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# ENVIRONMENTAL AND LIVELIHOODS VULNERABILITY MAPPING (ELVM) IN NORTH AND SOUTH DARFUR, SUDAN

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Final Report

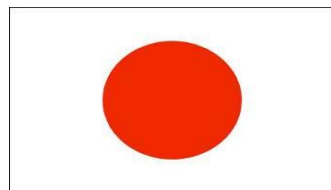
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## ACRONYMS AND ABBREVIATIONS

AC	Adaptive Capacity
ALCOM/WWF	Aquatic Resource Management for Local Community Development Programme/ World Wide Fund for Nature
APAR	Absorbed Photosynthetically Active Radiation
ARTEMIS	Africa Real Time Environmental Monitoring System
AVHRR	Advanced Very High Resolution Radiometer
CBS	Central Bureau of Statistics
CEAPs	Community Environmental Action Plans
CGIAR-CSI	Consortium for Spatial Information
CIAT	International Center for Tropical Agriculture
CRC-TREM	Cooperative Research Centre for Tropical Rainforest Ecology and Management
CSB	Controlled Settlement Boundary
CV	Coefficient of Variation
DFID	UK Department for International Development
DMC	Disaster Monitoring Constellation
ELVI	Environmental and Livelihoods Vulnerability Index
ELVM	Environmental and Livelihoods Vulnerability Mapping
EnviSat	Environmental Satellite
EPR	Environmental Planning for Return
FAO	Food and Agriculture Organization
FAO LocClim	FAO Local Climate Estimator
FEWS-NET	Famine Early Warning Systems Network
FRA-2000	Forest Resources Assessment 2000
GCM	Global Circulation Models
GE	Google Earth
GHCN	Global Historical Climatology Network
GHG	Greenhouse Gas
GIMMS	Global Inventory Modelling and Mapping Studies
GIS	Geographic Information System
HIC	Humanitarian Information Centre
HPG	Humanitarian Policy Group
HTS	Hunting Technical Services
IDP	Internally Displaced Person
IIED	International Institute for Environment and Development
ILRI	International Livestock Research Institute
IMWG	Information Management Working Group
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISR	incoming shortwave radiation
ITCZ	Inter Tropical Convergence Zone
JLC	Joint Logistics Centre
JRC/SOAS	Japan Research Centre/School of Oriental and African Studies
LAI	Leaf Area Index
Landsat- MSS	Landsat Multispectral Scanner
Landsat TM	Landsat Thematic Mapper
LCCS	Land Cover Classification System
MAI	Mean Annual Increment

MERIS	Medium Resolution Imaging Spectrometer
MHVI	Multi Hazard Vulnerability Index
MJ	Mega Joules
MODIS	Moderate Resolution Imaging Spectroradiometer
NAPA	National Adaptation Plan of Action
NASA	National Aeronautics and Space Administration
NBSAP	National Biodiversity Strategy and Action Plan
NDDU	National Drought and Desertification Unit
NDVI	Normalised Difference Vegetation Index
NFI	Non Food Items
NGO	Non Governmental Organization
NIR	Near-infrared
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
ODI	Overseas Development Institute
ORNL	Oak Ridge National Laboratory
PET	Potential evapotranspiration
PGA	Potential groundwater availability
PRA	Potential rainfall water availability
PTP	Population Tracking Project
PTVAP	Population Tracking and Village Assessment Project
PWS	Potential woodfuel sufficiency
RP	Rainfall predictability
RPOP	Relative Population Distribution
RSDI	Remote Sensing Drought Index
RWDB/SWB	River-Surface Water Body Network/ Surface Waterbody
SCUK	Save the Children-UK
SCUK DFIS	SCUK - Darfur Food Information System
SIM	Sudan Interagency Mapping
SRTM	Shuttle Radar Topographic Mission
SPOT VGT	'Satellite pour l'Observation de la Terre' Vegetation
Sudan-MDTF	Sudan Multi Donor Trust Fund
TLU	Tropical Livestock Unit
UML	Universal Modelling Language
UN	United Nations
UNDP	United Nations Development Programme
UNDP TRMA	UNDP Threat and Risk Mapping and Analysis
UNEP	United Nations Environmental Programme
UNHCR	United Nations High Commissioner for Refugee
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNU-EHS	United Nations University - Institute for Environment and Human Security
VCI	Vegetation Condition Index
WFP-VAM	World Food Programme's Vulnerability Analysis and Mapping
WHO	World Health Organization
WISDOM	Woodfuel integrated Supply/Demand Overview Mapping
WSDC	Western Savannah Development Corporation

## EXECUTIVE SUMMARY

The International Organization for Migration (IOM) has been working in Sudan since 2000. Initially its activities focused on the resettlement of refugees from Sudan to respective receiving countries, in collaboration with the Office of the United Nations High Commissioner for Refugees. Under the terms of the 2004 Memorandum of Understanding signed by IOM with the Government of Sudan and the United Nations (2004 MoU), IOM is currently mandated to monitor, verify and provide assistance to returns in Darfur, where appropriate. In addition to the protection and monitoring of IDPs return and relocation movements, IOM Sudan is involved in the registration of IDPs and aid beneficiaries, population tracking and village assessment, and support to returnees. As part of its current programme IOM is working to ensure that its activities are conducted with due regard to environmental impact and are contributing to the humanitarian community's knowledge base on environmental and livelihoods vulnerabilities in Darfur.

ProAct Network was requested to assist with certain environmental components of IOM's operations in Darfur which has included the following main activities:

- strengthening environmental components into existing IOM village assessment reporting;
- undertaking basic environmental assessments at selected sites;
- initiating a community environmental action planning process at priority selected sites; and
- mapping environmental and livelihoods vulnerability across North and South Darfur.

The overarching theme of this work has been to enhance the potential for durable return by consulting specific communities, gathering knowledge pertinent to peoples' use of natural resources and contributing to the sustainability of the return process by supporting sustainable environmental management and livelihood security and developing a comprehensive understanding of spatialised environmental and livelihood information that can be used to assist decision making in the return process. The current report focuses on this latter mapping component of the work.

The Environmental and Livelihoods Vulnerability Mapping (ELVM) project, undertaken with funding from the Government of Japan, evaluates and maps the vulnerability of traditional rural livelihoods and their resource bases across North and South Darfur and provides this information at a local level across the entire study area, in 16kmx16km grid cells. It is anticipated that the knowledge and data generated from the ELVM project will complement IOM's work on IDP return and relocation movements. The vulnerability maps produced by the project have the potential to guide and inform return and resettlement planning and processes, show where natural resources are climatically stable and where they are subject to inter-annual variations, and provide a framework for comparing vulnerabilities, and identify potential interventions to address those vulnerabilities across the study area. The spatial vulnerability ranking across North and South Darfur potentially allows IOM, the Government of Sudan and other key agencies involved in the humanitarian operation to

base future decisions on more complete and reliable environmental data, much of which underpins livelihoods, security and overall peace in the region.

Founded upon a clear and Darfur-focused conceptual framework, the project has processed existing and satellite-derived information to estimate the exposure to environmental hazards and the adaptive capacity of communities at continuous geographic areas across the two Darfur States. The project results are presented in simple and readily interpretable maps that allow the identification of the most vulnerable geographic units, the comparison of vulnerability among locations and a determination of the main drivers of vulnerability at each 16km x 16km grid cell. It is expected that these results constitute a baseline upon which local, national and international stakeholders and external donors can better target their support towards the return process of Internally Displaced Persons (IDPs) in Darfur.

### **Summary of the development, representation and application of the ELVM framework**

The ELVM framework is founded on the definitions outlined below, which have been applied at 16km x 16km cells across the entire study area. In the framing definitions for the project, the 'system' is defined as a contiguous area of land, and its associated environment, which is exploited by a traditional natural resource-based livelihood activity or collection of activities.

- “*Vulnerability*” is the extent to which a system may be impacted by a hazardous event to which it is exposed, after accounting for the system’s adaptive capacity.
- “*Exposure*” is the probability of the system experiencing a hazard.
- A “*hazard*” is a natural or man-made threat to the system’s condition.
- An “*impact*” is the extent of change in the system’s condition due to the occurrence of a hazardous event.
- “*Adaptive capacity*” is a system's ability to adapt to a hazardous event – by anticipating it, resisting it, coping with its impacts and recovering from them.

Against this definitional context and based on a literature review of environmental factors, livelihoods classifications, rural production systems and natural resource use and management in Darfur, expert accounts and preliminary analysis of the data available to the project, the following factors were identified as the four major environmental limiting factors for production (and thus rural livelihood activities) across Darfur that could be mapped in the context of the project:

- potential rainfall water availability;
- rainfall predictability;
- potential groundwater availability; and
- potential energy – woodfuel– sufficiency.

In addition to these factors, the project added population distribution and then adaptive capacity as further components to assess environmental and livelihood vulnerability in North and South Darfur. Each of these six components was then assessed and quantified at each 16km x 16km cell across the study area.

Additional components to the overall vulnerability framework may of course be added at a theoretical level but the above components are those finally chosen by the project team to address one of the key challenges posed in developing an ELVM framework for a study area covering 454,978km<sup>2</sup> – roughly the combined land area of Germany and the Czech Republic – namely the quality and coverage of available data. Inevitably the different data sets used in the framework differ in terms of their completeness, precision, accuracy, consistency and currency and in order to achieve full coverage across North and South Darfur the project had to rely on data sets that were available for this full area, in some cases ignoring relevant data sets that were more complete or accurate, but which were only available for much smaller geographic units.

A brief overview of each of the six components to the ELVM Framework is provided below:

**Potential rainfall water availability:** In the absence of long-term meteorological records that cover the study area the project used the Normalized Difference Vegetation Index (NDVI), yearly precipitation proxy derived from the analysis of satellite imagery for the 1981-2006 period. This was done as the NDVI index correlates very accurately with mean annual rainfall and offers the only reliable, long-term climatic information available for the entire region. It is particularly important to bear in mind that rainfall amounts underpin rainfed agriculture and herding activities and that rainfall is the main source of water in areas where there is either no potential underground water or there is no infrastructure to exploit it.

**Rainfall predictability:** Low rainfall amounts are not the only cause of vulnerability in the region. The high variation in the amount and occurrence of rainfall between years has led to catastrophic drought in the past. To account for the variation in rainfall between years, the project once again used the multi-year NDVI rainfall equivalent values to calculate for every 16km x 16km grid cell the coefficient of variation (CV), a measure of rainfall variability among years and, based on CV values, a rainfall predictability index was created. High values of the rainfall predictability index indicate small changes in annual precipitation between years, i.e. high rainfall predictability. Low values denote high fluctuation in rainfall amounts between years, i.e. high rainfall unpredictability.

**Potential groundwater availability:** Available groundwater resources are determined by the hydrogeology of the region, i.e. location of rock formations and superficial deposits, the extent and interaction between these geological elements and their properties (for example porosity, or storage capacity). In North and South Darfur there are five major geological formations with different potential for groundwater storage and although these formations had been mapped in detail for several zones within the region, a continuous map across North and South Darfur had not been produced before, as far as the ELVM team was able to establish. Consequently, historical hydrogeological maps of the region were sourced, digitised and merged, and a Darfur-wide hydrogeological map was produced. The geological and surface deposit elements from this map were further classified according to their groundwater availability potential and plotted. The resulting map indicates the potential for natural storage, extraction and use of groundwater at each 16 km x 16 km grid cell.

**Potential energy – woodfuel – sufficiency:** As woodfuel is the main source of energy across Darfur, rural and urban livelihoods are constrained by its availability - i.e. in the context of the project the lack of access to woody resources is defined as a hazard and thus a component of overall livelihood vulnerability. The project assessed energy availability across the region using the Woodfuel Integrated Supply/Demand Overview Mapping methodology (WISDOM, as originally applied in East Africa and developed by FAO) to calculate the demand, the supply and the net woodfuel availability balance of across the region, based on an analysis of land cover satellite imagery, population densities, assumed per capita yearly energy consumption and annual woody vegetation biomass regeneration rates.

**Population distribution:** In the absence of data from the recently completed census the project modelled the distribution of population across the study area using commercially available population data. This permitted accounting for the human population vulnerable to multiple natural hazards at each 16 km x 16 km grid cell. Adding a 'human component' to physical vulnerability estimates followed the assumption that between two identical geographic areas that experience similar exposure to hazards, the more populated one is more vulnerable. Including population distribution in the ELVM framework and resulting maps also provides a rapid indication of areas where interventions could potentially have a greater number of beneficiaries.

**Adaptive capacity:** The adaptive capacity component of the ELVM vulnerability framework was represented by a combined measure of people's access to physical and natural assets. This measure included access to surface water resources, boreholes, hand pumps, major markets, health facilities, education and IDP camps. Accessibility was calculated as the cost (effort) of travelling from a certain location to the nearest asset of interest, assuming that people try to minimise the effort/cost of travelling (e.g. try to use roads instead of crossing thorn scrubs, even if the distance is larger). Access maps were created for each social and physical asset category using friction surfaces (which indicate the ease/difficulty of movement between places) and from these, the overall potential adaptive capacity in every 16km x 16km grid cell was calculated and standardized.

Once all limiting factors and the adaptive capacity components of the ELVM framework were mapped, a North and South Darfur wide map of exposure to multiple hazards was created, by adding the standardized hazard values at each 16km x 16km grid cell. The following steps were to add the estimate of overall adaptive capacity to the multiple hazards average to produce an overall estimate of vulnerability (MHVI) per 16km x 16km grid cell and to multiply this vulnerability index by one minus the proportion of the population in North and South Darfur estimated to inhabit each grid cell. The Environmental and Livelihoods Vulnerability Index (ELVI), calculated in this last step, allowed the project to include human exposure to the spatial vulnerability estimates and to show in a single map the areas where interventions could potentially have a greater number of beneficiaries.

For the sake of simplicity and for better understanding how hazards, adaptive capacity and population distribution interact at each 16km x 16km grid cell, software was created to generate vulnerability diagrams (radar charts) where potential rainfall water availability,

rainfall predictability, potential groundwater availability, potential woodfuel sufficiency, relative population distribution and potential adaptive capacity are plotted on radial axes. The interpretation of vulnerability in both the ELVI and vulnerability diagrams is exemplified for several representative sites across North and South Darfur in Section 6 of the report but it should be noted that these diagrams are available for every 16km x 16km grid cell across the study area in an online platform (see [www.vulnerability-mapping.org](http://www.vulnerability-mapping.org)) and can also be manually constructed from the tables given in Annex 10.4.

The vulnerability maps and 16km x 16km cell-specific diagrams produced by the project provide:

- rapid, non-technical assessments of environmental and livelihoods vulnerability;
- a readily understandable representation of the drivers of vulnerability at any location (16km x 16km grid cell) across North and South Darfur;
- comparative evaluations of vulnerability at different locations;
- identification of potential appropriate interventions at the community level;
- improves the levels of spatial environmental and livelihood information available to IOM, the Government of Sudan and other actors on which to base future decisions; and
- in particular for IOM, the framework provides environmental and livelihood information to assist in planning interventions to support returning communities.

# 1. INTRODUCTION

The International Organization for Migration (IOM) has been working in Sudan since 2000. Initially its activities focused on the resettlement of refugees from Sudan to respective receiving countries, in collaboration with the Office of the United Nations High Commissioner for Refugees (UNHCR). Under the terms of the 2004 Memorandum of Understanding signed by IOM with the Government of Sudan and the United Nations, IOM is currently mandated to monitor, verify and provide assistance to returns in Darfur, where appropriate. In addition to protection monitoring of Internally Displaced Persons (IDPs) return and relocation movements, IOM Sudan is involved in the registration of IDPs and aid beneficiaries, population tracking and village assessment, and support to returnees. IOM is working to ensure that its activities are conducted with due regard to environmental impact and are contributing to the humanitarian community's knowledge base on environmental and livelihoods vulnerabilities in Darfur.

IOM's Main Projects in Darfur are summarised as follows:

- protection monitoring for returns/relocations;
- registration of IDPs and aid beneficiaries;
- population tracking and village assessment; and
- transport for the Non-food Items (NFI) Common Pipeline.

ProAct Network is providing support to IOM activities in Darfur by generating environment-related knowledge and building capacity to include these considerations in existing activities. To achieve this objective the following activities were undertaken: improving IOM's knowledge of vulnerability in North and South Darfur, through the Environmental and Livelihoods Vulnerability Mapping (ELVM) project; strengthening of IOM's village assessment surveys through the development of an environmentally oriented assessment – Environmental Planning for Return (EPR); and the development of Community Environmental Action Plans (CEAPs) through which IOM will assist selected return communities and villages in terms of environmental management and related technical support.

Through this approach ProAct has sought to strengthen and build-on IOM's existing activities, in particular those of the Population Tracking and Village Assessment Unit. In this work, IOM identified a number of priority locations (villages) where IDP returns have taken place. A number of village assessments have already been undertaken in order to identify and assess certain criteria at those sites. Environmental Planning for Return (EPR) assessments and implementation activities took place at selected priority locations<sup>1</sup>.

The knowledge and data generated from these initiatives is expected to complement IOM's work on IDP return and relocation movements. Vulnerability maps generated through this work are now able to guide and inform return and resettlement planning and processes. Maps will

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<sup>1</sup> For more information please refer to (EPR, Community-Based Environmental Action Plans in South Darfur Report, May 2010 and to the Field Mission Report for the ELVM and EPR projects for the period 18 January to 10 February, 2010).

also show where ecosystems are climatically stable and where they are subject to inter-annual variations.

To enrich this work further the EPR project aimed to expand IOM's knowledge of selected return sites for IDPs in Darfur in order to support grassroots-based actions to improve the livelihoods of returnees and host communities through enhanced environmental management. This project gathered key environmental baseline data in priority return villages and, using rapid environmental assessments and community participatory approaches, identified major threats and opportunities for immediate environmental interventions and as well as issues that require further specialist assistance.

While the atlas of ELVM maps will constitute an initial source of information for humanitarian actions and return planning, the overall framework could be further developed to include additional environmental and socio-economic parameters. This would allow temporal and spatial information – which is essential for sound planning and action – in the context of Darfur to be taken more fully into account.

## **1.1 Overview of the Report**

Section 1 provides a short introduction to this project. This is followed in Section 2 with a general description of the major environmental factors in North and South Darfur, its climate – including climate change, both past and future – a biophysical description of the study area (Section 2.1) and an overview of traditional natural resource-based livelihood activities, including livestock, agriculture and forestry-related livelihood activities (Section 2.2).

Section 2.3 then reviews the current state of vulnerability assessments and mapping approaches globally and develops a vulnerability framework that includes both intrinsic and extrinsic factors relating to the environment and livelihoods and uses North and South Darfur context-specific indicators for which reliable data was available or could be extracted from remote sensing analyses.

A brief summary of the ELVM methodology is then provided in Section 3, before the Framework and its constituent components are explained in detail, in Section 4. Section 5 covers the validation procedures undertaken, which included a field verification mission and the comparative use of different satellite imagery. Section 6 provides applications of the Framework at four representative locations in the study area, while Section 7 details further uses of data sourced and processed throughout the project that have direct practical applications in planning interventions involving, for example, livestock or millet production.

The report concludes recommendations – Section 8 – after which, references and technical annexes are provided.

## **2. BACKGROUND**

### **2.1 General Description of Major Environmental Factors in North and South Darfur**

#### **2.1.1 Situation**

The states of North and South Darfur extend from approximately 8°30' to 20° North and from 22°45' to 27° 56' East, covering 454,978km<sup>2</sup>, roughly the combined land area of Germany and the Czech Republic. These states share borders with Libya, Chad, the Central African Republic and with the Sudanese States of Northern, North and South Kordofan and North and West Bahr el Ghazal (Figure 1).

North and South Darfur are located along a north-south gradient of increasing rainfall amount and predictability. Rainfall conditions, geomorphological processes and soil types largely determine the natural resource-based livelihoods that are possible at specific locations. Several classifications used to describe ecological, agro-ecological and land use zones in the region (e.g. Lebon, 1965; Watson *et al.*, 1977; UNOCHA, 2006; UNEP, 2007) agree on the limits of a desert zone towards 16.5°N. A review of existing literature, maps and satellite imagery shows that human density as well as agricultural and pastoral range activities in the desert zone is minimal, a result of which was the delineation of 17°N as the northern limit for the ELVM project study area (see Figure 1 and Figure 2).

#### **2.1.2 Climate**

Rain in Darfur is driven by the seasonal movement of the Inter Tropical Convergence Zone (ITCZ)<sup>2</sup>, and the northerly movement of the south-west monsoon. The Jebel Marra massif plays an all-important role in modifying the weather in terms of temperature, clouds and rainfall. The rainy season generally starts in April with sporadic showers that gradually intensify towards June. These showers are followed by the main rains in July and August, and by a period of declining intensity in September. However, rainfall amounts and predictability and the length of the rainy season decrease along the ITCZ's south-north movement. This decrease in precipitation is accompanied by a gradual increase in mean annual temperature.

On average, temperatures across North and South Darfur are relatively high throughout the year (e.g. the mean annual temperature in Nyala is 27.3°C), with two exceptions, a short cool season, locally known as *Darat*, between January and February, and a substantial temperature drop during the peak of the main rains, towards August. Local sandstorms frequently affect Darfur from November to April. These are more pronounced in the northernmost areas and are caused by the dry north and north-east winds that prevail during the dry season. During the

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<sup>2</sup> The ITCZ is a band of low air pressure, centred on the Equator, where dry north-east and moist south-west trade winds converge and rise creating, as they ascend and cool down, a zone of cumulus clouds and rain activity. The ITCZ is not stationary; it shifts north and south of the Equator following the sun's seasonal movement due to the Earth's inclination.

rainy season, the main winds blow from the south-west, causing orographic rain (also known as relief precipitation) on the western slopes of the Jebel Marra massif.

#### **2.1.2.1 Climate Change – Past and Future**

Several reports (e.g. University for Peace, 2004; Young *et al.*, 2005; Bromwich *et al.*, 2007; NAPA, 2007; UNEP, 2007; Zakieldein, 2009) and local accounts describe that rainfall in the region has declined and its pattern has become increasingly erratic in the past 50 years, leading to series of drought years, crop failures and food shortages. While these accounts are supported by meteorological data analyses for Darfur, Sudan and the whole Sahel region (e.g. Hulme, 1990; L'Hôte *et al.*, 2002; Hoerling *et al.*, 2006; Serigne *et al.*, 2006; IPCC, 2007; Kevane and Gray, 2008), declining rainfall trends have been attributed to various factors (reviewed in Brooks, 2004 and Serigne *et al.*, 2006), which include land degradation from human activities, 'natural' changes in global and sea-level temperature patterns, and land-atmosphere feedback mechanisms mediated by vegetation and dust from the Sahara.

