E
38°E
40°E
42°E
44°E
18°N
16°N
14°N



Eritrea Zoba Debub
IFAD
ICARDA
Potential for
macro-catchment water harvesting system.
3. Suitability for agricultural use (field crops)
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Asmara
Dbarwa
Halhale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorona
Mai Mine
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Km
0 2.5 5 10 15 20 25
Legend
Suitability score
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007



Eritrea Zoba Debub
Potential for
macro-catchment water harvesting system.
4. Areas with high suitability for catchment use and tree crops within 1 km proximity
IFAD
ICARDA
Asmara
Dekemhare
Segeneiti
Dbarwa
Hadnale
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajli
Senafe
Adi Quala
Tsorena
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Legend
Highly suitable for catchment and agricultural use
Highly suitable for agricultural use, Tree crops
Highly suitable for catchment use
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007. Either very small and/or dry dams or dams constructed since 2006/2007
0 2.5 5 10 15 20 25 Km


Eritrea Zoba Debub
Potential for
macro-catchment water harvesting system.
5. Areas with high suitability for catchment use
and field crops within 1 km proximity
IFAD
ICARDA
Asmara
Dbarwa
Hainale
Dekemhare
Segeneiti
Areza
Mendefera
Adi Keyh
Mai Dima
Mai Aini
Emni Hajji
Senafe
Adi Quala
Tsorona
Mai Mine
38°30'E
39°0'E
39°30'E
15°0'N
14°30'N
Legend
Map prepared by GIS Unit, ICARDA, 2010.
Author: E. De Pauw.
GIS handling: M.F. Tulaymat.
ICARDA is no authority on country boundaries and follows United Nations practice for country-boundary location, as indicated on the UN cartographic web site
http://www.un.org/Depts/Cartographic/english/htmain.htm
Highly suitable for catchment and agricultural use
Highly suitable for agricultural use, Field crops
Highly suitable for catchment use
zoba
subzoba
Major roads
Minor roads
Drainage lines
Sub-Zoba Centres
Unverified dams*
Verified small dams:Constructed before 2006/2007
Verified medium-sized dams:Constructed before 2006/2007
Observation Points 2010 Observation points ICARDA Team April/May 2010
Spate Irrigation areas
Notes:
*Small and medium-sized dams appearing on Map of Ministry of Agriculture, but not visible on Google Earth images dated 2006 and 2007.
Either very small and/or dry dams or dams constructed since 2006/2007
0 2.5 5 10 15 20 25 Km

# ANNEX 6

## Training Course for MoA GIS Staff
## (11-15 July 2010)

## SCHEDULE

**Staff trained:**

1. Yonas Welday Tekle, (MOA Zoba Debub) - GIS and soil and water conservation senior expert
2. Maeza Abraha Woldeselassie ,(MOA Head office) - GIS senior expert

<table>
<tr><td colspan="2">Sunday 11 July 2010</td></tr>
<tr><td><u>9:00-12:00H</u><br>• Discussion on course content<br>• Overview of the Arc Catalogue<br>(E. De Pauw, F. Tulaymat)</td><td><u>13:00-15:00H</u><br>• Overview of the Arc Map<br>(F.Tulaymat)</td></tr>
<tr><td colspan="2">Monday 12 July 2010</td></tr>
<tr><td><u>9:00-12:00H</u><br>• Applications of the DEM:<br>  • hydrological applications<br>(F. Tulaymat)</td><td><u>13:00-15:00H</u><br>• Applications of the DEM (Continued)<br>(F. Tulaymat)</td></tr>
<tr><td colspan="2">Tuesday 13 July 2010</td></tr>
<tr><td><u>9:00-12:00H</u><br>• Working with ArcGIS Spatial Analyst.<br>  • Zonal statistics<br>(F. Tulaymat)</td><td><u>13:00-15:00H</u><br>• Zonal statistics (Continued)<br>• Interpolation methods<br>( F. Tulaymat)</td></tr>
<tr><td colspan="2">Wednesday 14 July 2010</td></tr>
<tr><td><u>9:00-12:00H</u><br>• Using software for climate surface generating.<br>(L. Atassi)</td><td><u>13:00-15:00H</u><br>• Climate surface mapping (Continued)<br>(L. Atassi)</td></tr>
<tr><td colspan="2">Thursday 15 July 2010</td></tr>
<tr><td><u>9:00-12:00H</u><br>• Working with Google earth<br>  • Digitizing in Google earth<br>(L. Atassi)</td><td><u>13:00-15:00H</u><br>• Q&A session on topics of the week<br>• Discussion on further work.<br>( F. Tulaymat, L. Atassi)</td></tr>
</table>