Increasing greenhouse gas (GHG) concentrations have also been suggested as a major causal factor for the decline in Sahelian annual rainfall (e.g. IPCC, 2007). However, this (very popular) explanation has been challenged by Hoerling *et al.* (2006), who after modelling changes in the Sahelian summer rainfall response to GHG between 1950 and 1999 concluded that GHG forcing played little or no role in the well known drying trends. The most satisfactory explanation for this dry episode involves changes in atmospheric circulation patterns driven by warmer sea surface temperatures in southern hemisphere oceans relative to those of northern hemisphere oceans (see Brooks, 2004; Hoerling *et al.* 2006).

Discrepancies also exist among predictions of future annual rainfall in the Sahel, as climate change models have projected both drier and wetter conditions (e.g. Maynard *et al.*, 2002; Wang and Eltahir, 2002; Held *et al.*, 2005; Hoerling *et al.*, 2006; IPCC, 2007). Whilst most models take into consideration the same sort of drivers used to describe previous drought episodes (e.g. contrasts in sea surface temperatures between northern and southern hemisphere oceans), many factors contribute to the divergent predictions; for example, a slight variation in parameterisations or climate sensitivities in Global Circulation Models (GCM) can lead to completely different rainfall forecasts under the same forcing. Lack of long-term meteorological records, essential to estimate past and predict future climatic patterns, and high uncertainty on the degree of future GHG emissions, are other constraints to future conditions forecasting.

Adding to the controversy about future climatic conditions in the Sahel is an observed region-wide 'greening' phenomenon that has been attributed, at least in part, to a recovery in annual rainfall since 1998 (Gebresenbet, 2009). However, several other processes that may (or may not) be associated with climate change are potential causal agents for the Sahelian greening, among them nitrogen deposition, CO<sub>2</sub> fertilisation, changes in livelihood activities – including migration – and transformation of rural agricultural practices (for a review see Gebresenbet, 2009). In summary, more research and field level data acquisition is necessary to elucidate the future of the Sahel's climate.

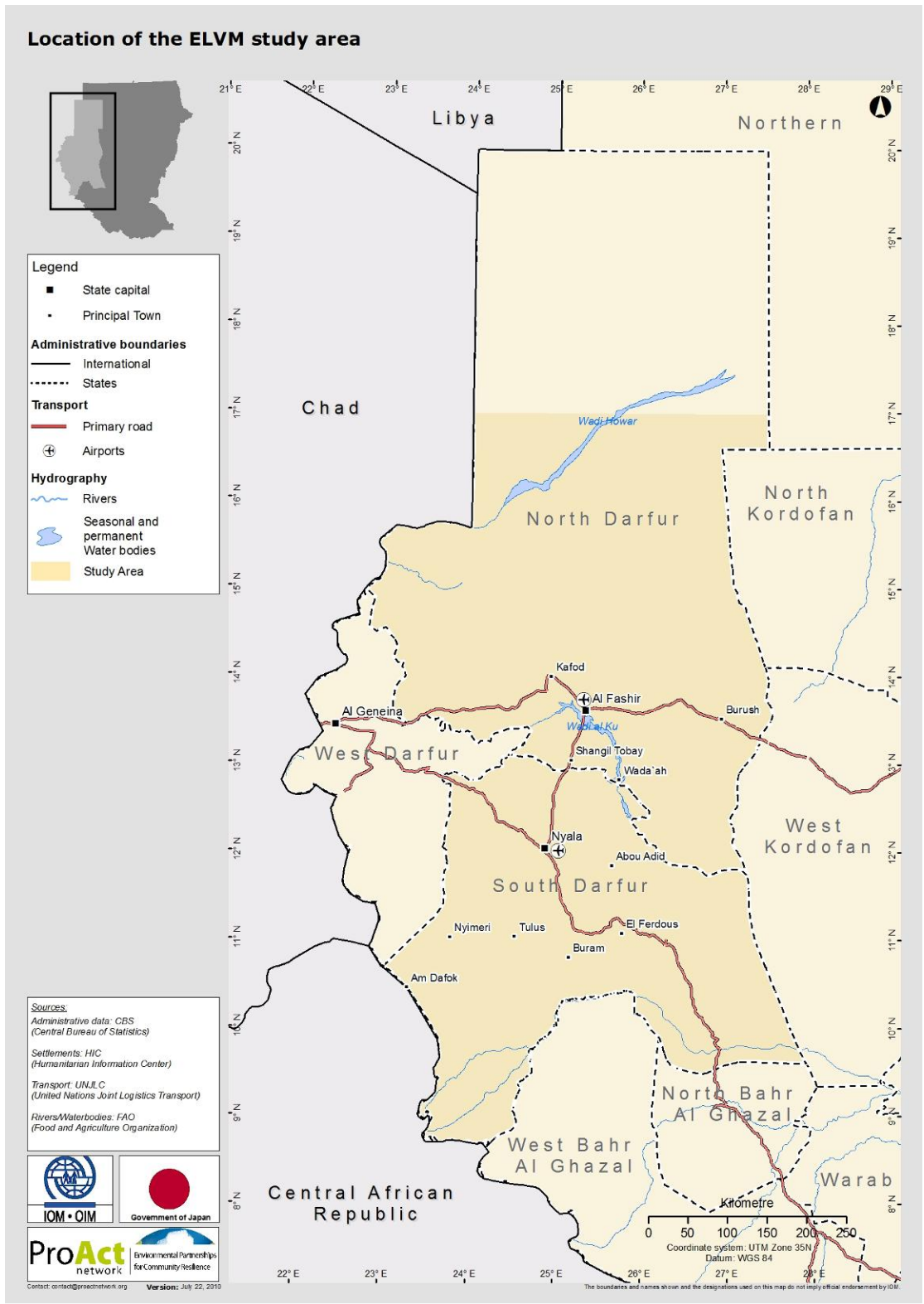
### 2.1.3 Geology and Soils

Subsurface water availability, soil and vegetation types across North and South Darfur are related to underlying geological formations of volcanic, sedimentary and metamorphic origin (see Figure 17 and Figure 18). The most prominent geological elements in the region are:

- a) The Pre-cambrian Basement Complex, a dissected plateau composed of hard crystalline metamorphic rocks, including gneisses, granites, schists of various metasediments and metavolcanics. Basement rock covers almost the entire study area in North and South Darfur, either beneath Nubian Sandstone or as superficial outcrops.
- b) The Basement Complex has been intruded by the Jebel Marra massif, a complex late-Cenozoic strato-volcano composed of basalts, trachytes and pyroclastics that lies on the western edge of the area. Jebel Marra itself is in a dormant (fumarolic) stage at present (Vail, 1972a, b; Francis *et al.*, 1973; Williams *et al.*, 1980; Philibert *et al.*, 2010). Other volcanic outcrops in the study area are the Jebel Meidob massif, the Meidob Hills in the north-east and other volcanic plugs around Mellit and the Berti hills in North Darfur.
- c) The Nubian Sandstone, a sedimentary formation, overlies the Basement Complex. Outcrops of Nubian Sandstone occur at the Teiga Plateau and are frequently observed on a smaller scale in North and eastern Darfur.
- d) Umm Rwaba Formation sediments are an undifferentiated complex of various alluvial deposits that are older than the alluvium of the *wadis*, and younger than the Nubian rocks. They are derived from erosion of these other formations and were deposited in basins and drainage systems that lie beneath the present ones.
- e) The most recent formations that overlie these rock formations in North and South Darfur are stabilised sand sheets (*Qoz*)<sup>3</sup>, active windblown sand sheets, colluvium on slopes, and alluvium in *wadis* and drainage basins.

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<sup>3</sup> The *Qoz* are stabilised sand sheets partly derived locally from the erosion of Nubian series sandstones but also from influx of wind transported sands from the Sahara and were probably stabilised during the Pleistocene, a period which ended some 30,000 to 20,000 years ago (Parry and Wickens, 1981). Largely consisting of quartz grains, the *Qoz* are deep, sandy soils of low natural fertility. Nevertheless, they support savanna woodland that increases in density to the south and are among the most widely used soils for agriculture in the project area. They are well suited to millet cultivation with bush-fallow rotation (Parry and Wickens, 1981).



**Figure 1.** Location of the ELVM study area.

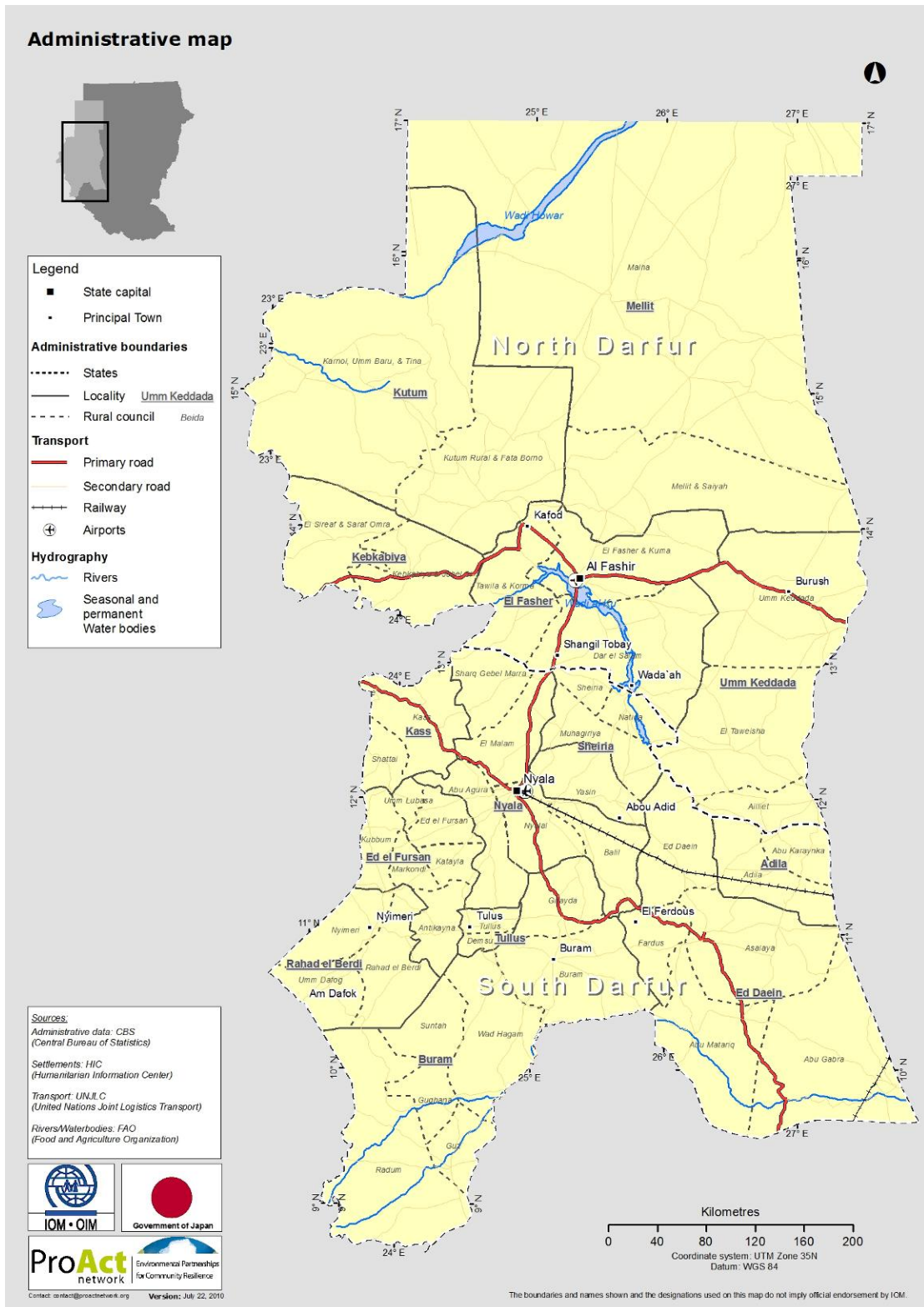


Figure 2. Administrative map of the ELVM study area.

Active aeolian sandsheets and dunes, occur in the arid north region, and move across all geological formations. Some are derived from Nubian Sandstone while others are sands that move in from Libya.

Sedentary soils have developed *in situ* over large areas of the Basement Complex. Because these underdeveloped shallow soils exhibit high compaction and low permeability, they are prone to sheet and gully erosion.

Volcanic soils have formed *in situ* from the breaking down of lavas, basalts and tufts in the volcanic mountain regions. Streams flowing out of Jebel Marra may transport elements from these soils and deposit them in terraces and deltas.

Alluvial soils, deposited on a narrow depth along the banks of watercourses, have clays, loams and a moderate to high silt content. The origin of these soils depends on the substrate over which the water drains. They are generally constituted by Basement Complex-derived materials and contain volcanic elements from the Jebel Marra massif, the origin of most streams in the region. Along drainage basins, the coarser materials (silts) are deposited earlier, along the slopes and the finest (clays) last, in flatter floodplains. Alluvial soils are the most fertile soils in the region, and are used for growing nutrient-demanding crops such as tobacco, vegetables and fruit.

#### **2.1.4 Topography**

The topography of Darfur is greatly influenced by its geology and is dominated by the Jebel Marra massif. The impervious Basement Complex is intruded by the volcanic rocks of Jebel Marra whose peak rises to 3,000m above sea level near the intersection of the boundaries of North, West and South Darfur. This central massif is largely composed of Basement Complex with a central area of volcanic rock. In South Darfur the Basement Complex terrain falls away from Jebel Marra to the south-east and then across very flat plains of shallow slope on the Nubian Sandstone and Umm Ruwaba substrates to the lowest elevations in Darfur, approximately 400m above sea level in the extreme south-east. Directly to the south, the land first falls to sandstone and then rises again onto Basement Complex in the far south.

In North Darfur the transition away from the Volcanic Rock of Jebel Marra to Basement Complex and then Nubian Sandstone is similar to the south but elevations of 1,000m and more are common across both the Basement Complex and the Nubian Sandstone. A central spine of hills extends to the north and east towards the volcanic Meidob Hills and the sandstone Teiga Plateau. There are numerous small volcanic domes scattered across this landscape.

The morphology of the terrain is governed largely by the geology and surface deposits with the Basement Complex areas having a well developed drainage pattern, the Nubian Sandstone in North Darfur having a deeply incised drainage pattern and the *qoz* covered sandstone and agglomerates of South Darfur having almost no drainage pattern (Figure 3).

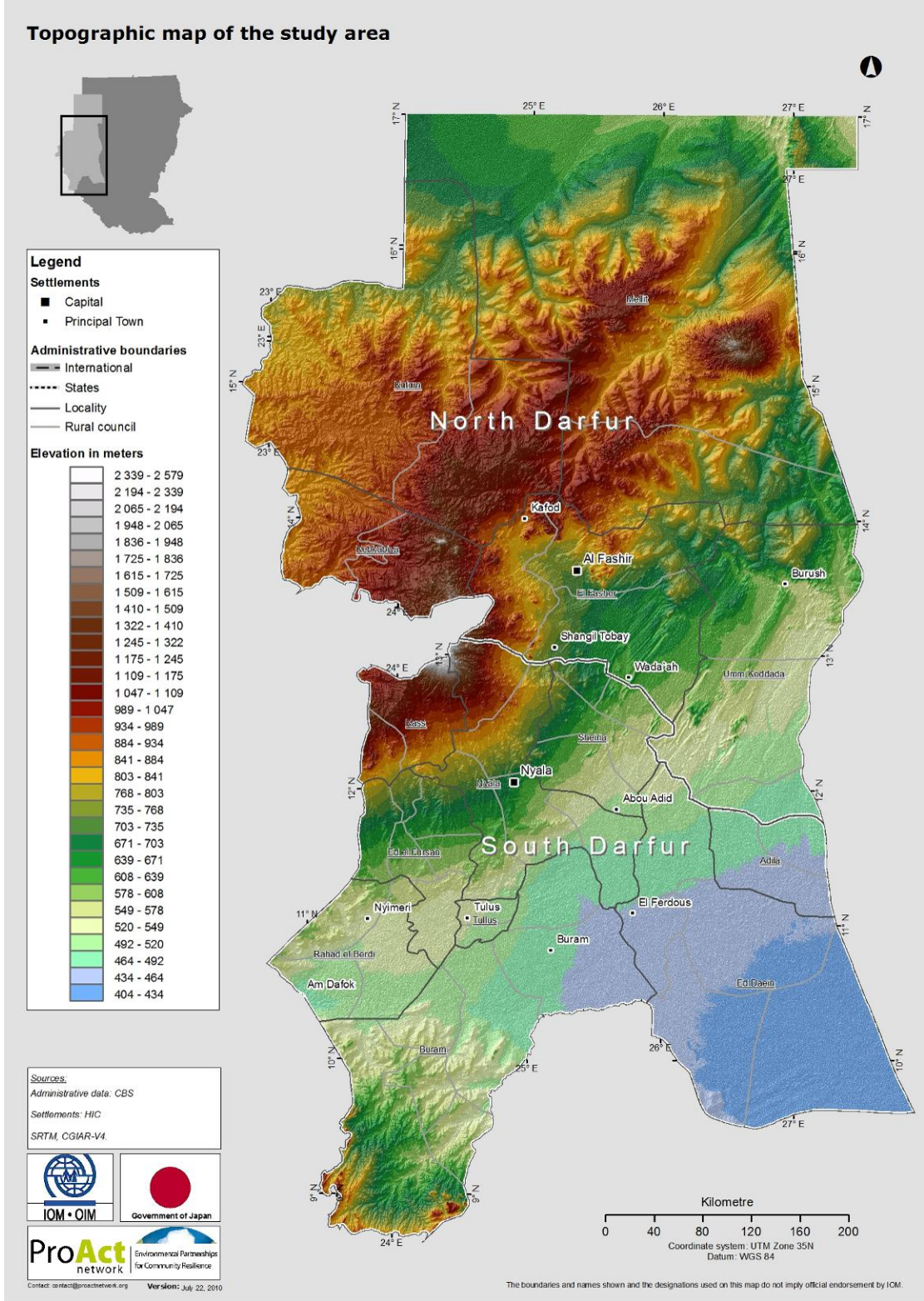


Figure 3. Topography of the ELVM study area.

### 2.1.5 Vegetation

From the Libyan Desert in the north to the humid southern border of South Darfur, native vegetation types gradually change across the region, depicting transitions in rainfall, geology and soil conditions and landforms. North of 17° latitude, the desert zone is devoid of vegetation except for the basins of major – and largely highly ephemeral – *wadis* (e.g. Wadi Howar), where some perennial species, growing throughout the year, are accompanied by herbs and grasses after the rains.

To the south, between 14° and 17°N, sparse grasses and herbs with scattered shrubs and occasional trees characterise the semi-desert. Within this vegetation belt, at the fringe of the desert edge, a sparse patchy growth of herbs and short, tufted grasses, locally called *Gizzu*, appears between the end of the rainy season and before the north-eastern winds start blowing. This ephemeral vegetation type, dominated by legumes, has been traditionally used by camel herders for their animals to browse during the cool season (Lebon, 1965).

With increasing rainfall, the semi desert landscapes transform into open thorn savannas with sparse arboreal cover. Dominant elements of this plant formation are various species of *Acacia*, including *Acacia senegal Willd. (Hashab)*, which produces gum arabic, a traditional and major export.

As tree and shrub cover substantially increase south of latitude 14°N, a woodland savanna emerges. In this vegetation type, shrub, tree and annual and perennial herbaceous species grow more vigorously but in various proportions. Vegetation includes grasslands with sparse tree cover and areas where trees are so dense that canopy closure does not allow herbaceous development. The dominant arboreal components of this plant formation are various legumes (including several species of *Acacia*), *Adansonia digitata* L. (*Tabaldi* or *Baobab*) and several species of the Combretaceae family.

These vegetation types, and the ecosystems they represent, have undergone extensive transformation and degradation due to a combination of factors, including increasingly frequent drought, enormous human pressure, and what is generally regarded as unsustainable natural resource management. Fuelwood and charcoal extraction have led to woodland destruction, agricultural expansion on unsuitable soils and overgrazing have resulted in soil exhaustion and widespread erosive processes (Ayoub, 1998). Due to environmental degradation, the natural resource base of many livelihoods has been depleted, and highly degraded landscapes are now present in some areas of North and South Darfur.<sup>4</sup>

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<sup>4</sup> Main sources include: Elsidig. E. A. (2007); Lebon (1965); Morton (1985); Ramsay (1958) and Wickens (1976).

## 2.2 Natural Resource-Based Livelihood Activities in North and South Darfur

### 2.2.1 Livelihoods – A Definition

Livelihoods are about people, their resources and what they do with them in order to ‘make a living’, or to attempt to do so while coping with risks and uncertainties. Formally, a livelihood can be defined as ‘the activities, the assets, and the access that jointly determine the living gained by an individual or household’ (Ellis, 1999). Accordingly, DFID’s Sustainable Livelihoods Framework (DFID, 1999) asserts that the inherent potential of people to achieve their goals (livelihood outcomes) through activities and choices (livelihood strategies) relies on their resources within their specific governance settings.

This Framework divides livelihood resources (capital) into:

- human capital – skills, knowledge, ability to labour and good health;
- social capital – networks and connectedness, trust, collaboration, attitudes, values and norms;
- financial capital – savings, credit, labour income, pensions, remittances, jewellery, livestock, and so forth;
- physical capital – infrastructure, tools and equipment; and
- natural capital – natural resources and their goods and services, e.g. land, water, forests and air quality.

Because these capitals, governance settings and people’s priorities and strategies change over time, livelihoods are dynamic.

### 2.2.2 Livelihoods in Darfur

According to Young (2006) ‘*all rural livelihoods in Darfur are based on a similar range of livelihood strategies, with farming and herding predominating. These core livelihood strategies are supplemented with other activities, including trade, collecting wild foods and other natural resources, and finally labour migration and remittances. There are of course local variants, for example the production of tobac (chewing tobacco) and artisanry (leatherwork, metalwork, etc), membership of the military or the militias and a range of illegal activities, but in essence all livelihood groups in rural Darfur practice the same five livelihood strategies*’. In fact, because the precise set of livelihood strategies that traditionally separated sedentary farmers and mobile herders has converged over the past decades, competition over limited resources has resulted in conflicts among these major groups (Young, 2006). This adds to a larger set of historical socio-political processes of marginalisation and neglect towards Darfur and confrontation with neighbouring Chad and Libya to explain the most recent conflict in the region (Young *et al.*, 2005; Bromwich, 2008).

The conflict has shattered the lives and livelihoods of more than a million people across Darfur mainly through its devastating effects on livelihood resources, massive human displacement, looting and loss of financial and physical assets (houses, livestock, agricultural tools and

infrastructure), restrictions on livestock movement, access to agricultural farmland and wild food collection sites; disruption in trade and markets, blocks to labour migration and difficulties for those living abroad in sending back remittances. In addition, internal displacement has led to severe degradation of the natural resource base around camps and towns, and to the depletion of water resources and overgrazing in areas where pastoralists have concentrated (Buchanan-Smith and Jaspers, 2006), particularly in areas with seasonally recharged aquifers. Natural resource scarcity and environmental degradation have been cited as contributing factors to the Darfur conflict by University for Peace (2004, 2009); UNEP (2007); Bromwich *et al.* (2007); Bromwich (2008) and Buchanan-Smith *et al.* (2008), among other studies.

Affected by insecurity and restrictions on the movement of people and livestock, traditional livelihoods that have persisted during the conflict now operate at much reduced levels; large numbers of Darfuris have become dependent on daily labour and petty trade, and activities such as brick-making have gained increasing relevance (Buchanan-Smith and Jaspers, 2006). Conflict-driven changes in traditional livelihood strategies are detailed in Young *et al.* (2005), Buchanan-Smith and Jaspers (2006), Young *et al.* (2007), Buchanan-Smith *et al.* (2008) and Young *et al.* (2009), amongst others.

### **2.2.3 Natural Resource-Based Livelihood Activities in Darfur**

It has been indicated that although useful for management and planning purposes, categorised classifications of livelihoods in Darfur may create an illusion of more homogeneity within rather than between livelihood classes (Young, 2006). The ELVM approach to livelihoods in Darfur seeks to avoid creating this illusion, by evaluating the vulnerability of major natural resource based-livelihood activities across the region. This provides information on the most suitable traditional rural activities that can take place at any location and provides a background for livelihood support activities.

Following a literature review on livelihood classifications, rural production systems and natural resource use and management in Darfur (see Annex 10.1), the following section characterises the major natural resource-based activities that have traditionally been undertaken in the region.

#### **2.2.3.1 Livestock-Related Activities**

Livestock rearing, production, herding, trading and the use and trade of by-products (milk, meat, leather) is a traditional foundation for many key livelihood activities in Darfur. With pastoral and agricultural livelihoods converging in the region, livestock production is now undertaken mostly by transhumant or sedentary farmers who maintain herds, in addition to crop production and/or wage labour and, on a larger scale, by nomadic groups who customarily owned the largest herds (camels in North Darfur and cattle in South Darfur) and engaged in year-round livestock breeding and long-distance migration. Sedentary farmers and urban dwellers also keep livestock, such as donkeys for transport and/or small ruminants and chickens for domestic use or trade.

Darfur is crossed by numerous North-South livestock migration routes that, according to Morton (1985), have been designed for herds to graze on northern basement complex areas during the

wet season and to move to southern/south-western low-lying alluviums during the dry season. This movement traditionally allowed winter grazing on the best quality grass (which grows on the basement complex) while the alluvium is flooded, and to reach available water sources (commonly by digging wells) and feed on crop residues in the alluviums during the dry season. However, within major routes, migration patterns remained flexible to adapt to within-year rainfall variations.

An important, recognised variation in the general pastoral migration pattern occurs in North Darfur where, after the rains, herders bring their camels and sheep northwards to graze on a highly nutritious yet ephemeral group of plants, commonly known as *Gizzu*. The appearance of *Gizzu* pastures is driven by residual moisture from the rainy season. Therefore, during years of drought, these pastures are unavailable. Sudan's National Biodiversity Strategy and Action Plan (NBSAP, 2000) reported that the *Gizzu* disappeared for over 20 years from the desert areas of Darfur in the last century.

The traditional livestock migration system was in many ways beneficial to both farmers and pastoralists<sup>5</sup>. Based on high levels of cooperation and traditional rules, herds were allowed to transit through agricultural fields to feed on harvest residuals and access water sources. In exchange, livestock manure would fertilize agricultural land. However, agricultural expansion and severe prolonged drought periods have, along with other factors, increased tensions between the two major livelihood groups along migration routes, even before the most recent crisis. Another serious issue is the decrease of palatable species and increase of unpalatable and invading species in the rangelands (An *et al.*, 2007; NBSAP, 2000). This has been attributed to a significant increase in livestock populations resulting from improved veterinary and drinking water services (NBSAP, 2000).

As previously mentioned, the most recent conflict has had disastrous consequences on livestock-related livelihoods. Due to insecurity, certain traditional winter grazing pastures are rendered inaccessible, and markets and livestock trading routes disrupted (Young *et al.* 2005). Pastoralists sell livestock to avoid attacks and looting, in certain cases using the income generated to buy arms for protection. This contributes to increasing sedentarism, and leads to escalating tensions with resident populations over scarce natural resources (Young *et al.*, 2007).

### **2.2.3.2 Agriculture**

Rainfed agriculture, based on smallholders' traditional methods, dominates the agrarian economy of Darfur. This low input agriculture requires intensive labour. Until 1977, less than one per cent of the cropped area in North and South Darfur was irrigated, and mechanised agriculture was only practiced in 1.8 per cent of South Darfur's cropped area (Morton, 1985).

A shift from traditional subsistence to cash agriculture (mainly grain and oil seeds) across the region has been described by Morton (1985) for the period prior to the conflict. In the same report it is noted that cash cropping rapidly expanded, mainly in Darfur's south where cultivable

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<sup>5</sup> Traditional livestock management schemes are detailed in Morton (1985) and Young *et al.* (2005)

soils are relatively extensive, although infertile. In the north, a wider range of crops were planted, but at a smaller scale. Pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) are the staple and most widely cultivated foods. Several other cultivars and wild varieties are grown in Darfur (Table 1), mixed with major crops (e.g. a mix of sorghum and groundnuts) in large plantations where they are locally important (e.g. watermelon in South Darfur's Ma'aliya area) or widely cultivated in small amounts (e.g. okra).

A major problem for the agrarian sector in Darfur is the continuous and marked decline in yields per unit area. It has been reported that under good rainfall conditions, an average hectare of land (*qoz*) recently cleared for cultivation in North Darfur may produce approximately 1,200kg of millet grains (1,800kg in South Darfur), however this drops to approximately 600kg after three or four consecutive planting seasons. Similar declines have been reported for other grains in Sudan's drylands and have been attributed to the low fertility of *qoz* soils, drought, the shortening of fallow periods, agricultural use of marginal lands and wind erosion. To compensate for low productivity, cultivation areas are usually expanded. These negative effects on *qoz* soils have led to more intense planting in the *wadis*, where water harvesting systems have been historically developed to permit agriculture on a seasonal – by flood irrigation – or a more permanent basis, by flood irrigation plus bunds, locally known as *teras*.

### **2.2.3.3 Forestry-Related Livelihood Activities**

#### **Timber and woodfuel extraction**

In Darfur, natural tree cover positively correlates with annual rainfall (see Figure 7) so that in general, forests and other tree resources are more abundant in South than in North Darfur (Buchanan-Smith *et al.*, 2008). Extraction of building materials and woodfuel – firewood and charcoal – from forested areas has traditionally provided the basic supplies for local populations and elements for trade in central Sudan. However, significant deforestation has occurred. First, as a consequence of land clearance for agricultural expansion and, most recently, as a result of woodfuel and timber extraction and trade becoming the major economic activity of large numbers of people who lost their livelihoods during the conflict. In addition, numerous local bakeries and brick-making industries have emerged, which demand large amounts of woodfuel, further contributing to deforestation (Buchanan-Smith *et al.*, 2008).

The extent of deforestation is remarkable. It has been estimated that before the most recent crisis, Darfur was losing 1 per cent of its tree resources annually (Buchanan-Smith *et al.* 2008). An illustration is the case of the Hamada forest. This forest, which covers an area of 143km<sup>2</sup> to the north of Nyala, was used by 700 households from the surrounding area before the conflict. However, with the arrival of 217 households to the Manawashi IDP camp, resources became over-extracted. Every month, 7,300 trees are cut for firewood and charcoal and 355 donkey carts of firewood collected and loaded every week<sup>6</sup>. It is clear from this example that urgent measures are necessary to prevent forest remnants, the associated livelihood activities, and the services they provide from disappearing.

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<sup>6</sup> In: Sudan UN Resident Coordinator's Support Office Weekly Report, 4-10 April 2010

## **Gum Arabic**

Sudan is the world's largest producer of gum arabic, an exudate from the *Hashab* tree (*Acacia senegal*) which is highly demanded by food and pharmaceutical industries worldwide. Within Sudan, 20 per cent of the national gum arabic extraction comes from Darfur (Sudan-MDTFs, 2007), where its production is undertaken by small-scale farmers in rainfed areas, as a supplementary activity to traditional crop production. Gum arabic not only provides farmers with an additional income, its production also constitutes a coping strategy in times of crop failure. Planting *Hashab* trees also protects against soil and wind erosion (Sudan-MDTFs, 2007).

*Acacia senegal* trees are grown following a 'bush fallow' system whereby agricultural crops are planted for a number of years (3 to 5) until their productivity declines. Then, *Hashab* trees are planted. Five to seven years after planting, the trees produce gum arabic and it will take between 15 and 20 years for their productivity to decline. When this occurs, the trees are cut and replaced by traditional agricultural crops, for the cycle to recommence.

Although *Hashab* trees are resistant to periods of water stress, the combination of consecutive droughts, change in farming practices, conflicts between farmers and herders and the most recent crisis have negatively impacted the production of gum arabic in North Darfur. As a result, production has shifted towards the south, South Darfur included.

### **2.2.3.4. Small-scale Natural Resource-based Livelihood Activities**

Other activities that are directly related to natural resources in Darfur and which are central to the livelihoods of certain individuals or households – but of lower economic relevance at the Darfur-wide scale include:

- collection and trade of palm leaves and fodder;
- fruit production and trade;
- wild food collection, processing and trade;
- collection and trade of salts for animal consumption; and
- craft making and hut construction, particularly widespread in Darfur, where the majority of homes and fences are constructed almost entirely of thatch and building wood poles which need to be replaced approximately every two years. Hut construction is based on a *Nafir* system of cooperation and implies the participation of a skilled architect, as the conical roof and the lower round base are separately constructed, before assembling. Furthermore, some families base their entire income on collection of grasses for the thatching industry (Elsiddig, 2007).

		<b>Horticultural crops</b>	
<b>Cereals</b>			
Sorghum	<i>Sorghum bicolor</i> (L.) Moench	Okra	<i>Abelmoschus esculentus</i> (L.) Moench
Pearl Millet	<i>Pennisetum glaucum</i> (L.) R. Br.	Onion	<i>Allium cepa</i> L.
Wheat	<i>Triticum aestivum</i> L.	Tomato	<i>Lycopersicon lycopersicum</i> (L.) H. Karst.
Maize	<i>Zea mays</i> L.	Hot pepper	<i>Capsicum</i> spp. L.
Upland rice	<i>Oryza sativa</i> L.	Potato	<i>Solanum tuberosum</i> L.
Barley	<i>Hordeum vulgare</i> L.	Eggplant	<i>Solanum melongena</i> L.
Finger millet	<i>Eleusine corocana</i> (L.) Gaertn.	Melon	<i>Cucumis melo</i> L.
		Watermelon	<i>Citrullus lanatus</i> (Thunb.) Mansf.
<b>Oil crops</b>			
Sesame	<i>Sesamum indicum</i> L.	<b>Leafy vegetables</b>	
Groundnut	<i>Arachis hypogea</i> L.	Purslane	<i>Portulaca oleracea</i> L.
Sunflower	<i>Helianthus annuus</i> L.	Rocket	<i>Eruca sativa</i> Mill.
Niger	<i>Guizotia abyssinica</i> Cass.		
<b>Grain legumes</b>		<b>Fruits</b>	
Faba bean	<i>Vicia Faba</i> L.	Date palm	<i>Phoenix dactylifera</i> L.
Haricot bean	<i>Phaseolus vulgaris</i> L.	Mango	<i>Mangifera indica</i> L.
Chick pea	<i>Cicer arietinum</i> L.	Sweet orange	<i>Citrus sinensis</i> (L.) Osbeck
Lentil	<i>Lens culinaris</i> Medik.	Grapefruit	<i>Citrus paradisi</i> Macfad.
Lupin	<i>Lupinus albus</i> L.	Sour orange	<i>Citrus aurantium</i> L.
Cowpea	<i>Vigna unguiculata</i> (L.) Walp.	Lemon	<i>Citrus limon</i> (L.) Osbeck
Pigeon pea	<i>Cajanus cajan</i> (L.) Millsp.	Guava	<i>Psidium guajava</i> L.
Hyacinth bean	<i>Lablab niger</i> Medik.	Banana	<i>Musa</i> sp
Bambara groundnut	<i>Voandzeia subterranea</i> (L.) Thouars	<b>Other crops</b>	
		Sugarcane	<i>Saccharum sinense</i> Roxb.
<b>Fiber crops</b>		Tombac	<i>Nicotiana tabacum</i> L.
Cotton	<i>Gossypium</i> sp. L.	Roxelle / Karkadeh	<i>Hibiscus sabdariffa</i> L.

**Table 1.** Plant species cultivated in Darfur (extracted from NBSAP, 2000).

## **2.3 Vulnerability**

### **2.3.1 Conceptual Issues**

Vulnerability assessments and monitoring have been conducted in various scientific fields with the objective of informing stakeholders and decision-makers about the potential consequences of hazardous events and existing opportunities for proactive measures and policy interventions that can lead to effective hazard preparedness and risk reduction (Birkmann, 2006). Vulnerability is broadly understood as the condition of a system that results from its level of exposure to a given external process that may affect it – hazard – and its intrinsic characteristics. Because a system’s vulnerability may differ among hazard types, magnitude and frequency and, vulnerability to a given hazard may vary over time and space and between system scales - such as individuals, households, social groups, ecosystems or regions –, sound vulnerability assessments depend on conceptual frameworks that are context-, hazard-, system- and scale-dependent. Unfortunately, the numerous quantitative and theoretical efforts to address vulnerability have given place to a plethora of terms and approaches (reviews in Birkmann, 2006 and Hahn *et al.*, 2009) and significant progress towards adopting unified operational definitions has only occurred within certain realms, e.g. climate change research.

Conceptually, the major point of divergence among vulnerability assessment studies has been the inclusion of indicators for adaptive capacity, i.e. the intrinsic characteristics of the system which allow it to anticipate, withstand, cope with and recover from a hazardous event. Therefore, the range of vulnerability definitions and quantitative methodologies developed thus far encompass those that express vulnerability as a direct function of exposure to the hazard, those that determine it as the inverse of adaptive capacity and studies that incorporate both internal and external factors. Even within this last category, there is a multitude of interpretations about how best to select, calculate, aggregate and weigh indicators for each component of quantitative vulnerability measures.

### **2.3.2 Social and Environmental Vulnerability Assessments**

Traditionally, most vulnerability analyses approached the social dimension of vulnerability and focused on the socio-economic impacts of hazardous events on individuals or groups, disaggregated by factors such as gender, ethnicity, age, activity, income distribution or immigration status. These studies also encompass the effects of hazardous events on the human-built environment, e.g. infrastructure or institutions. The environmental dimension of vulnerability, which has comparatively received less attention, has recently gained unprecedented relevance and is frequently included in human-centred vulnerability assessments. This is because abiotic and biotic – including human-induced – impacts on ecosystems affect the goods and services they provide and the communities that depend on them. This relationship is not linear: as the provision of ecosystem goods and services decreases, the vulnerability of dependent communities increases. This, in turn, may

translate into increased human pressure on already fragile ecological systems, which further increases social and environmental vulnerability.

Until now, conceptual frameworks that capture the social-environmental interface of vulnerability (reviewed in Eakin and Luers, 2006) are necessarily oversimplified and, in practice, limited to project the loss of ecosystem services, to establish the dependency of certain communities to a small number of ecosystem services and to evaluate the vulnerability of certain ecosystem components (e.g. land, soil, vegetation, water) to specific hazards. These frameworks use elements from social vulnerability analysis which, in turn, adhere to well established sociological theories (reviews in Cannon *et al.*, 2003 and Birkmann, 2006), such as the sustainable livelihoods approach (DFID, 1999). Consequently, in holistic human-environmental vulnerability analyses, the social dimension should, at least theoretically, be expressed through indicators of well-being (e.g. nutritional status, physical and mental health), livelihood and resilience (e.g. assets and capitals, income and qualifications), self-protection (capabilities and willingness to lower impacts, for instance building safe homes), social protection (preparedness) and social and political networks and institutions.

### **2.3.3 Vulnerability Mapping**

While multiple context, scale and system tailored assessment methodologies for social and environmental vulnerability are available, vulnerability mapping stands out as a useful and widely accepted tool for communicating assessment results to a wide range of audiences. Separate maps can be presented for the geographic extent of exposure to hazards, adaptive capacity and ranked vulnerability measures. This allows the user to visually follow steps undertaken during the analysis, identify vulnerability drivers across geographic units or sectors and detect priority areas for intervention. The main limitation of this approach is that it provides only a “snapshot” picture of vulnerability, disregarding its inherent dynamic characteristics. Exceptions to this are monitoring frameworks, in which indicators are updated and vulnerability estimates recalculated frequently. One such example is the Famine Early Warning System Network (FEWS-NET) which periodically provides vulnerability information on emerging and evolving food security issues across Africa and some countries in Latin America, South-east Asia and the Middle East.

Other vulnerability mapping exercises that combine environmental and social components, and that are relevant to the ELVM project, come from the realm of climate change research where efforts have focused on translating climate and global change trends and scenarios into potential impacts on ecosystem services (e.g. Metzger and Schroeter, 2006 for Europe; Yusuf and Francisco, 2009 for South-east Asia; Thornton *et al.*, 2006 for Africa; and, O’Brien *et al.*, 2004 for India). In addition to these, other “static” mapping approaches that were reviewed and are relevant to the present study are the World Food Programme’s Vulnerability Analysis and Mapping (VAM) (WFP, 2010) where maps of vulnerability to food insecurity are produced to support the WFP’s ground operations, and the ecosystem services and accessibility approach adopted by UNEP to assess and map ecosystem vulnerability to anthropogenic hazards in Liberia (Richards *et al.*, 2006).

### 2.3.4 Vulnerability Related Definitions in the ELVM Project

Following an extensive desk review of existing literature on environmental and livelihoods vulnerability concepts, models, and quantitative methodologies (See Annex 10.2), a vulnerability assessment framework was developed for the ELVM project (Section 4). This framework includes both environment and livelihoods intrinsic and extrinsic factors and uses North and South Darfur context-specific indicators for which reliable data was available or could be extracted from remote sensing analyses.

The ELVM approach is founded upon the following definitions:

*“Vulnerability”* is the extent to which a system may be impacted by a hazardous event to which it is exposed, after accounting for the system’s adaptive capacity.

*“Exposure”* is the probability of the system experiencing a hazard.

A *“hazard”* is a natural or man-made threat to the system’s condition.

An *“impact”* is the extent of change in the system’s condition due to the occurrence of a hazardous event.

*“Adaptive capacity”* is a system's ability to adapt to a hazardous event – by anticipating it, resisting it, coping with its impacts and recovering from them.

In line with the objectives of the ELVM project, the 'system' is defined as a contiguous area of land, and its associated environment, which is exploited by a traditional natural resource-based livelihood activity or collection of activities. Ideally this would be based on community footprints on the ground but these cannot yet be defined with certainty because of imprecision in the location of villages in the region<sup>7</sup>. For this reason, the study area has been divided into 16km x 16km grid cells (see Figure 4).

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<sup>7</sup> Thiessen polygons centred on villages and towns would give a reasonable approximation of community footprints but the uncertainty of knowing the precise location of many villages means that a regular grid has been used instead.

### Division of study area into 16x16 km grid cells

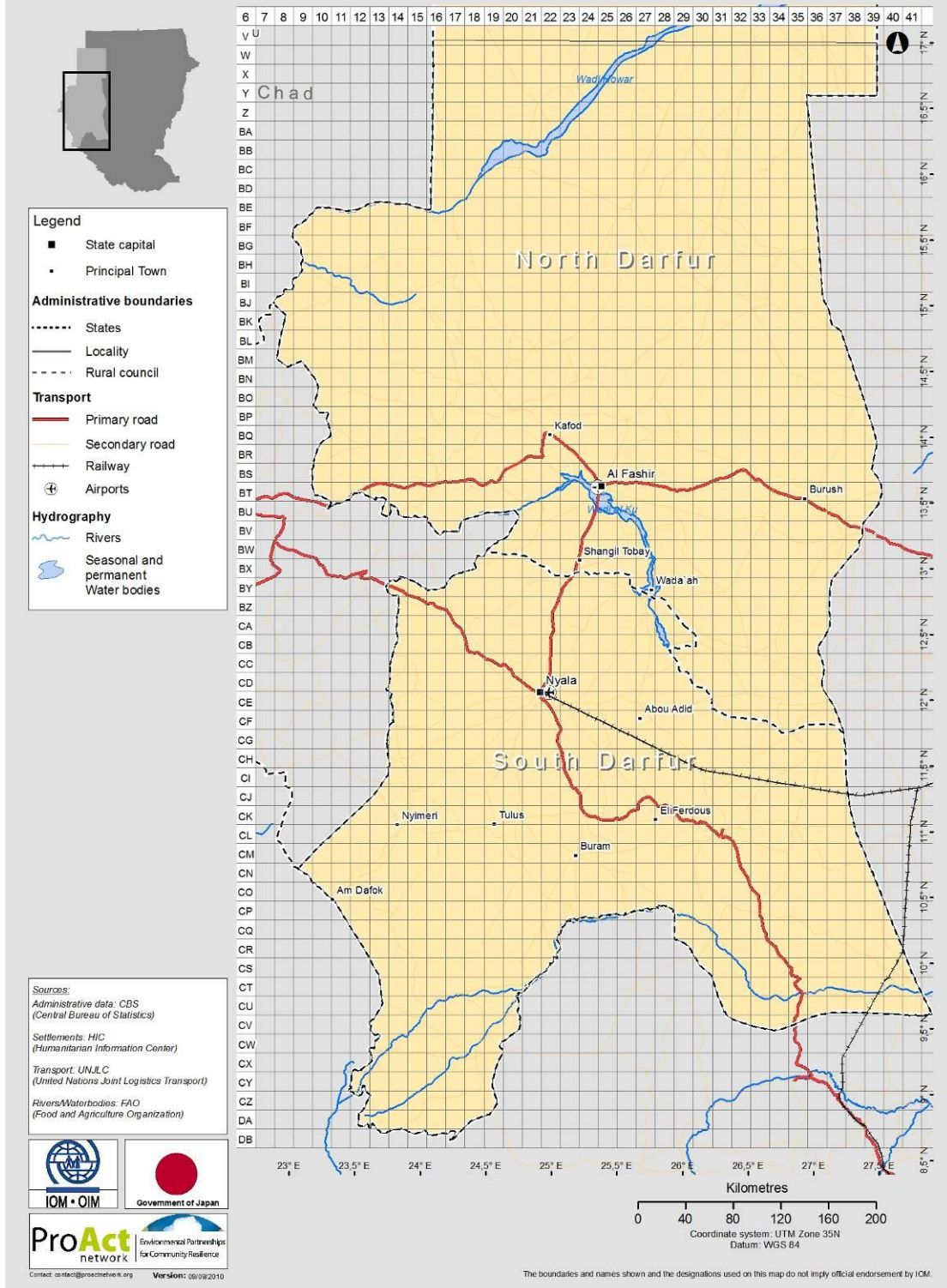


Figure 4. Division of the study area in 16km x 16km grid cells.

### **3. ELVM METHODOLOGY – A SUMMARY**

This ELVM project constitutes the first attempt to evaluate and map the vulnerability of traditional rural livelihoods and their resource base in Darfur. Founded upon a clear and Darfur-focused conceptual framework, the project has processed existing and satellite-derived information to estimate exposure to natural hazards and the adaptive capacity of communities at continuous geographic areas across North and South Darfur. The project results are presented in a simple and readily interpretable manner, which allows the most vulnerable geographic units to be identified, vulnerability to be compared among locations and the main drivers of vulnerability determined at each site. These results constitute a baseline upon which local, national and international stakeholders and external donors can better target future support towards the return process of IDPs in Darfur.

The development of the ELVM vulnerability framework started at a project inception meeting held in Nyon, Switzerland, from 18-20 November 2009. During this meeting ELVM team members reached consensus on the vulnerability-related definitions to be adopted for the project, discussed potential analytical approaches and assessed data availability. In the months that followed this meeting, data assembly and analysis were undertaken, with progress and limitations discussed at regular intervals. A complete description of each activity, including technical data processing details is presented in Section 4.

Developing the ELVM framework involved three initial steps:

- a) an extensive review of existing literature on Darfur's environment and livelihoods and on conceptual and methodological approaches for vulnerability evaluation;
- b) identification of major limiting factors – hazards – for rural production systems in the region; and
- c) data selection and acquisition.

Based on the literature review, expert accounts and preliminary analysis of the data available to the project, potential rainfall water availability, rainfall predictability, potential groundwater availability and potential energy -woodfuel- sufficiency were identified as major limiting factors for production and thus rural livelihood activities in the two Darfur states, with low values of these factors considered environmental hazards.

Data on infrastructure and supporting services were considered to best reflect the capacity of people to cope with limiting factors, while population distribution was included to add a 'human component' to physical vulnerability estimates, i.e. to account for the human population vulnerable to multiple natural hazards at any location. This follows the assumption that between two identical geographic areas that experience similar exposure to hazards, the more populated one is more vulnerable. Including population distribution in the ELVM framework also provides a rapid indication of the proportion of the total population who would directly or indirectly benefit from an intervention at any site. The methodological steps followed to create the final ELVM vulnerability map are described below.

To understand the spectrum of environmental hazards, their impacts and relationships with each other and with natural resource-based livelihood activities, a conceptual model was constructed using Unified Modelling Language (UML). This is a formal visual language which is used to help to deconstruct and to understand complex systems. This initial analysis assisted in identifying each of the entities necessary to undertake the ELVM and the relationships between them. It also provided a vocabulary of hazards, impacts, livelihoods and assets and their relationships, providing a firm foundation on which to construct the ELVM framework.

The following step was to divide the study area into 16km x 16km grid cells to quantify limiting factors (hazards), adaptive capacity, population and the overall vulnerability index at the grid cell scale.

Potential rainfall water availability was calculated at every 16km x 16km grid cell as the average of the annual precipitation amounts received from 1981-2006. These amounts were obtained from an analysis of the relationship between satellite derived NDVI images and ground rainfall measurements. The annual NDVI rainfall equivalent was also used to calculate the coefficient of variation (CV) for each grid cell, a measure of rainfall variability among years. CV values were later integrated into a rainfall predictability index (RP). High RP values indicate small changes in annual precipitation between years, i.e. high rainfall predictability. Low RP values denote high fluctuation in rainfall amounts between years, i.e. high rainfall unpredictability. NDVI rainfall equivalent figures were used in these calculations because this index accurately reflects rainfall in the study area (Figure 10) and because field-level meteorological records are punctual and scarce in Darfur, while the ELVM framework requires reliable, long-term information across the two states.

Available groundwater resources are determined by the hydrogeology of the region, i.e. location of rock formations and superficial deposits, the extent and interaction between these geological elements and their properties, for example porosity or storage capacity. Therefore, to evaluate potential groundwater availability, historical hydrogeological maps of the region were digitised, merged and a Darfur-wide hydrogeological map was produced (Figure 17). The geological and surface deposit elements from this map were further classified and plotted according to their groundwater availability potential. The resulting map (Figure 36) indicates the potential for natural storage, extraction and use of groundwater at each 16km x 16km grid cell.

Next to water availability and reliability, sufficiency of energy (woodfuel) sources is considered in the ELVM project as a major limiting factor to traditional livelihoods in North and South Darfur. The project assessed energy availability across the region using the Woodfuel Integrated Supply/Demand Overview Mapping methodology (WISDOM). This implied gathering and extracting from historical sources, data on land cover, population densities, per capita yearly energy consumption and woody vegetation biomass stocking rates, among other information for obtaining a regional woodfuel balance map (Figure 33). This map clearly separates those areas with sufficient woodfuel available to meet the needs

of the local population from those where woodfuel is insufficient and its exploitation unsustainable.

The adaptive capacity component of the ELVM vulnerability framework was represented by a combined measure of people's access to natural and physical assets. This measure included access to surface water resources, boreholes, hand pumps, major markets, health facilities, education and the location of IDP camps. Accessibility was calculated as the cost (effort) of travelling from a certain location to the nearest asset of interest, assuming that people try to minimise the effort/cost of travelling, e.g. try to use roads instead of crossing thorn scrub, even if the distance is larger. Access maps were created for each social and physical asset category using friction surfaces – which indicate the ease/difficulty of movement between places. From these, the overall potential adaptive capacity in every 16km x 16km grid cell was standardised as one minus the sum of costs incurred while moving from the cell to the nearest asset in each asset category (see adaptive capacity map in Figure 39).

Once all limiting factors and the adaptive capacity components of the ELVM framework were mapped, a North and South Darfur wide map of exposure to multiple hazards was created, by averaging the values of all limiting factors at each 16km x 16km grid cell (Figure 41). Remaining steps were to add the estimates of the adaptive capacity index to the multiple hazards average to produce an overall estimate of vulnerability (MHVI) per cell (Figure 42) and to multiply this vulnerability index by one minus the proportion of the population in North and South Darfur estimated to inhabit each grid cell. The Environmental and Livelihoods Vulnerability Index (ELVI), calculated in this last step, allowed the project to include human exposure into the spatial vulnerability estimates and to show in a single map (Figure 44), those areas where interventions could potentially have a greater number of beneficiaries.

For the sake of simplicity and for a better understanding of how hazards, adaptive capacity and population distribution interact at each 16km x 16km grid cell, it is recommended that ELVI values are interpreted with the support of vulnerability diagrams (radar charts) where: potential rainfall water availability, potential rainfall predictability, potential groundwater availability, potential woodfuel sufficiency, relative population distribution and potential adaptive capacity are plotted on radial axes. The interpretation of vulnerability estimates using vulnerability diagrams is exemplified for several representative sites across North and South Darfur in Section 6.

## 4. DEVELOPMENT OF THE ELVM CONCEPTUAL FRAMEWORK

### 4.1 Limiting Factors to Primary Production and Livelihoods

From a biophysical perspective, and ignoring exogenous inputs such as food aid and fuel imports, natural resource-based rural livelihood activities are ultimately dependent on the primary production of plants, i.e. the conversion of sunlight and carbon dioxide into organic compounds through photosynthesis. This is true of rural livelihood activities everywhere. The products of primary production provide communities with food from crops, wood resources for building and fuel and pasture for livestock. Primary production is dependent on critical inputs and in particular water availability, adequate temperature for plant growth, soil nutrients and sunlight. Each of these factors varies greatly across the Earth's surface.

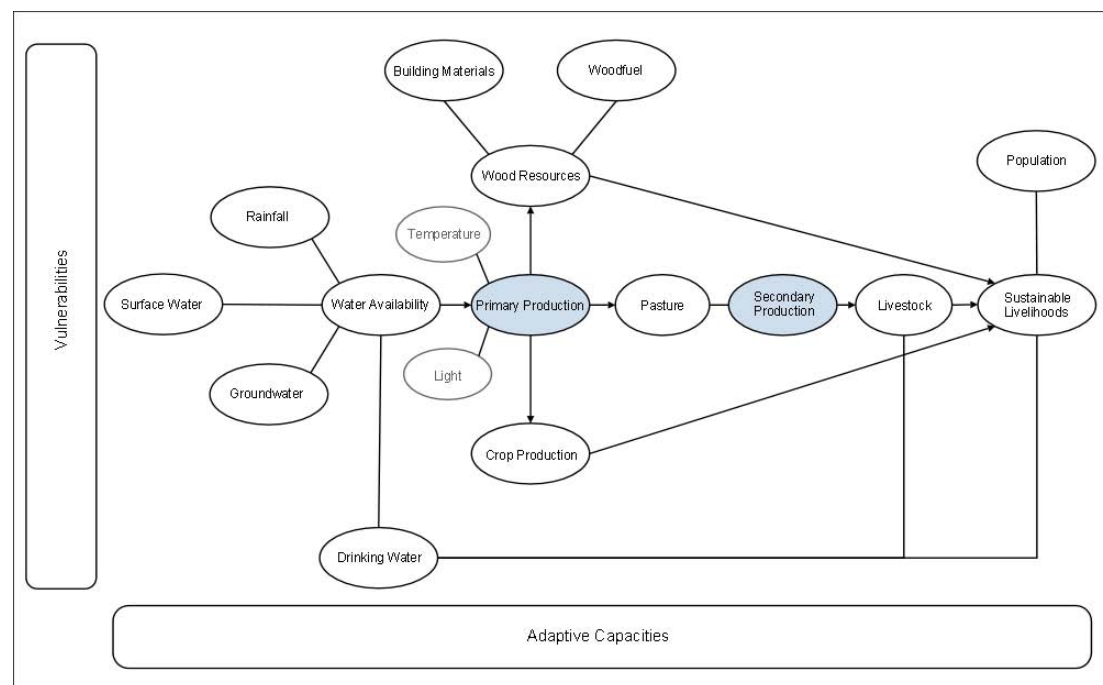


Figure 5. A biophysical view of production in Darfur.

Darfur is a diverse place and, in parts, is a marginal environment for plant growth. Consequently, livelihoods which are dependent on primary and secondary production are vulnerable to fundamental limiting factors. Temperature, sunlight and rainfall are dependent on the time of year and the position of the ITCZ, as described in section 2.1.

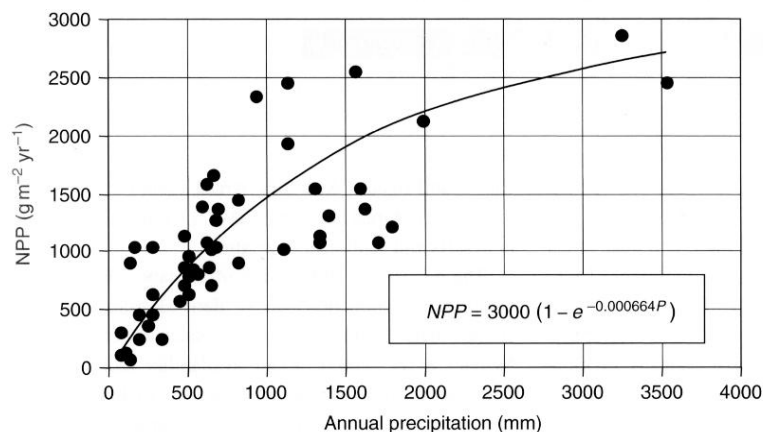
- **Temperature** is generally not a limiting factor to plant growth in Darfur, the mean monthly temperature range in Nyala is between 23°C in January and 31°C in May (FAO, 1982).
- **Water availability** both from rainfall and groundwater sources is in places a major limiting factor to plant growth and consumption for both people and livestock.

- **Evapotranspiration**<sup>8</sup> is a limiting factor during much of the year with the potential rate of evapotranspiration exceeding rainfall.
- **Sunlight** is not in short supply in Darfur but during the rainy season will significantly decline due to cloud cover (see Table 2).

These factors all co-vary with each other.

The availability of water in Darfur is a key determinant of what rural livelihood activities can be pursued, where they can take place and when they can happen. Water is available from two primary sources – rainfall and groundwater – including both fossil water and aquifers recharged through percolation. Knowledge of the spatial distribution of these water sources is essential to understand how livelihoods fit into their environmental context.

The relationship between rainfall and primary production is non-linear (see Figure 6). Precipitation is a limiting factor at low levels of annual rainfall and there is a near linear relationship between annual rainfall and Net Primary Productivity (NPP)<sup>9</sup> (Bonan, 2008). As annual rainfall increases above about 1,000mm water is no longer a major limiting factor to plant growth and increased rainfall does not necessarily result in a proportionate increase in NPP. As a result, the slope of the relationship in Figure 6 becomes shallower.



**Figure 6.** Relationship between NPP and Rainfall (Taken from Lieth, 1975).

In Darfur, maximum annual rainfall is approximately 1,300mm and a near-linear relationship between rainfall and NPP can be assumed. From a rainfed farming perspective this means that if it doesn't rain then crops will fail.

Knowing the long-term relationship between rainfall and NPP would provide an insight into the distribution of NPP in space and its variability with time – and consequently in the

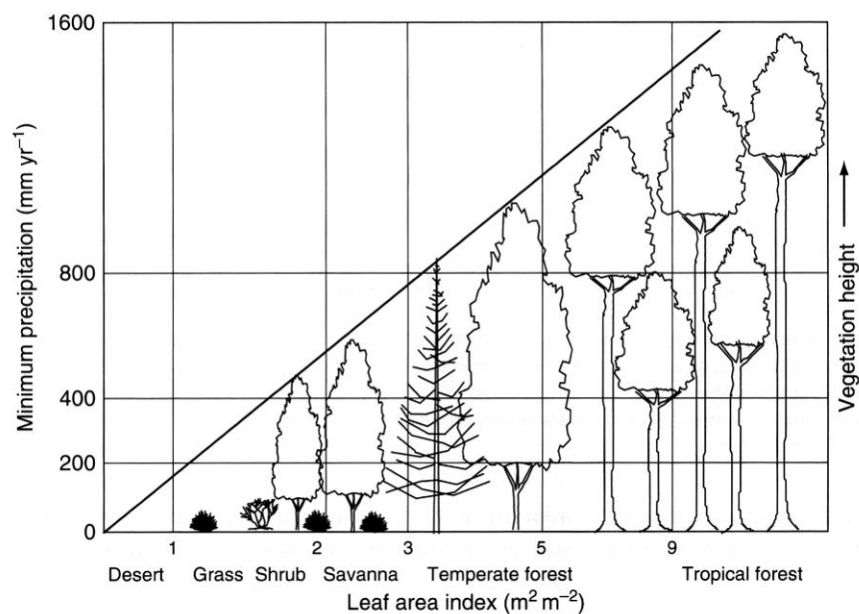
<sup>8</sup> Evapotranspiration is the transfer of water from the Earth's land surface to the atmosphere through evaporation from the soil surface and plant transpiration. The rate of evapotranspiration is dependent on temperature, wind, soil and vegetation type.

<sup>9</sup> NPP is the difference between carbon uptake by photosynthesis and carbon loss through respiration or gross primary production (GPP) minus autotrophic respiration (R).

vulnerability of rural livelihood activities to drought and crop failure. Climate data produced by the FAO LocClim software in Table 2 shows that in Darfur the NPP is limited by rainfall rather than temperature as the temperature is always high.

Changes in vegetation structure along rainfall gradients are reflected by a relationship between minimum yearly precipitation, vegetation height and leaf area index (LAI)<sup>10</sup>, as shown in Figure 7 (from Bonan, 2008). The rainfall gradient in Darfur covers much of this range, up to about 1300mm, including temperate forest.

The strong correlation between precipitation, NPP and LAI over the precipitation range experienced in Darfur is evident from Figure 6 and Figure 7 and is expanded in the following sections.



**Figure 7.** Relationship between vegetation height and leaf area index in relation to minimum annual precipitation (From Bonan, 2008)

Precipitation falling on land can take a variety of pathways which include: interception by physical structures, including plants, infiltration into the soil and surface flow. Only a portion of the rainfall will be available to plants via soil moisture. In the Darfur environment there is nevertheless a strong relationship between annual rainfall, the effective rainfall<sup>11</sup> available to plants and plant growth.

Changes in vegetal cover and plant growth can be detected through analysis of both LAI and NPP. These parameters can be estimated by satellite images of plant canopies which are explored further in the following sections.

<sup>10</sup> LAI is the area of leaves in a canopy that cover a unit area on the ground.

<sup>11</sup> Effective rainfall is the portion of rainfall which finds its way to plant's roots and which is available to be taken up by plants.

### 4.1.1. Climatic Factors

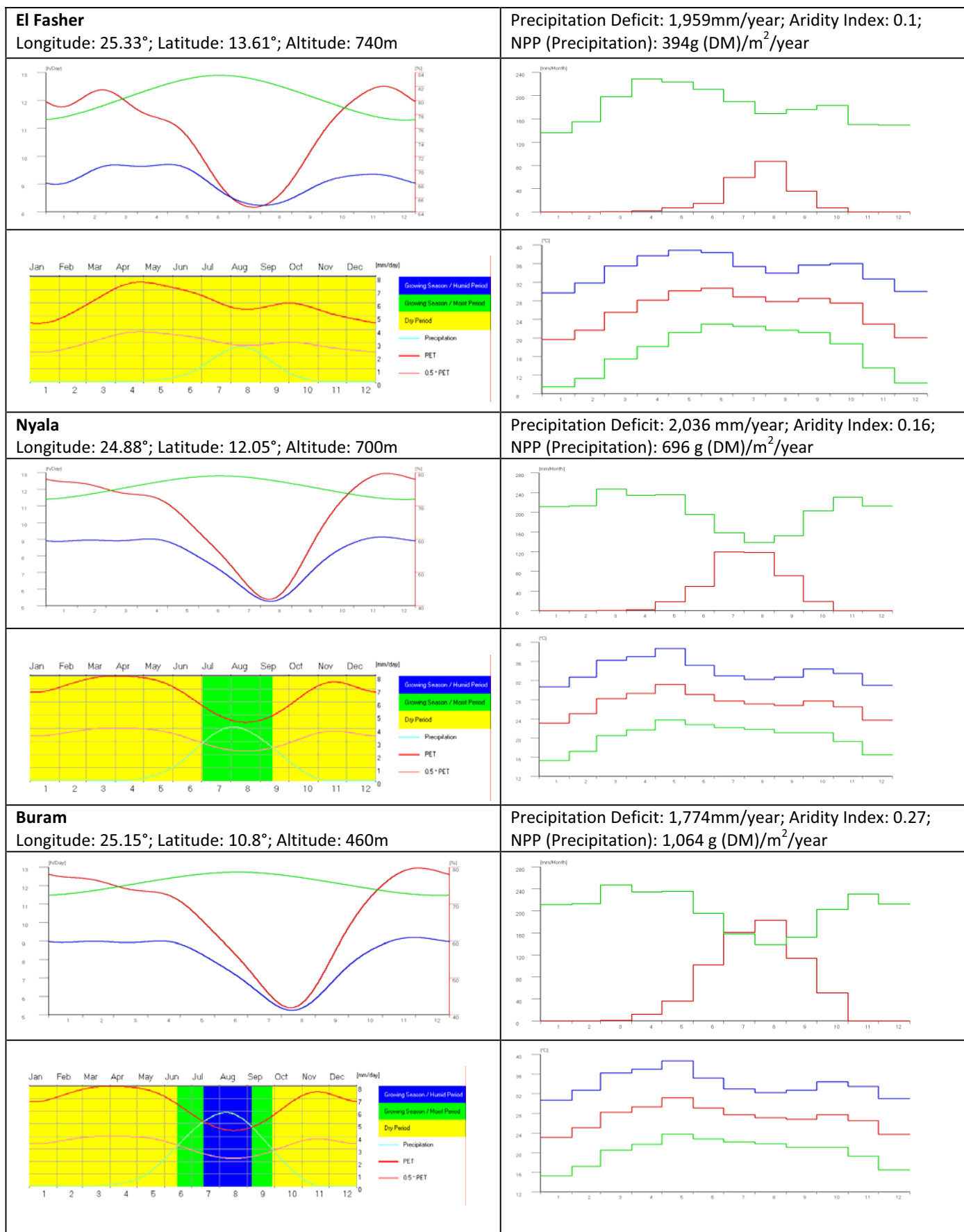
#### 4.1.1.1. Rainfall, Temperature, Potential Evapotranspiration (PET) and Aridity

Table 2 contains climate data from the FAO *New LocClim* software application and climate database which contain long-term average global climate statistics for the period 1961-1990 (FAO, 2005). The table contains standard data for three meteorological stations located at different latitudes in Darfur – El Fasher, Nyala and Buram. The plots contain the following six panels for each station.

Location and altitude	Summary statistics: precipitation deficit, aridity index and Leith's NPP in grams of dry matter per m <sup>2</sup> per year.
Sunshine – including: sunshine fraction (red) (the % of time that bright sunshine is recorded), day length (green) and sunshine hours (blue)	Mean monthly rainfall (red) and potential evapotranspiration (PET) (green)
Mean growing season period showing PET <sup>12</sup> , 0.5 PET and rainfall. Also shown are the dry season (yellow), the growing season pre- and post- moist periods when rainfall is greater than 0.5 PET (green), the growing season humid period when rainfall is greater than PET (blue) – indicating that the water balance is positive	Mean minimum (green), mean (red) and maximum (blue) temperature in °C

At each of these locations NPP is limited by precipitation and not by temperature because temperature is always adequate for plant growth. Within the extent of Darfur three of the six characteristic global growing seasons are exhibited by these stations – all year around dry (El Fasher), growing season without a humid period (Nyala) and growing season with both moist and humid periods (Buram).

<sup>12</sup> Potential evapotranspiration (PET) is equivalent to the depth of water that would be evaporated from the soil and transpired by a short green crop in a given area with a plentiful supply of water.



**Table 2.** Average monthly climatic conditions at three sites in Darfur (Source: FAO LocClim database).

Monthly temperatures are at a minimum in December and January and increase as the sun rises to its solstice in late June. However, as the ITCZ progresses northwards cloud cover and evaporation depress temperatures between June and September. The PET follows a similar profile to temperature but with its minimum coinciding with peak rainfall in August and its maximum occurring in April.

This table highlights the marginality of rainfed farming at 13°6 N at El Fasher and the need to capitalise on the concentration of rainwater by the terrain into *wadis* and rainwater concentrating structures.

#### 4.1.1.2. A Satellite-based Rainfall Proxy

Reporting rainfall stations in Darfur are sparse and have been disrupted by recent conflicts. Further, they provide only point measurements of meteorological variables with no estimates between stations. Satellite imagery in the visible and near infrared (NIR) regions of the electromagnetic spectrum<sup>13</sup> has been shown to provide effective indicators of photosynthetic activity in plants (Steven, 1983). In particular the NDVI is known to be correlated with a range of biotic measures including LAI and NPP (Goward, 1985; Bonan, 2008). The NDVI is one of a range of vegetation indices available and is defined by the difference between reflectance ( $r$ )<sup>14</sup> in the near infrared minus reflectance in red, divided by the sum of reflectance in the near infrared plus the reflectance in red.

$$\text{NDVI} = (r_{\text{NIR}} - r_{\text{Red}}) / (r_{\text{NIR}} + r_{\text{Red}})$$

The characteristic difference between the absorption by photosynthetically active leaves of red radiation – which powers photosynthesis – and the high reflectance by leaves in the near infra-red means that vegetation and vegetation vigour are readily identified by remote sensing systems.

The integration of positive response of NDVI through time is proportional to NPP over a growing season or year (see Figure 8). Assuming the near linear relationship between annual rainfall and NPP in Darfur, then satellite derived vegetation indices can be used as a proxy for effective rainfall. Because of the scarcity of reporting rainfall stations in Darfur it is necessary to establish the rainfall vs. NDVI relationship using reporting stations for all of Sudan.

Image processing systems have traditionally focused on the spatial rather than the temporal dimension of satellite imagery making it difficult to fully utilise the information content on

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<sup>13</sup> The electromagnetic spectrum includes solar radiation which makes up the visible spectrum we are familiar with, the near infrared just beyond human perception and thermal infrared which we feel as heat.

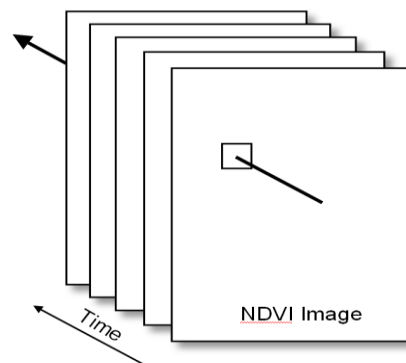
<sup>14</sup> Reflectance is the portion of radiation reflected by an object rather than absorbed by it. For example, vegetation generally reflects green radiation but absorbs red radiation.

image time series. In 1994, the NDDU/HTS<sup>15</sup> study (HTS, 1995a) developed bespoke computer software to process FAO ARTEMIS NOAA AVHRR imagery to interpolate and smooth NDVI data in the time dimension, to remove unwanted noise and to integrate the annual NDVI signal over the year. These data were successfully used to build a simple regression model with annual rainfall statistics across Sudan. Despite the apparent strong correlation between rainfall and NDVI in Sudan, studies by Kassa (1999) and JRC/SOAS (2001) have identified contradictory empirical evidence that in some areas higher rainfall can result in relatively low NDVI. However the two studies come to different conclusions: the former identifies a possible inter-annual lag between rainfall and vegetation response, while the latter identifies a dependency between ecological zone and water use efficiency by vegetation. The dependency of rain-use efficiency by ecological zone has also been noted by Huxman *et al.* (2004) as an important area for research. Unfortunately there has not been the opportunity to pursue this line of thinking further in the current project.

Satellite derived NDVI images were obtained for the period 1981 to 2006 from the NOAA AVHRR sensor from the Global Inventory Modelling and Mapping Studies (GIMMS) project. These images are available at a spatial resolution of approximately 8 km. This dataset was chosen for the ELVM project because it has the longest time series available and because it has undergone a high degree of data cleaning and pre-processing to provide a consistent time series over the entire 25 year period. The data processing of NOAA AVHRR global area coverage is quite complicated and is covered in detail in Kidwell (1998).

As the GIMMS data set has already been smoothed and interpolated there is no need to apply the NDDU data pre-processing routines in the present context. Further the recently released Earth Trends Modeller of the Idrisi software package was also used for processing the time series data, in particular in the NDVI trend analysis.

The 1982 – 2006 GIMMS NDVI image stack (Figure 8) contains approximately 600 images and the temporal profile defined by each pixel charts the evolution of vegetation phenology<sup>16</sup> during the period (see Figure 9).



**Figure 8.** NDVI Temporal dimension, each pixel is repeated every 15 days.

<sup>15</sup> In 1993/94 Hunting Technical Services (HTS) assisted Sudan’s National Drought and Desertification Unit (NDDU) of the Ministry of Agriculture, Natural Resources and Animal Wealth to establish a Geographic Information System (GIS) facility in preparedness for the Convention to Combat Desertification.

<sup>16</sup> Phenology is the seasonal vegetation cycle (greening and senescence) in response to the annual climate cycle.

From this temporal profile the 'normal' NDVI conditions at each location can be derived. Figure 9 shows the NDVI annual profiles for three sites, located at different latitudes in the study area (15°N, 12.28°N and 9.81°N) to illustrate the variation in vegetation photosynthetic activity and seasonality in the study area. The upper and lower dashed lines are the maximum and minimum NDVI values to have occurred in each month during the period 1982 – 2006 at that location, while the central solid grey line shows the mean profile and the central green line shows the profile for 1993, a generally average year.

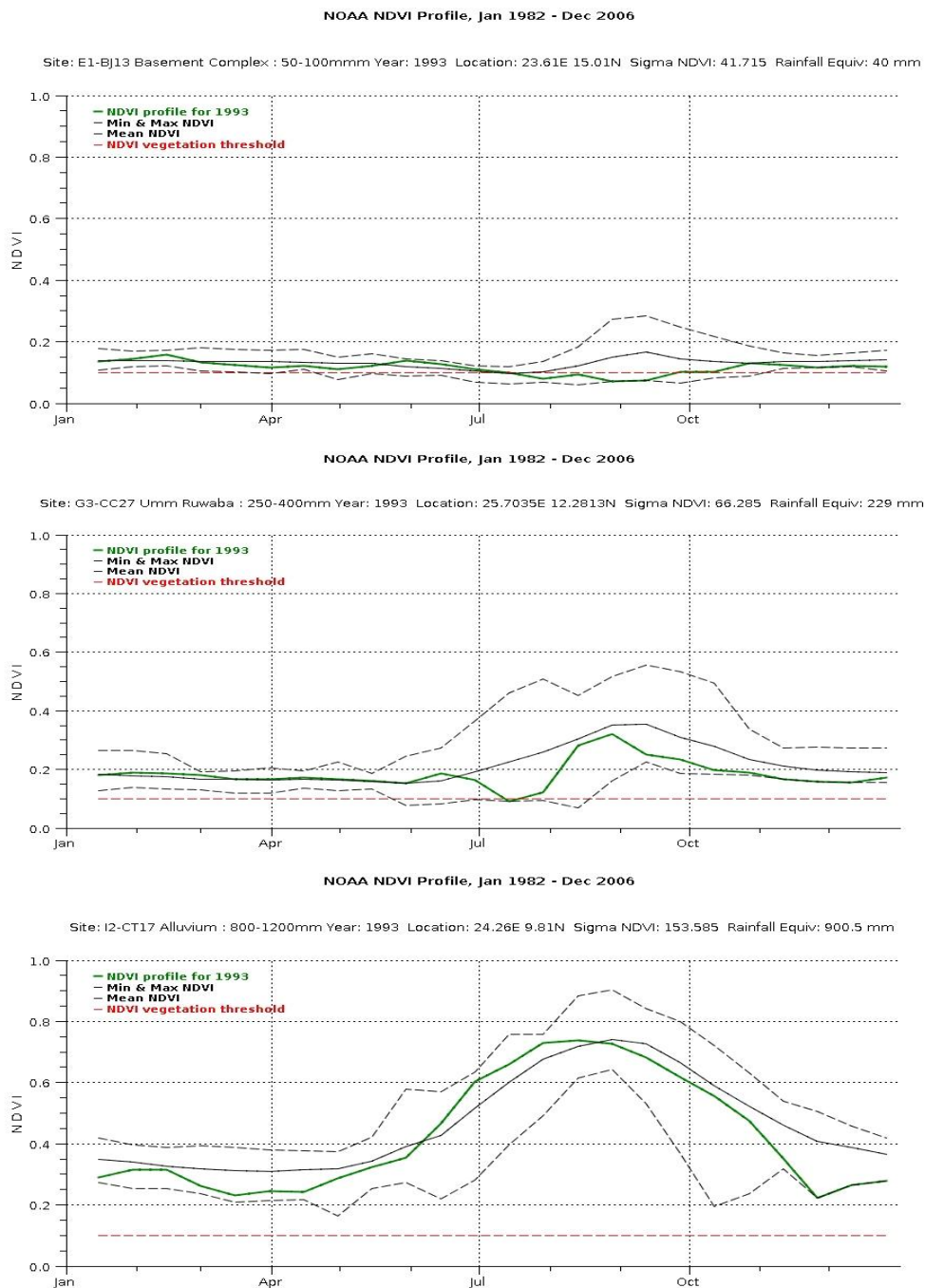


Figure 9. Example NDVI profiles for three locations.

Software developed by this project allows these plots to be produced at any location in Darfur. Comparisons with the climate data from FAO LocClim indicate that the NDVI profiles lag the average climate profiles by approximately one month.

Different biomes exhibit different characteristic profiles. Throughout the year the integrated NDVI value – the area beneath the NDVI profile – is the measure that is most strongly correlated with NPP and, by proxy, with effective rainfall (see Table 3).

Monthly rainfall statistics are available from the Sudan Meteorological Authority although these data were not available to the project. In their place, rainfall data were acquired from the NOAA's Global Historical Climatology Network (GHCN) database, which will ultimately have originated at the Sudan Meteorological Authority. Unfortunately these data become increasingly sporadic and, in recent years, some stations have not reported, while others have reported only intermittently. In 1982, 66 stations reported complete monthly rainfall statistics while in 1991 only 19 did so. The decline in reporting stations after 1991 made data after this date unusable.

Figure 10 shows the relationship between rainfall and integrated NDVI at the 66 reporting stations in 1982, enabling a NDVI rainfall equivalence to be established. The slope and intercept of the relationship varies a little between years and NDDU/HTS calculated it annually (HTS, 1994). For this report it was not possible to make a complete set of annual regressions because of the missing rainfall data in recent years, so average slope and intercept values derived from the available data (1982 – 1991, Table 4) were used for the entire period.

To undertake this analysis each of the 15 day NDVI maximum value composites were added together to produce an annually integrated NDVI image – for each year from 1982 to 2006. This annually integrated NDVI image is proportional to the integrated APAR and NPP detailed in Table 3. It was then possible to estimate the relationship between the annually integrated NDVI (NPP) and annual rainfall, in a similar manner to the linear portion of Lieth's NPP model shown in Figure 6. This approach makes use of all 600 NDVI images available from the GIMMS project archive.

Rainfall stations located in areas of irrigated agriculture identified in the 2005 Globcover land cover map (in ESA and Medias France, 2008) were excluded from the analysis as – clearly in irrigated areas – the relationship between rainfall and vegetation growth is not causal. The NOAA-derived average NDVI rainfall equivalent for 1982 – 2006 is shown in Figure 11.

### Making the link between NDVI and NPP

It has been shown that NDVI is a function of absorbed photosynthetically active radiation (APAR) and also of LAI :

$$\text{NDVI} = f[\text{APAR}] = f[\text{LAI}]$$

In turn APAR is a function of LAI, incoming shortwave radiation (ISR) and plant canopy geometry :

$$\text{APAR} = f[\text{LAI}, \text{ISR}, \text{Canopy geometry}]$$

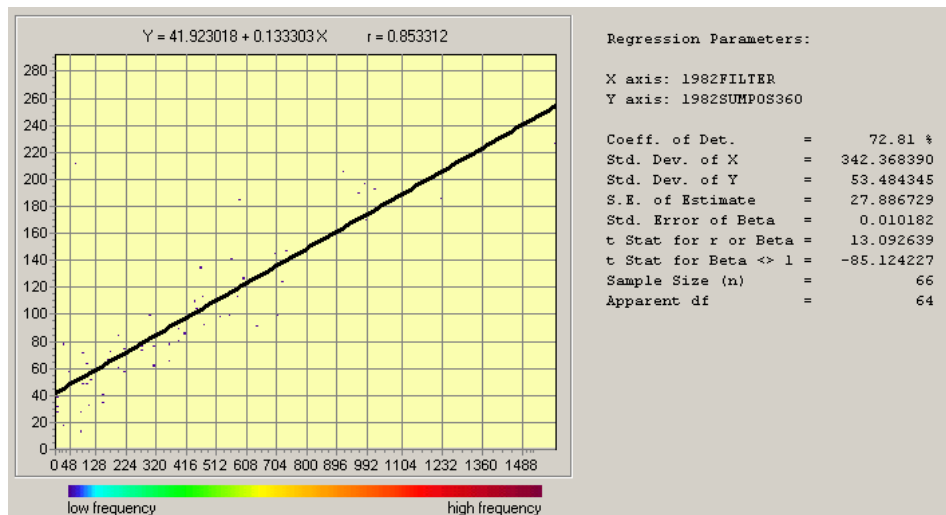
An estimate of NPP can be made by integrating APAR over the year or the growing season:

$$\text{NPP} = f[\Sigma\text{APAR}] \times \epsilon$$

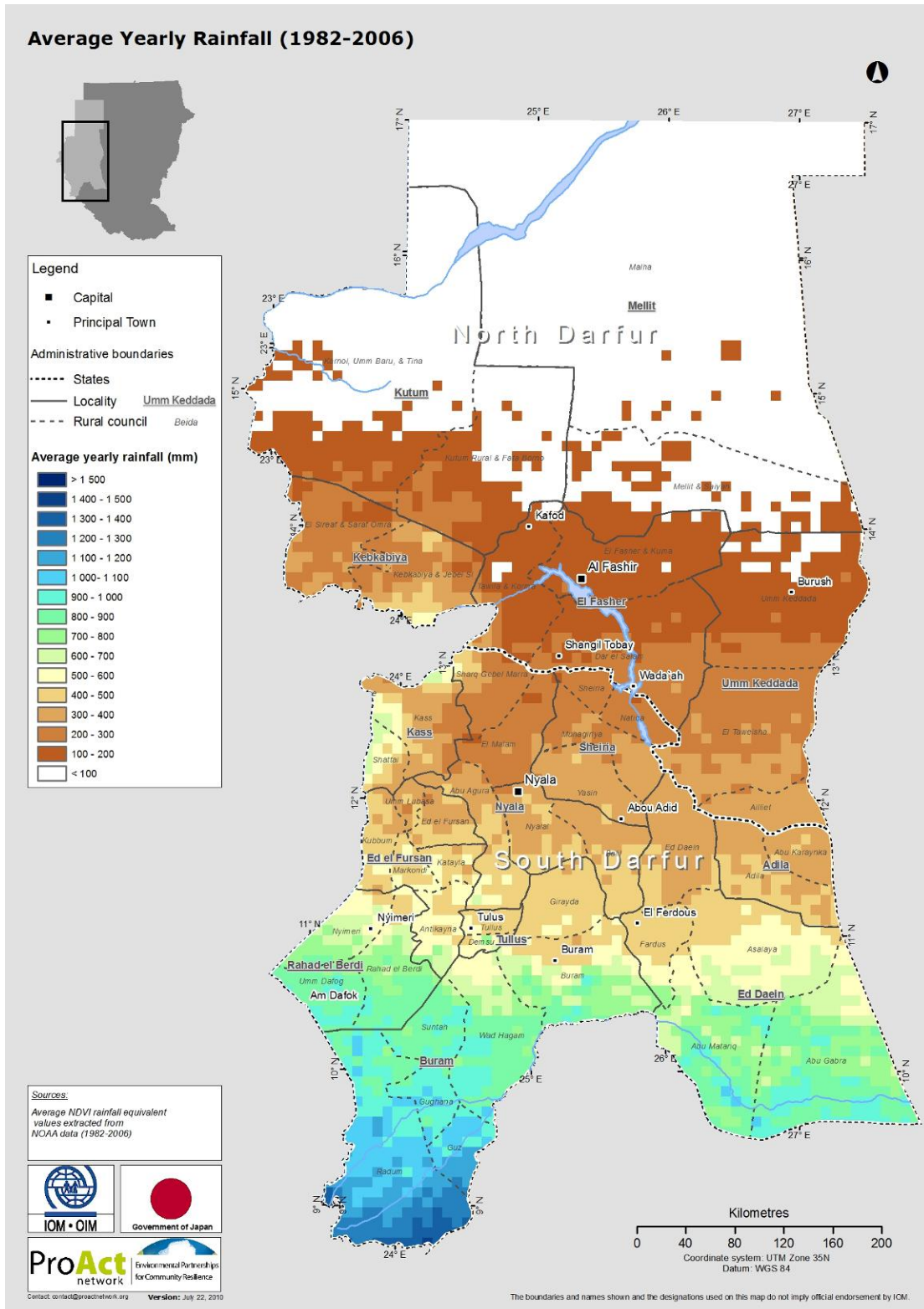
Where  $\epsilon$  = energy-conversion efficiency in g/MJ.

(Source: Goward *et al.* 1985)

**Table 3** . Link between NDVI and NPP



**Figure 10.** Rainfall vs. NDVI regression, 1982.



**Figure 11.** Average NDVI Rainfall equivalent, 1982-2006.

Year	Intercept (c)	Slope (m)	R	Population
1982	41.92	0.13	0.85	66
1983	34.61	0.16	0.89	62
1984	39.21	0.14	0.90	57
1985	38.71	0.12	0.92	44
1986	44.23	0.12	0.83	50
1987	35.38	0.13	0.82	38
1988	26.97	0.11	0.90	45
1989	34.58	0.11	0.95	31
1990	33.67	0.14	0.93	24
1991	35.93	0.12	0.92	19
<b>Mean</b>	<b>36.52</b>	<b>0.13</b>	<b>0.89</b>	<b>43.60</b>

**Table 4.** Rainfall vs. NOAA NDVI regression coefficients (1982-1991).

A similar but separate analysis was performed for SPOT VGT, which presented its own complex set of data processing problems. The availability of the newer generation of satellite sensors, (such as VGT, MODIS and MERIS), with their superior spatial and spectral resolutions and calibration, coincides with the decline in regular reporting of rainfall across Sudan and makes this type of analysis increasingly difficult. The production of the NDVI equivalent rainfall maps represents a major data processing effort for both the NOAA and the SPOT archives. A number of products such as an eco-climatic classification of the study area (Section 4.1.1.5), a classification of potential livestock production systems and a spatial analysis of sustainable millet production (Section 7) have been derived from this data set.

The basic relationship between rainfall and NPP is moderated by other factors, in particular, the concentration of water by the terrain morphology through run-off and sub-surface flow, the consumption of NPP by secondary producers such as livestock and by land use. Despite these moderating factors the basic relationship between rainfall and NPP in Darfur remains valid. These moderating factors partly explain the scattered appearance of humid points (>50mm yearly rainfall) in the arid northern region of the study area (Figure 11).

### **Interannual rainfall variability**

The variability of the annual NDVI rainfall equivalent can be measured by the coefficient of variation (CV). The CV enables the standard deviations of an array of pixel time-series to be compared and is defined as the standard deviation of the 25 annual integrated NDVI values divided by the mean. The calculation of the CV assumes a normal probability distribution of values at each pixel location.

Rainfall in Darfur is generally perceived to be very variable and declining (e.g. University for Peace, 2004; Young *et al.* 2005; Bromwich *et al.* 2007; NAPA, 2007; UNEP, 2007; Zakieldeem, 2009). The CV of the NDVI rainfall equivalent enables both the temporal and spatial variability to be estimated. It is well known that rainfall in Darfur increases from north to south and it might be expected for the variability in rainfall to show an inverse trend and increase from south to north.

Figure 12 shows the CV of annual NDVI rainfall equivalent for the period 1982 – 2006. This figure illustrates that the south-north trend in variation is not simply latitudinal but varies with the orographic effect of the terrain on rainfall. In the far south the variation in NDVI rainfall equivalent is effectively zero (pale green) – the rainfall is almost entirely predictable. Moving northwards the NDVI rainfall equivalent become increasingly variable with a general north-west to south-east trend with pockets of higher variability. To the north the trend switches to a south-west to north-east trend along the desert margin where variation is very high (orange and red). At the desert however, the variation becomes negligible (white) as no sufficient effective rainfall for plant growth that can be detected with NDVI occurs there, except for certain locations where the variation appears to be associated with the moderating effects mentioned above. In particular the Meidob Hills<sup>17</sup> in central-eastern North Darfur are visible as an area of very high variation, surrounded by a ring of lower variation. These hills are a large basalt outcrop with little soil and the surrounding area of lower variation may be the effect of runoff watering the surrounding area. Similar water-concentrating terrain effects are also visible in the orientation of the drainage patterns to the south and west of the hills.

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<sup>17</sup> Note that the basaltic Meidob hills are something of an anomaly as basalt can, unusually, have a positive NDVI response.

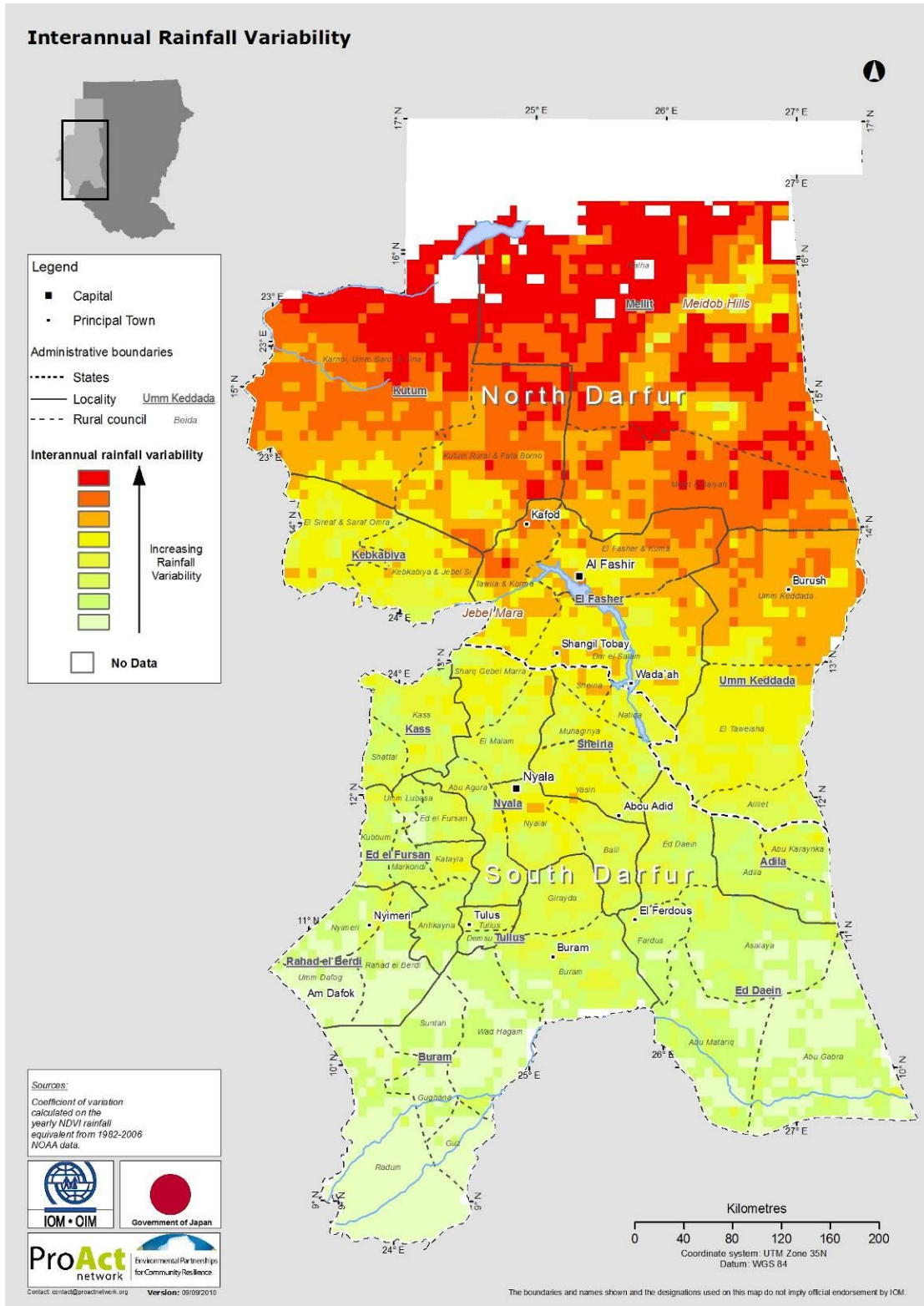
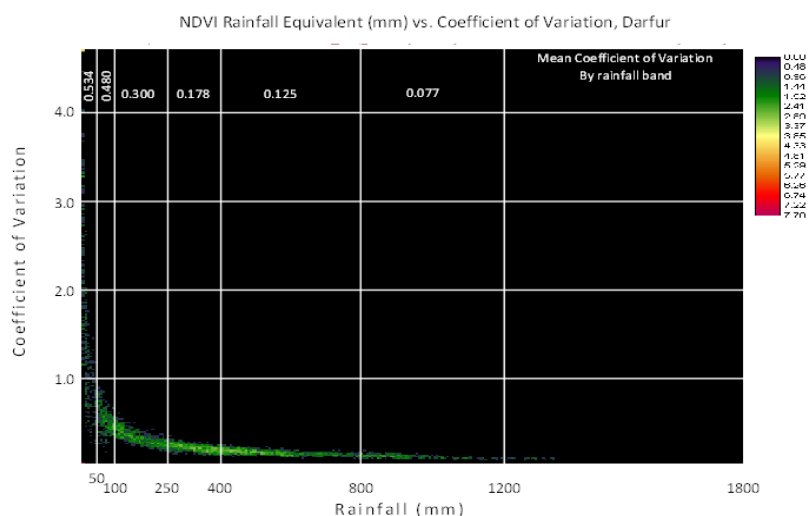


Figure 12. Interannual rainfall variability.

Figure 13 shows a scatter plot of the NDVI rainfall equivalent vs. the CV. The rainfall bands of the eco-climatic maps described below are also shown together with the mean CV by rainfall zone. The graph clearly illustrates the way that the CV increases exponentially with decreasing rainfall.

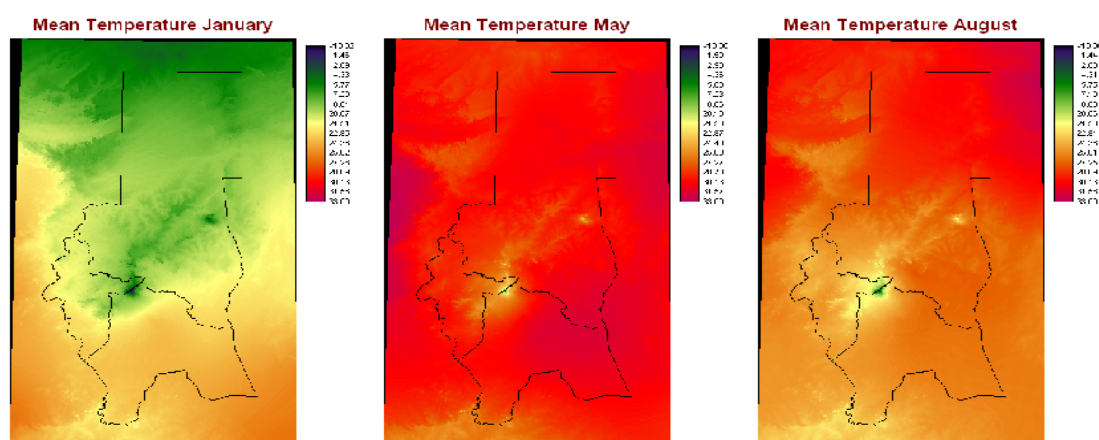


**Figure 13.** Scatter plot of NDVI rainfall equivalent vs. CV. Eco-climatic zones are indicated on the rainfall axis. Mean CV per eco-climatic zone are indicated along the top of the figure.

Clearly there is some linkage between the variability of rainfall in an area and the livelihood activities that can be pursued in that area, together with the coping strategies that need to be adopted to cope with risks and uncertainties.

#### 4.1.1.3. Temperature

Figure 14 shows the regional mean monthly temperatures for January, May and August (for the period 1950-2000). The spatial inversion of temperatures north to south between January and August is dramatic as is the influence of the Jebel Marra massif. While the mean temperature in May is hot at 33°C the maximum temperature in May can reach over 40°C.



**Figure 14.** Regional mean daytime temperatures in °C, January, May and August (WorldClim 1950-2000 data).

#### 4.1.1.4. Potential Evapotranspiration

Table 2 includes estimates of PET at El Fasher, Nyala and Buram, however PET is not yet an available spatial data from WorldClim. Spatial interpolation of PET in map form would allow further work to be conducted on water balance and crop water requirements. In relation to climate change it should be noted that increasing temperature and corresponding increases in PET, as well as potentially decreasing rainfall, will have an effect on the viability of rainfed farming in affected areas.

#### 4.1.1.5. Eco-climatic Zones

Because the NDVI rainfall equivalent in the Darfur environment is related directly to vegetation formations (see Figure 7) and the work described in Section 4.3 on woodfuel supply and demand needs an eco-climatic zone classification, a set of eco-climatic zones based on yearly NDVI rainfall equivalent values were established for the study area. Various eco-climatic categorisations have been proposed based on rainfall alone. Rather than adopt an existing, and perhaps arbitrary scheme, a categorisation specific to the project's requirements was defined by adapting the scheme described Brouwer and Heibloem (1986). As the adapted zonation sets a threshold at the 250mm isohyets, it is also useful for delineating the extent of sustainable dryland agriculture (see Section 7.2). The following rainfall categories have been used:

Mean Annual Rainfall range (mm)
0 - 50
50 - 100
100 – 250
250 – 400
400 – 800
800 – 1200

The production of the NDVI equivalent rainfall maps represents a significant achievement in data processing in both the NOAA and the SPOT archives, but a considerable number of products can be readily derived from this data set, including the eco-climatic classification presented in Figure 15 and Figure 16. Two other major products derived from the dataset and analysed by the ELVM team are an eco-climatic classification of potential livestock production systems, which permits understanding stocking rates and livestock types that can be sustained in different areas of North and South Darfur (Section 7.1) and an analysis of areas where millet production can be reliably and sustainably undertaken (Section 7.2).

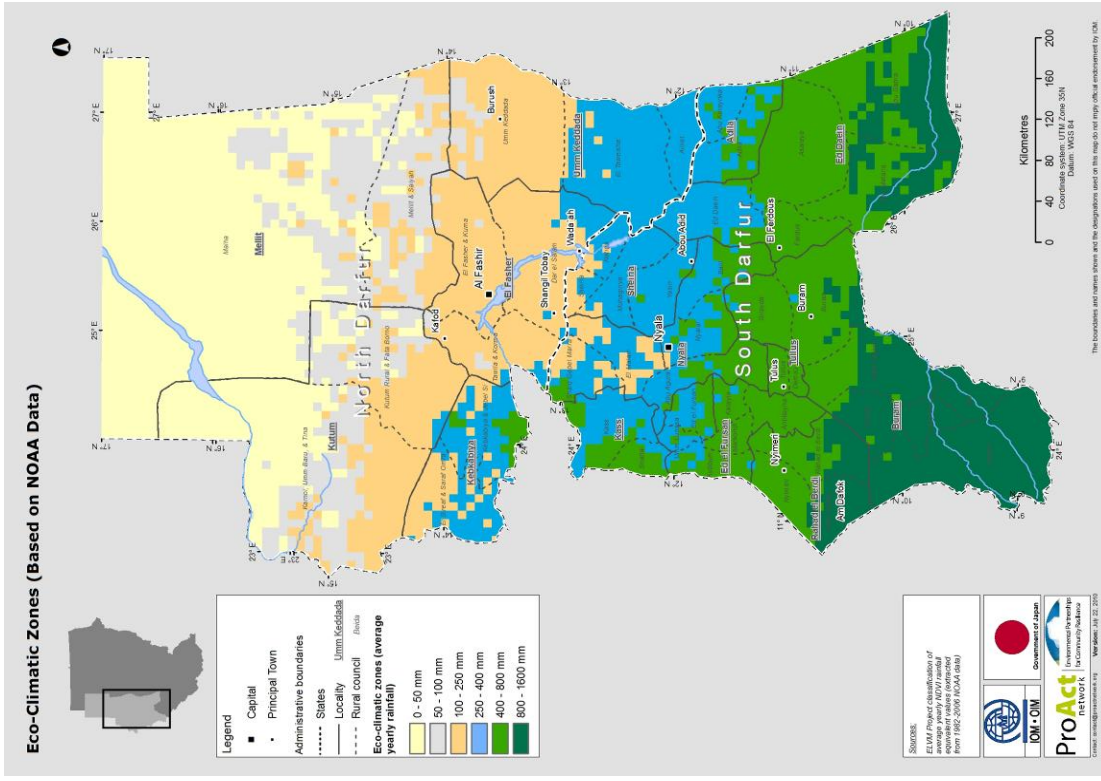


Figure 15. NOAA derived eco-climatic zones (1982-2006).

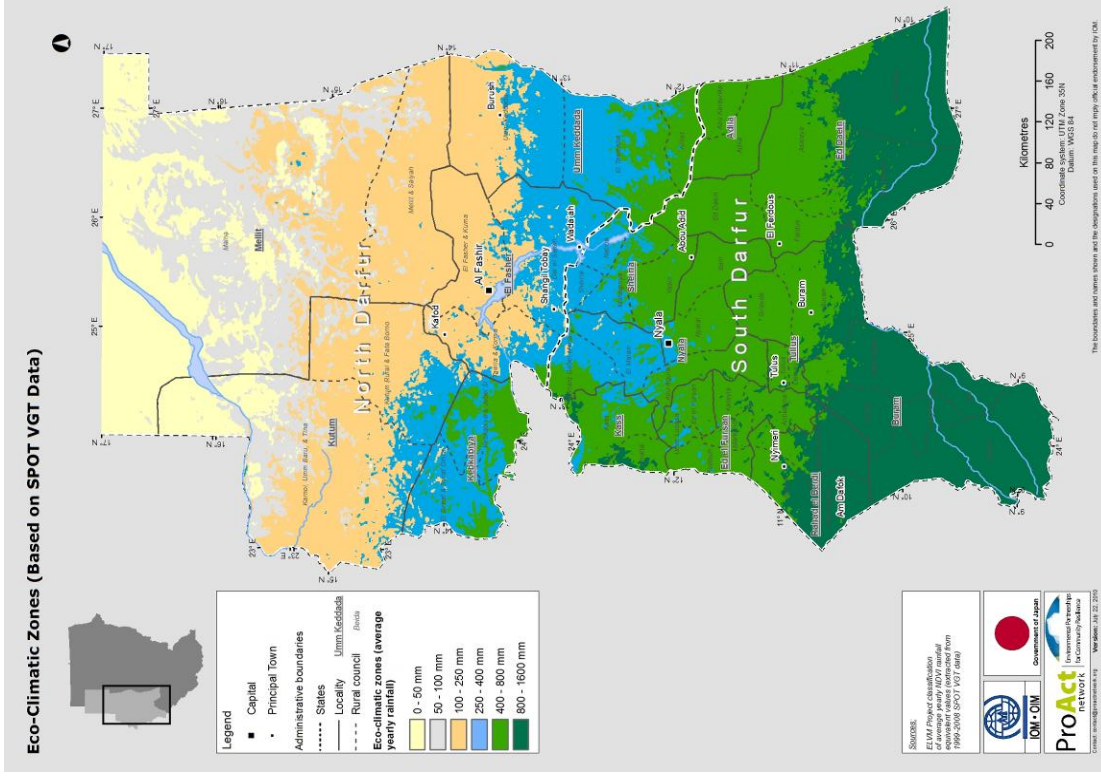


Figure 16. VGT derived eco-climatic zones (1999-2008).

#### 4.1.2. Hydrogeology – Groundwater and Soils

In addition to climate, knowledge of the hydrogeology<sup>18</sup> of Darfur is fundamental to understanding how and why people pursue different natural resource-based livelihood activities in different locations. The hydrogeology of Darfur was mapped, in part, 40 years ago and described in some detail by HGG and MMD (1969), TNO-DGV (1988) and Thorweihe *et al.* (1990) but this information, particularly in the form of digital spatial data, has been difficult to access. More recent water studies have tended to focus on the specific issue of water supply to IDP camps rather than the broader hydrological context within which IDP camps reside (Bromwich *et al.* 2007; UNEP, 2008) and where livelihoods are pursued.

Within the context of the Darfur Water Development Project of the Rural Water and Development Corporation, the hydrogeology of North Darfur was mapped by HGG and MMD (1969) and South and West Darfur was mapped by TNO-DGV in (1988). Ibrahim (1979) also published maps of the hydrogeology of North and West Darfur. These maps form a near complete but somewhat inconsistent picture of the hydrogeology of Darfur. The maps are derived from interpretations of satellite imagery and aerial photography together with field work. The HGG/MMD maps include both subsurface geology and surface deposits. The TNO-DGV map contains hydrogeological units but little information about surface deposits, while Ibrahim's maps are principally of surface features whether they are solid rocks or surface deposits. The HGG/MMD and TNO-DGV maps both provide hydrogeological sections across transects which provide important information about the three dimensional structure of the hydrogeology and aquifers, together with information about groundwater flow and height of the water table.

The three sets of maps described above were digitised and merged into a single hydrogeological map for Darfur. The main geological strata are described in Section 2.1.3 of this report, while the combined hydrogeological map is shown in Figure 17 and a hydrogeological cross-section is shown in Figure 18.

Jebel Marra and the Meidob Hills are the main outcrops of volcanic rocks and are accompanied by a multitude of small volcanic domes scattered across the landscape, including the Tagabo Hills located between the two main outcrops. These volcanic rocks puncture the surrounding basement complex which is either exposed or underlies the other formations. From Figure 17 it can be seen that the basement complex is generally exposed surrounding Jebel Marra and skirts around the massif to the south, east and north of Jebel Marra within both North and South Darfur. Overlying the basement complex to the north and east and to the south are the Nubian sandstone and the Umm Ruwaba aquifers.

The vertical cross-section in Figure 18 – which follows the section marked C –D on Figure 17 illustrates how the largely impervious basement complex is overlain in places by permeable sandstone (stippled) into which boreholes can be sunk. On the surface sheets of sand, *qoz*

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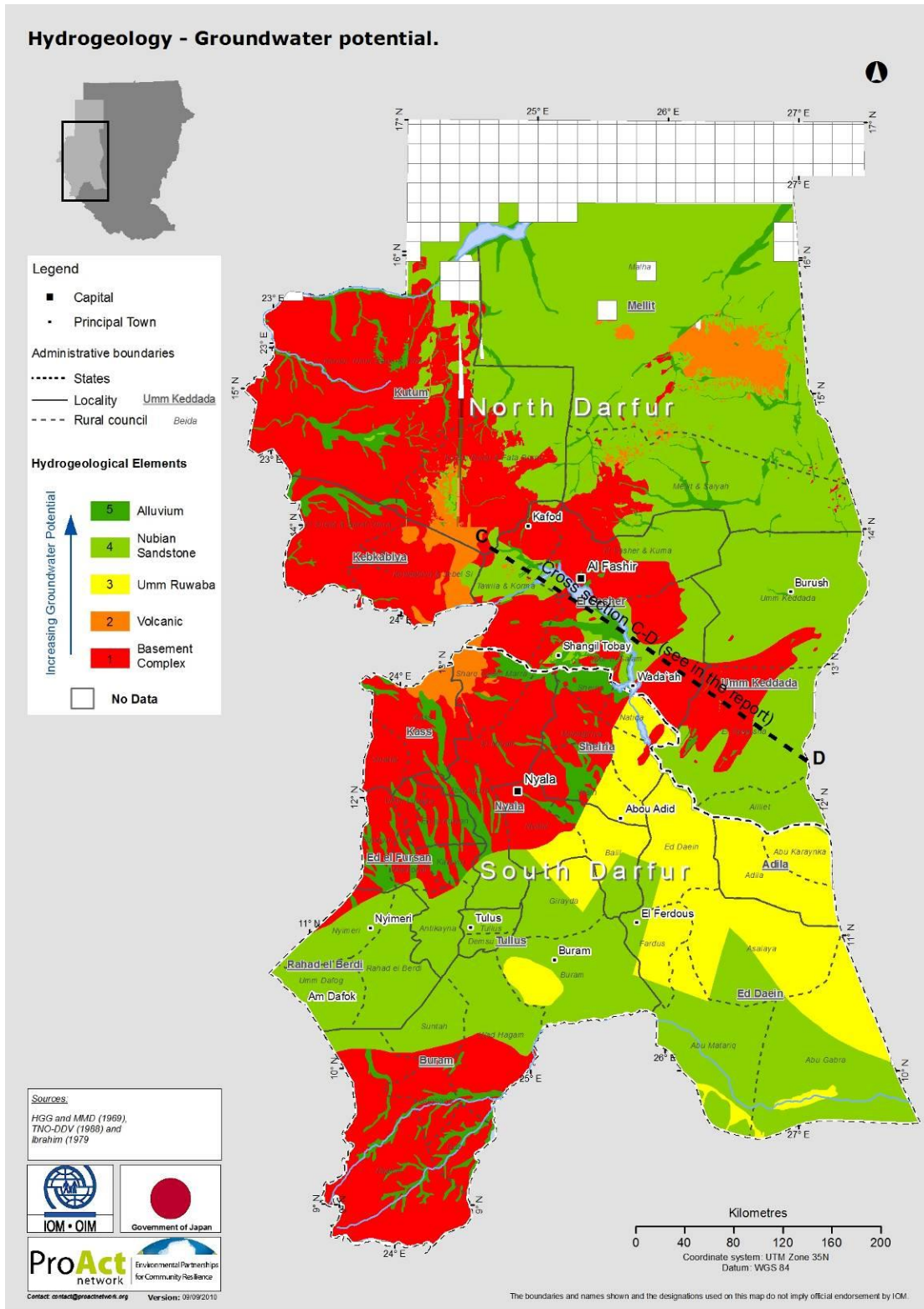
<sup>18</sup> Hydrogeology is the study of the distribution of water within geological structures.

(yellow) or eroded pediment surfaces and alluvium (brown) may overlay either basement complex or sandstone. Volcanic plugs (black) may puncture or intrude all of the other geological formations.

The groundwater potential of the main geological formations can be ordered in terms of decreasing potential as follows:

- Alluvium;
- Nubian Sandstone;
- Umm Ruwaba;
- Volcanic; and,
- Basement Complex.

The water-bearing potential of these rocks, their spatial distribution as well as their relationship to each other and to rainfall has a bearing on water supply for productive livelihoods. This is developed further in the following section.



**Figure 17.** Hydrogeologically significant geological formations in the study area. (Sources: HGG and MMD (1969), TNO-DGV (1988) and Ibrahim 1979).

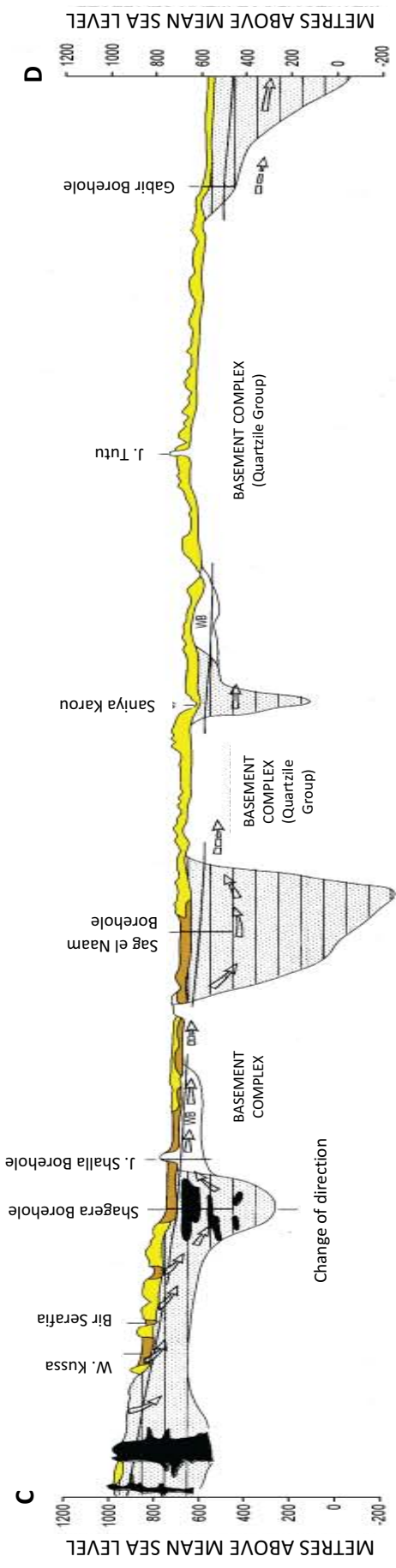


Figure 18. Hydrogeological cross-section (Taken from HGG and MMD, 1969).

#### 4.1.2.1. The Relationship between Rainfall and Groundwater

Rainfall and groundwater are both potential water sources to be utilised by livelihood activities. In some places the relationship between these two potential water sources may be closely linked, e.g. alluvial aquifers are generally recharged annually by rainfall. In other places there may be no relation between rainfall and groundwater resources – for example, on Qoz areas rainfall infiltrates into the soil profile but is either taken up by plants or evaporates before it reaches the groundwater (Parry and Wickens, 1981; Thorweihe *et al.* 1990). Significant exploitable potable groundwater may, however, exist at depth, recharged by groundwater flow from elsewhere or as fossil water. This section considers the relationships between rainfall and hydrogeology – both *potential* water sources.

A water availability matrix of potential rainfall versus groundwater potential was constructed to understand the relationship between these water sources and their part in determining the landscape and livelihood characteristics. Surface and sub-surface geology influences not only groundwater availability but also run-off and soil type. The initial motivation for the matrix was to produce a stratification of Darfur for the selection of a sample of representative sites for further investigation and acquisition of high resolution satellite images. The sample of sites was intended to be an indicative set rather than a rigorous statistical sample. The matrix also proved useful from a conceptual point of view because groundwater and boreholes tend to dictate where people live (Olsson, 1985b), while rainfall dictates what they can grow.

A sample frame of 16km x 16km grid cells was defined across North and South Darfur and each grid cell assigned a rainfall potential attribute and a groundwater potential attribute. The rainfall potential attribute is the eco-climatic zone in which the grid cell occurs while the groundwater potential attribute is calculated according to the water potential of the underlying aquifer. This resulted in a 6 x 5 matrix giving a possible set of 30 characteristic combinations or strata of rainfall and groundwater potential. It is proposed that these strata broadly define the water availability context within which natural resource-based livelihoods are determined. In each of the resulting 30 strata one arbitrary 16km x 16km grid cell was selected as a representative example of that stratum. Figure 19 shows the distribution of the water availability strata. Figure 20 shows the water availability matrix with the rainfall and hydrogeological categories, together with thumbnail images of the DMC image at the representative grid cells locations.

There are similarities between the potential water availability strata and the Darfur Livelihood Zones map developed by UN-OCHA (2006) – this should be no coincidence. The UN-OCHA map is an informal combination of climatic, soils, topographic, crop and livelihoods criteria, but not groundwater availability, whereas the potential water availability strata are derived from climatic and potential ground water information. Both maps have some similarities because of the dominance of both rainfall and the geological influence on soils, groundwater and terrain on potential livelihoods that can be pursued.

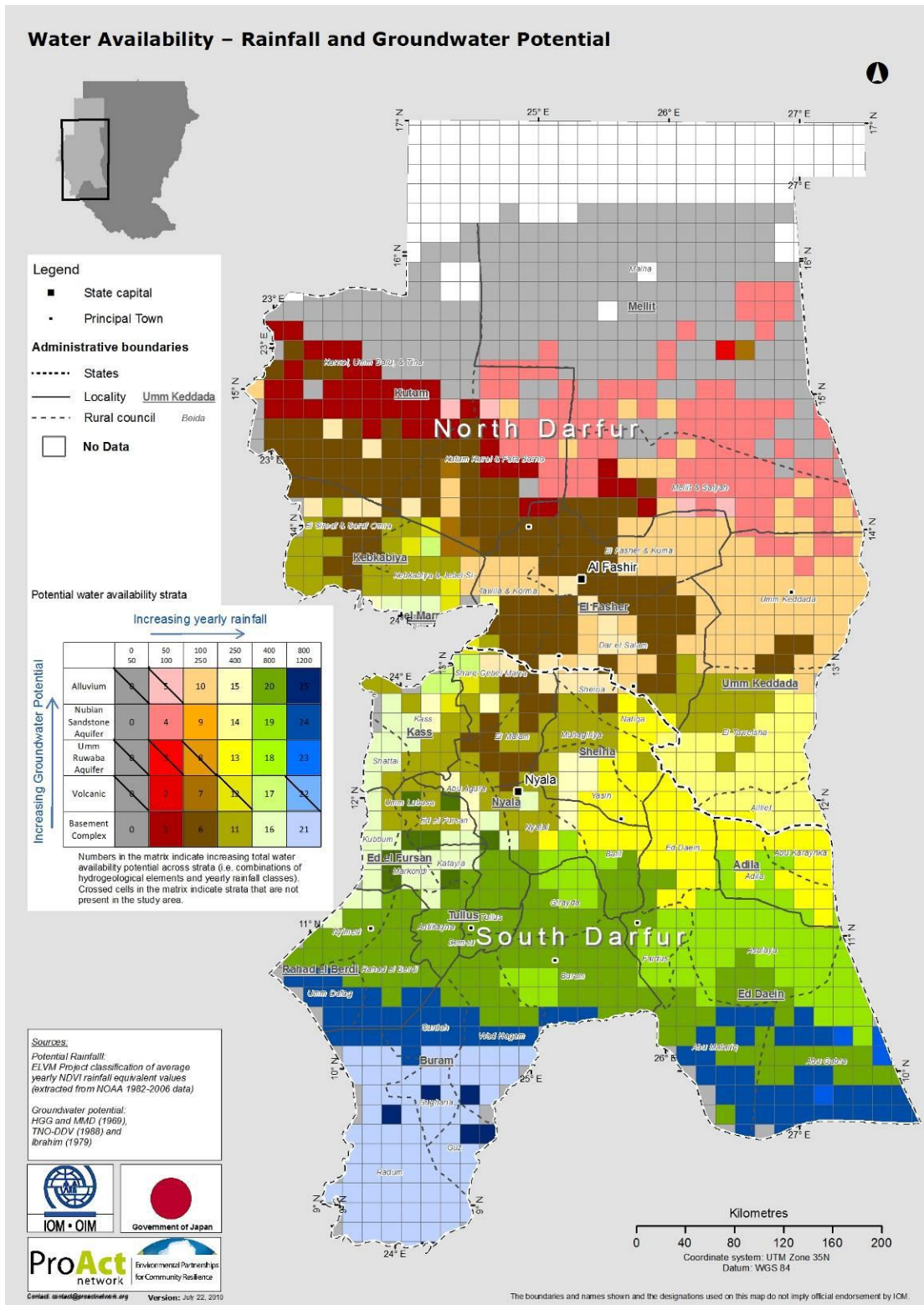
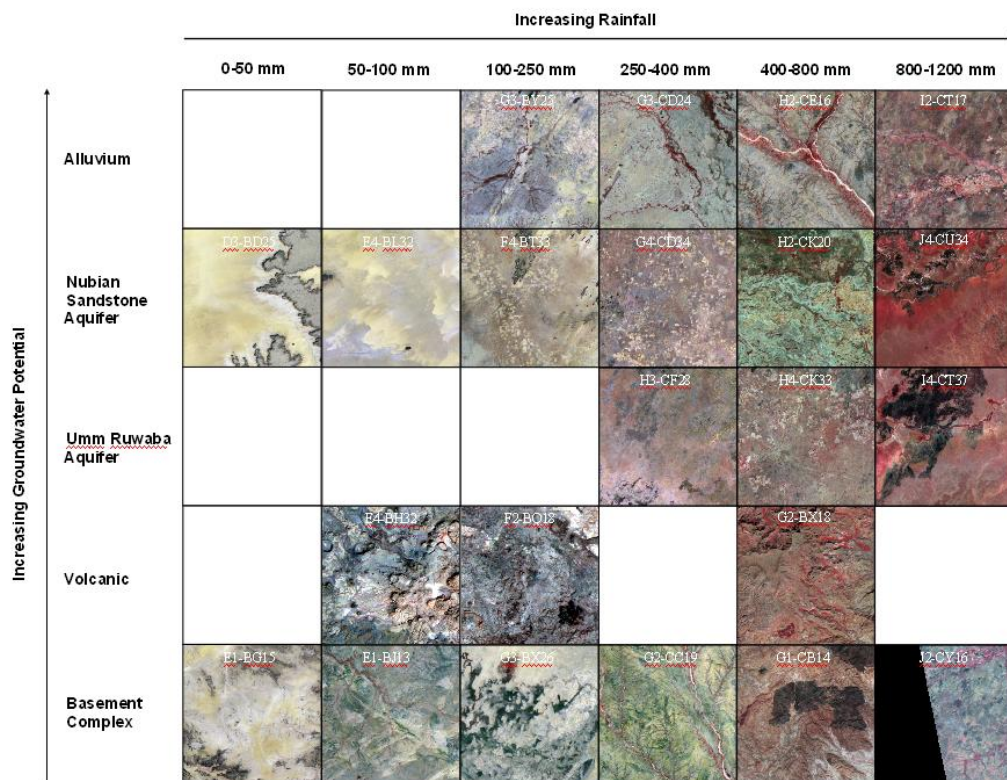


Figure 19. Potential water availability in the study area.



**Figure 20.** Potential water availability strata.

In Figure 20, the Y axis increases from the bottom to the top with increasing groundwater potential, i.e. from Basement Complex (least potential) to Alluvium (greatest potential). On the X axis, rainfall potential increases from left to right from arid conditions to humid conditions. Within each of the matrix's cells is an image chip of the DMC-2 image of the 16km x 16km grid cell. The increasing humidity from left to right and from bottom to top is visually evident in the images. Not all strata, however, are represented on the ground in North and South Darfur, for example the Alluvium class does not occur below the 100-250mm rainfall zone. This accounts for the blank squares in Figure 20.

Understanding the water availability characteristics of the 22 strata represented in Figure 20, together with the hydrogeological cross sections in Figure 18, should provide an understanding of the water availability characteristics of Darfur.

The matrix in Figure 20 can be interpreted by keeping in mind both the rainfall map in Figure 11 and the hydrogeology map in Figure 17. The rainfall distribution is easily appreciated from the map – more rainfall equates to an increased likelihood of being able to grow a crop. The hydrogeology map is related to two factors: i) the potential of being able to dig a well or sink a borehole – for drinking water and domestic use – into an aquifer, and ii) the potential for run-off. Both of these factors are governed by the permeability of the rocks and their water holding capacity. Two factors should be borne in mind:

- Basement Complex is rather impermeable and only has localised aquifers where it is fractured, so it has little capacity to hold water and water is likely to run off into water courses and *wadis* where it may be stored in localised shallow alluvial aquifers which may be accessible from hand dug wells; and
- Nubian Sandstone is permeable so rainfall falling on it may infiltrate and percolate deep into sub-surface aquifers, although the aquifers are more likely to contain fossil water as rainfall may be rapidly recycled because of the high temperatures. Plentiful water may exist but may be inaccessible because it requires a deep borehole and pump to extract it.

Counter intuitive situations may exist where there is high rainfall but little groundwater or, conversely, there may be little rainfall but plentiful groundwater. The availability of these two sources of water will have a profound impact on what livelihoods can be pursued in any given location.

The potential water availability matrix maps out the possible combinations of water from these two water sources. For example:

- 100-250mm of rainfall on Alluvium – this stratum has very little rainfall for rainfed agriculture but may have a localised alluvial aquifer accessible from hand pumps. The alluvium generally occurs on the Basement Complex so the aquifer may be recharged – when it does rain – by surface run-off. The alluvium may provide both water and a suitable soil for agriculture in what would otherwise be an inhospitable location – such as the 100-250mm Rainfall on Basement Complex strata.
- 100-250mm of rainfall on Nubian Sandstone will again provide little moisture for rainfed crops but plentiful water for domestic purposes and livestock from a borehole.
- >800mm of rainfall on any geological formation – there is likely to be sufficient surface and/or sub-surface water available for agriculture, pastures and domestic and livestock purposes.

The potential water availability strata can therefore provide an indication of the availability of water for different purposes within a locality. Conditions within each stratum are likely to be similar.

### **4.1.3. Drought**

Many drought indices have been developed based on meteorological data, soil water balance methods and satellite derived proxies such as the NDVI. Examples include the Palmer Drought Severity Index, Crop Moisture Index, Vegetation Condition Index and Remote Sensing Drought Index among others (see Hayes, 2006).

Drought is not an absolute term and different indices focus on different types of drought – atmospheric drought, agricultural drought and hydrological drought. These types of drought are important in the context of Darfur and, in particular, the distinction between agricultural and hydrological droughts. For example, lack of rainfall may result in a soil moisture deficit

leading to an agricultural drought and crop failure. Similarly, over-extraction of groundwater may cause hydrological drought in confined aquifers even in years of plentiful rainfall – for example near IDP camps on basement complex or alluvium. Mixed conditions may also exist where an agricultural drought causes crop failure on the surface but where drinking water is available from boreholes into a fossil aquifer. The general perception of an increasing occurrence of droughts in Darfur needs qualification and further examination of their context. Warren and Agnew (1988) suggest that drought needs to be defined in terms of land use and that the frequency of drought depends on that use, independent of climate. The location of an IDP camp over a hydrologically poor aquifer may therefore be the direct cause of an experienced drought rather than an anomaly or change in climate.

NDVI data have been used by various authors and organisations to monitor agricultural drought using different measures of vegetation production deficit. On an on-going operational basis these approaches can provide useful near-real-time information on the development of vegetation and rainfed crops during the growing season. Approaches such as the Vegetation Condition Index (VCI) (Kogan, 1990, 1991, 1995; HTS 1994, 1995a), and the Remote Sensing Drought Index (RSDI), (Mijiddorj, 2005) use the historical NDVI profile to identify anomalies in the current conditions compared to either the mean or range of NDVI conditions experienced to date. HTS (1995a) used Kogan's Vegetation Condition Index to produce annual maps of Sudan showing anomalies in NDVI each year between 1982 and 1994. Both the VCI and the RSDI use a linear subdivision of the range of NDVI experienced at any given location, which assumes a normal distribution of values between the maximum and minimum values and that these extreme values have been suitably filtered and are not affected by spurious noise. Using this type of index makes it difficult to readily ascertain if the occurrence of drought is increasing or decreasing because a normal distribution is assumed. The non-parametric method of deciles proposed by Abdel-Muttalib (1986) for a Sudanese drought monitoring system would have been preferable and is directly transferable to NDVI based approach, however time constraints precluded it from being implemented.

RSDI maps have been generated following the 25 year period but it is uncertain whether these can provide useful information outside of their specific temporal reference, i.e. they do not give information about trends over the period, only conditions at a point in time. Counting the number of below average conditions will result in half and the other half will be above average – because a normal distribution's mean is the same as its median value. However, trends are considered using a different approach in the following section.

#### **4.1.4. Environmental Resilience and Trends**

The long time-series of NDVI imagery from both NOAA and SPOT offer an opportunity to begin understanding environmental/vegetation resilience and trends at both, the Darfur and local scale.

Measuring environmental resilience implies recovery of the environment from an environmental perturbation or stress to a former “normal” baseline condition. In Darfur

establishing a baseline condition is difficult because the time scale of satellite data collection is short in relation to the natural and anthropogenic cycle of disturbance. Points to note include:

- The discussion above on rainfall trends indicates that it may be necessary to go back to at least 1900 to appreciate the long term cycles of the Darfur climate.
- The meteorological satellite NDVI archive only goes back to 1981 and the Landsat archive to 1972, both post the decline in rainfall noticeable in the record around 1970.
- The rainfall across much of Darfur is normally irregular so *irregularity* is part of the normal climate.
- The ground based measurement of rainfall and other meteorological variable has become unreliable in recent years.
- Clearly defined ecological boundaries are rare in much of the Darfur environment as ecoclines are evident rather than boundaries.

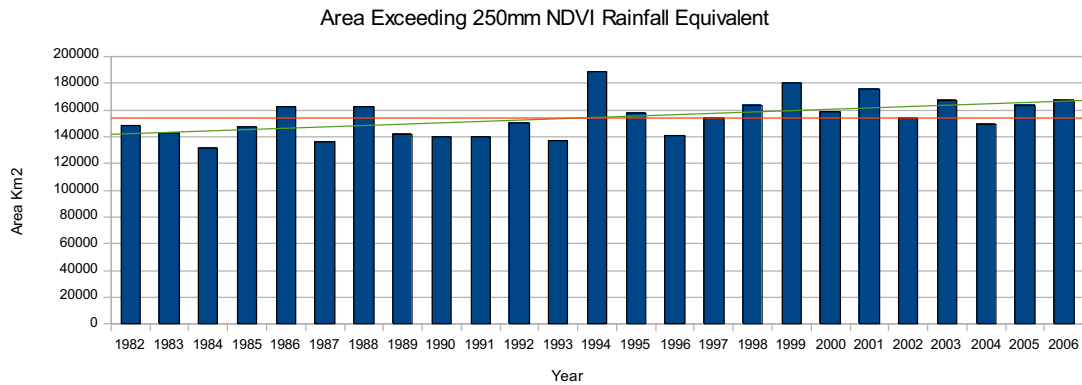
These issues limit measuring environmental resilience in Darfur because the baseline conditions cannot be readily established.

In section 7 of this report a methodology is developed to identify the area suitable for millet production based on the threshold of 250mm NDVI rainfall equivalent. This threshold is sensitive to the effective agronomic desert boundary in each year. The total area exceeding this threshold in North and South Darfur in each year is shown in Figure 21. *Surface area (km<sup>2</sup>) exceeding 250mm of rainfall per year in North and South Darfur. (Mean NDVI rainfall equivalent values from 1982 to 2006).*

The NOAA AVHRR time series commences in the early 1980s, which was a well known dry period and is therefore likely to show a positive trend through time. The figure shows the area (km<sup>2</sup>) exceeding the threshold in each year together with the mean and trend lines, shown in red and green respectively. The mean area is 154,643 km<sup>2</sup> and the trend over the period is positive – as expected.

The plot is symmetrical around 1994 which was a very wet year. Before 1994 only two years (1986 and 1988) were above the average, whilst after 1994 only two years (1996 and 2004) were below average. Speculatively it could be suggested that it was not until 1994 that vegetation recovered from the droughts of the early 1980s and subsequent years, although the time-series analysed is too short to draw and firm conclusions from these data.

The trend observed over the 1982-2006 period is positive, indicating increasingly humid conditions. Although, as already noted, the period commences in a dry phase so the positive trend may simply be a function of a low starting point. The observations of Thorweihe *et al.* (1990) in relation to the start and end dates chosen for rainfall trend analysis can also be made with regard to the NDVI time series. A longer time-series including the pre-1980s droughts might indicate a flatter trend.



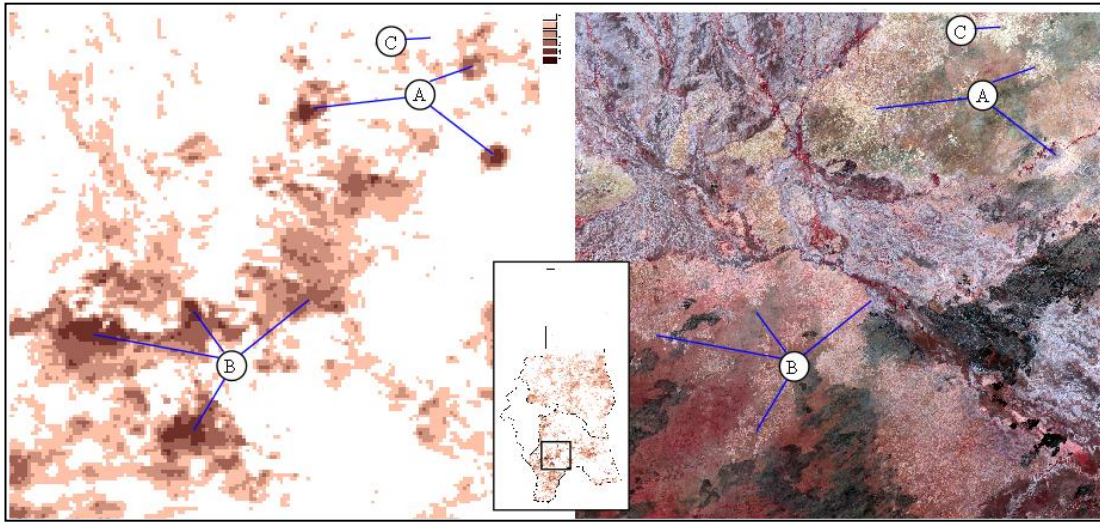
**Figure 21.** Surface area (km<sup>2</sup>) exceeding 250mm of rainfall per year in North and South Darfur. (Mean NDVI rainfall equivalent values from 1982 to 2006).

Notable years identifiable on this plot are: 1984 a notorious famine year; 1987 when conflict erupted in North Darfur<sup>19</sup>; 1988 a notorious wet year with major floods and 1994 another notoriously wet year<sup>20</sup>. Despite these events, which can be identified as lows and highs on the plot, there is a general positive trend which does not indicate an increasing occurrence or frequency of drought in Darfur, as sometimes reported.

While there is a positive trend at the Darfur scale (probably a function of climatic cycles) there are many localised areas where there are negative trends in NDVI which are related to anthropogenic land use and land cover change. SPOT VGT data, commencing in 1999 and ending in 2008, have been used to make a 1km resolution trend map over the past ten years. For example, Figure 22 shows an area of South Darfur which the VGT NDVI 10 year trend analysis indicates is affected by distinct negative trends. Examination of the DMC-2 imagery (December 2009 - January 2010) shows that some of the trends are associated with villages and their surrounding footprint on *qoz* areas, designated by “A”, whilst others are associated with clearing of the more humid grass and shrub lands to the south on non-*qoz* soils, indicated in the figure by “B”. Note that some villages, “C” do not show any indication of negative trends and presumably have not expanded or significantly changed during the period.

<sup>19</sup> See <http://www.eyesondarfur.com/conflict.html>

<sup>20</sup> See <http://www.reliefweb.int/rw/rwb.nsf/db900sid/OCHA-64DFUY?OpenDocument>



**Figure 22.** VGT negative NDVI Trends and DMC-2. A indicates degradation around villages on qoz, B indicates degradation / clearing of agricultural areas in shrubland.

Trend analysis using 1km SPOT VGT data is a powerful tool for identifying changes in primary production in specific areas. Schimmer (2009) has used a similar technique with MODIS data to identify areas in West Darfur of positive NDVI trends which were associated with depopulation. This macro-scale analysis could be used to identify land cover change hot-spots for more detailed study using more intensive data and analysis – see the section below.

## 4.2. Land Cover

Land is the fundamental resource on which terrestrial ecosystems and rural livelihoods depend and land cover is the expression of land surface characteristics, including vegetation, moderated by the influence of climate and management by humans. Land cover – what is on the land – should not be confused with land use, what the land is used for. Land cover is dynamic and may change over a broad spectrum of time scales, from millennia to a matter of weeks, therefore, land cover maps are snapshots in time. Furthermore, land cover is scale dependent and not an entirely objective concept as the cover may depend on how closely one looks at it. The main land cover map utilised by the project is the Africover land cover map derived from Landsat satellite image interpretations from imagery acquired between 1994 and 1999. Africover Sudan uses a comprehensive hierarchical *a priori* classification system specific to Sudan – the Land Cover Classification System -LCCS- (FAO and UNEP, 2005). The LCCS is very detailed but can be collapsed into its more general higher level classes.

As Africover is the most comprehensive land cover map available and because it forms the basis of the WISDOM methodology as first applied in East Africa (Drigo, 2005), described below, it has been used by the project, despite now being rather out of date. It had been hoped to use the DMC-2 image to update the Africover map if Darfur had been imaged in one pass of the satellite. However, it eventually took nine passes of the DMC satellite to

acquire the entire study area which makes the digital classification of the imagery difficult within the project's timeframe because of the unusual nature of the DMC-2 sensor configuration. Mixing digital classification of the DMC-2 image with visual interpretation of the Africover imagery would have produced very mixed results. The DMC-2 imagery, together with the SPOT VGT archive, could therefore be used to highlight areas of major change between 2000 and 2010. It is understood that a second round of Africover is being undertaken in 2010 by FAO and will be using DMC-2 imagery as its basis.

Natural resource-based livelihoods are integral to land use and frequently define land cover. Monitoring changes in land cover is an essential component of land management and key to understanding the relationship between natural resource-based livelihoods and the environment.

Concern over the degradation of Darfur's fragile environment is not new and is wrapped up in the long standing desertification / land degradation debate. Access to, and competition for land resources and the effects of climate change are often cited as direct causes of past and ongoing conflicts in Darfur, although this is not a universal view (HTS, 2004; Ibrahim, 2004). However, despite the intensive land use planning and mapping exercises undertaken in Darfur from the 1950s to the mid-1990s little of this valuable historical data is accessible in either paper or digital form. Satellite imagery was used for mapping purposes as early as the 1970s in Darfur. An initial visual comparison of the DMC-2 imagery and the Africover map shows that in places some considerable changes in land cover and use have indeed taken place in the recent past.

#### **4.2.1. Land Cover Dynamics – The Qozes of South Darfur**

Land cover in Darfur has been directly modified over the past 50 years by both climatic and anthropogenic factors. The impact of these factors on land cover and livelihoods is complicated, but not random, and for traditional rainfed agriculture is often described in the following general terms:

- reduced rainfall in some areas has led to a decline in crop yields;
- the decline in crop yields has led to expansion of cropping into marginal lands;
- declining yields and shortage of land has led to shortening of the traditional fallow period;
- shortening of the fallow period has led to declining soil fertility;
- declining soil fertility has led to further yield reduction and expansion into marginal lands;
- declining crop yields has led to intensification of *wadi* agriculture; and
- access to groundwater reserves through boreholes has opened up marginal areas – which were previously inaccessible due to lack of surface water – to farming.

Where land is not in short supply degraded land may simply be abandoned. However, where land is in short supply, for example where villages which have immediate neighbouring

villages on all sides, land use may be intensified to unsustainable levels. This cycle of land intensification and degradation is described by many authors, including Ibrahim (1978), Olsson (1985b), Ayoub (1998) and Elsiddig (2007).

The relationships between environmental and anthropogenic factors, their interactions and feedbacks, are easy to list but difficult to quantify. Understanding the relationships and limitations between land, livelihoods and environment is key not just to documenting the past land cover change but also to providing effective interventions to assist livelihood sustainability in the future. To provide effective and sustainable environmental interventions in the future these factors need to be both quantified and understood. This cycle of degradation is a particular problem of the extensive areas of sandy *qoz* soils.

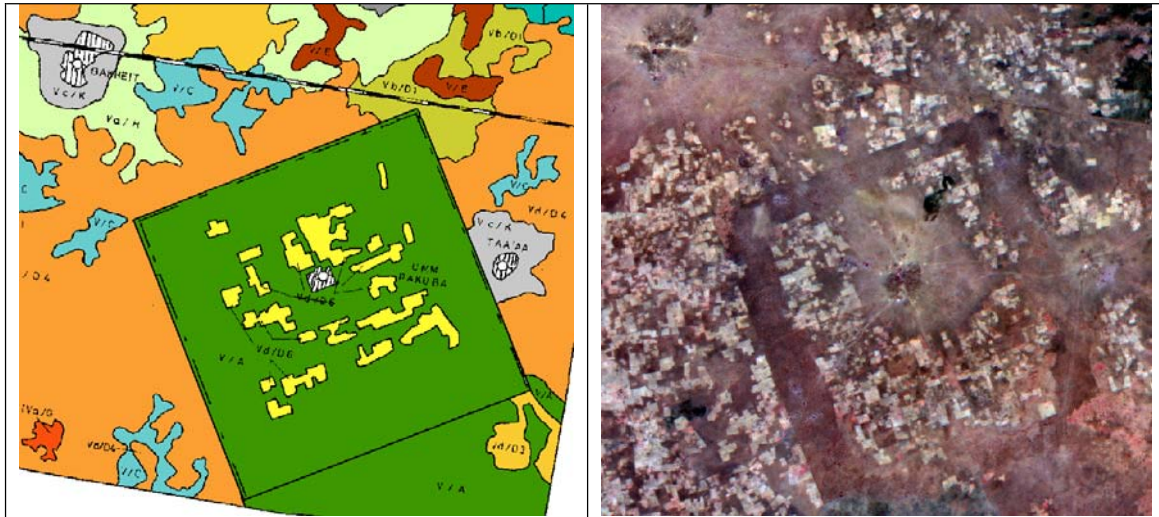
As recently as 1958 Harrison and Jackson (1958) described the *qoz* areas of South Darfur as “the unknown *Qozes* Salsigo and Dango” and speculated about their composition from “hearsay accounts” (Parry and Wickens, 1981). At that time it is thought that these *qoz* areas, dominated by savannah woodland, were largely unexploited – except at their margins – because of the lack of surface water availability. Since the 1960s, deep boreholes into the sandstone aquifers have opened up these marginal areas to more intensive exploitation. Since that time these extensive and marginal *qoz* areas have become highly modified. The extent to which they have been transformed over the past 50 years is, however, unknown.

During the 1980s, the Western Savannah Development Corporation (WSDC) (HTS, 1989) conducted a number of short-term studies of land use change in South Darfur and Jebel Marra using remote sensing (HTS, 1989). One study used SPOT imagery to assess vegetation and land use change at four sites in South Darfur with the objective to develop a baseline methodology for monitoring. This study used 1971-1972 aerial photography, panchromatic SPOT imagery for 1987 and contemporaneous field surveys to produce maps of vegetation and land use at 1:100,000 scale. HTS (2004) notes the main results between the 1971–1989 period as being:

1. climax woodland in sandy soils decreased markedly;
2. small areas of cropped land increased in *Qoz* lands;
3. density of cropping decreased markedly in the Baggara areas, with small areas of high density cultivation being replaced by low density over large areas; and
4. areas of short / long fallow have increased due to woodland clearance and extension of cultivation.

Bringing this 1972 - 1989 HTS study together with the Africover map (circa 1994 – 1999), the project’s Landsat (circa 2000) and the DMC-2 (2010) image mosaics could provide an important historical chronology of land cover / use and vegetation change in South Darfur over a 40 year period.

The HTS maps have been located but time has not permitted their digitization and analysis, however a small portion of the *Qoz* Ma’Aliya map is shown in Figure 23.



**Figure 23.** Land use and vegetation change between 1987 and 2010 for a selected area.

HTS land use and vegetation map (1987) left and DMC-2 false colour composite (2010) showing the WSDC controlled settlement boundary at Umm Rakuba. The Khartoum to Nyala rail link traverses the area from east to west.

The following extract describes the distinctive square pattern of the WSDC “controlled settlement boundary” (CSB) which contains the village of Umm Rakuba. On the HTS map the dark green = relatively undisturbed woodland savanna; orange = cropped and fallow land; grey = bare soil, not cultivated; dark red = fallow land planted with gum arabic; light green = medium term fallow; yellow = intensive cropping / fallow. The land use pattern on the 2010 DMC-2 image<sup>21</sup> is recognisable with the WSDC settlement boundary still visible, although it now contains a larger central mosaic of cropped and fallow land and the area of medium-term fallow around the town of Umm Rakuba has expanded. A border of savanna woodland remains around the settlement edge and to the south. The bare areas around each of the villages/boreholes in 1987 are no longer very evident but the medium-term fallow areas around the villages appear to have expanded considerably.

This example of the WSDC CSB is rather atypical because of its geometric shape. In Darfur, village footprints normally conform to a more hexagonal/Thiessen polygon configuration. It does, however, serve to illustrate the way that the area immediately adjacent to Umm Rakuba – which was previously cultivated – has now become fallow, with the cultivated areas being pushed out towards the settlement boundary. The land use cycle described above of cultivation followed by fallow, re-cultivation, fertility exhaustion and expansion into marginal areas should be quantifiable from the full sequence of maps now available.

The dynamics of land cover and land use in Darfur clearly operate on both short- and longer term cycles. The evolution of land use and land degradation may be operating on a timescale which is difficult to measure without a long-term view. A 40-year time series, starting with

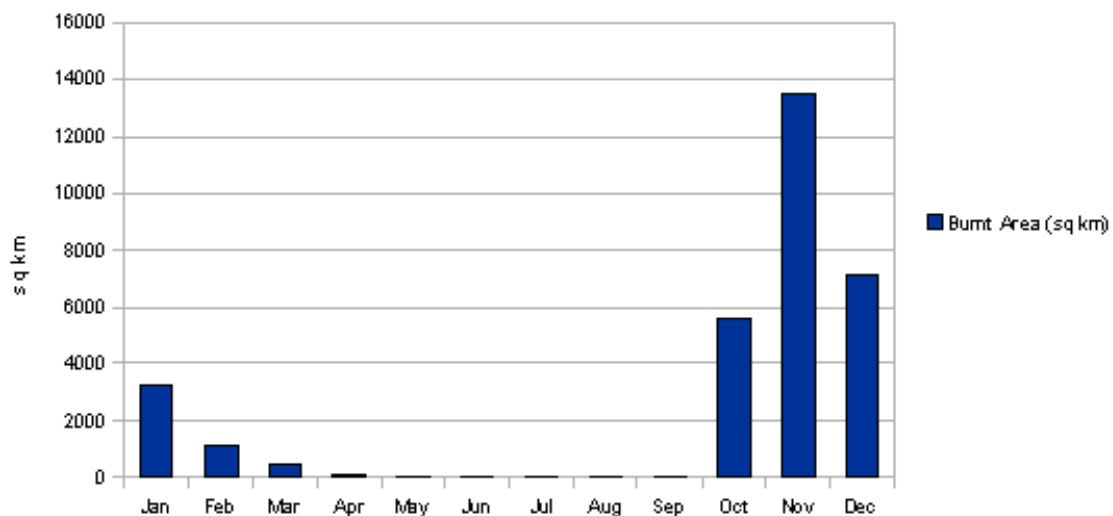
<sup>21</sup> The DMC-2 image is a false colour composite with photosynthetically active vegetation showing as red. The mosaic of fallow (dark red) and cropped (white) areas is clearly visible as are the large fallow areas around the settlements.

the HTS land use monitoring methodology described above, is now available which could shed light on the actual long-term cycles in land cover/use in South Darfur.

#### 4.2.2. Fire

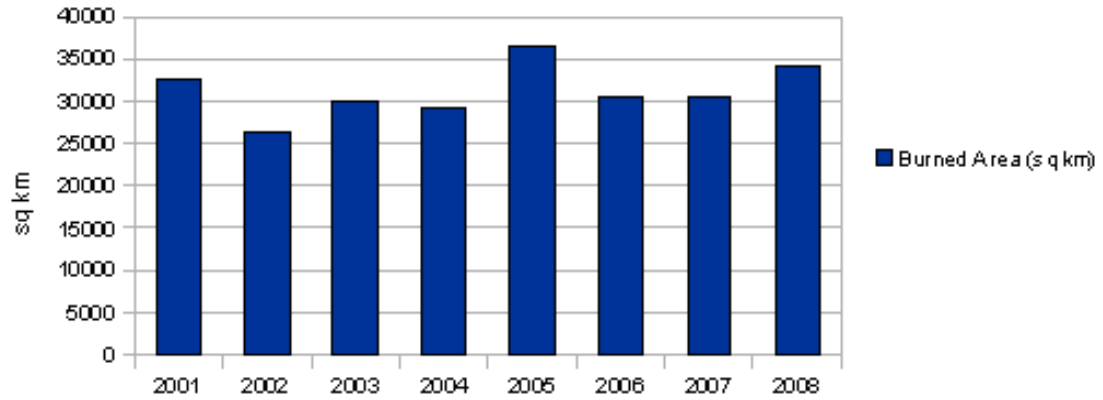
Fire plays an important role in creating and maintaining certain land cover types, including grasslands and woodland savannas. Fires can occur naturally but are more frequently part of a proactive land management strategy to encourage the growth of grass, to clear land for cultivation, and for bush control and the control of unpalatable species. The spatial and temporal patterns of burning are an indicator of these land management practices and indirectly of categories of land cover. As such, fire is considered here as an attribute of land cover rather than specifically as an environmental hazard, although in certain circumstances it certainly is. Another telling indicator is where fires do not occur – farmers do not want their crops or property to be damaged by extensive fires, although they may use fire post-harvest or prior to planting. Frequent burning might be an indicator of systematic land clearing and conversion.

With a view to understand Darfur's fire regime the MODIS burned area satellite archive was acquired and processed, resulting in a set of monthly burned area maps from 2001 to 2008.



**Figure 24.** Monthly burned areas in North and South Darfur (MODIS, 2004).

The monthly fire calendar for 2004 shown in Figure 24 illustrates a typical temporal pattern of burning during the dry season. Over the period for which the data are available (2001-2008) the annual area burned in North and South Darfur is relatively stable with a minimum in 2002 (Figure 25). The cumulative areas burned during the 2001-2008 period are shown in Figure 26.



**Figure 25.** Annual burned areas in North and South Darfur (MODIS, 2001-2008).

Of the areas burned 45 per cent belongs to the Africover herbaceous class, 32 per cent to shrubs, 15 per cent to trees, 3 per cent to woody vegetation and 4 per cent to crop lands (see Figure 27).

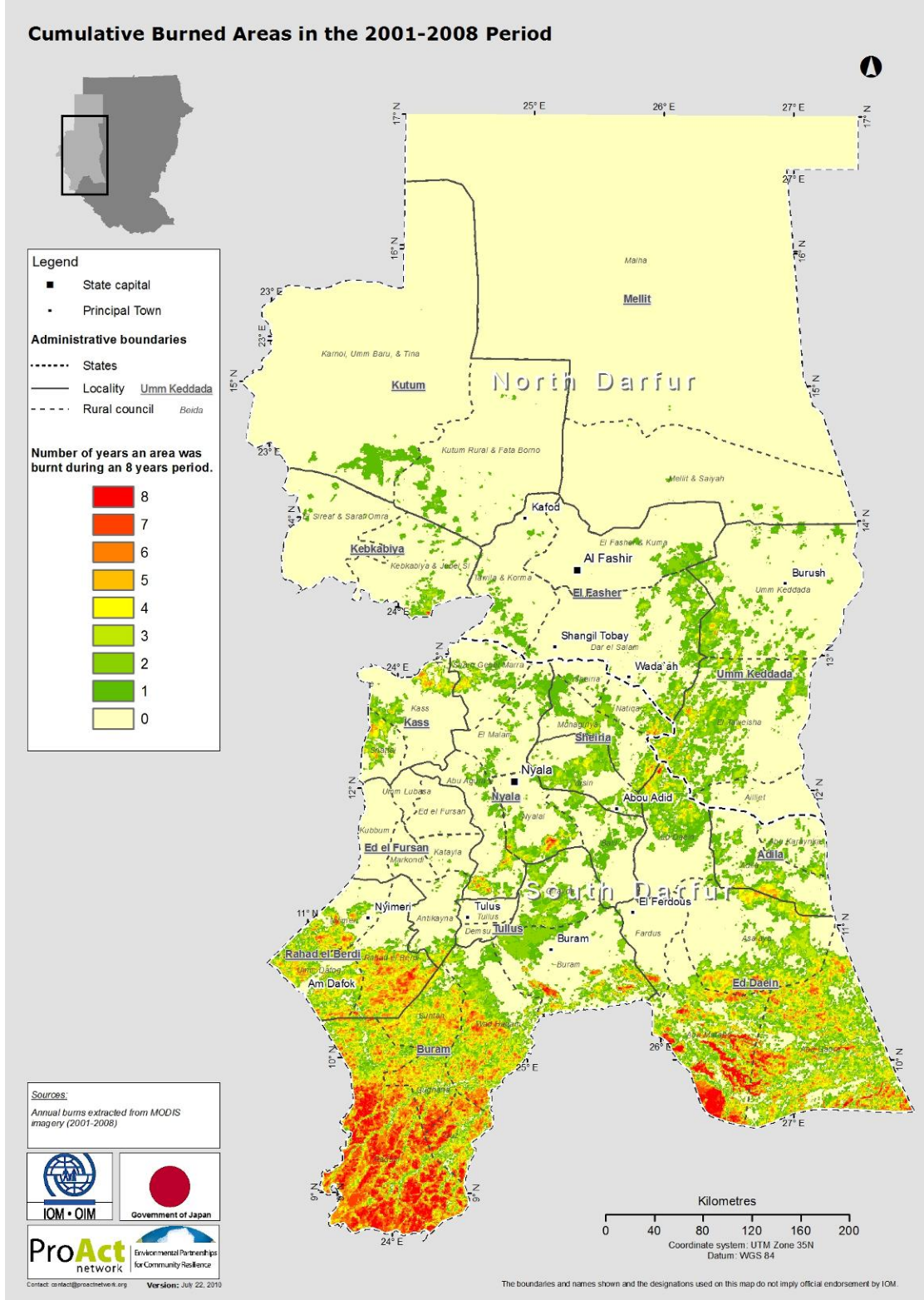
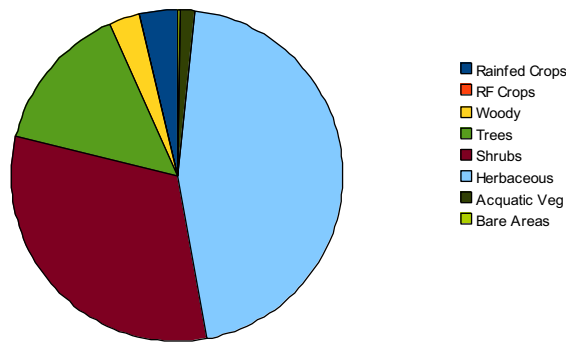


Figure 26. Cumulative areas burned between 2001 and 2008 (MODIS).



**Figure 27.** Land cover type of areas burned between 2001 and 2008 (MODIS data).

The spatial pattern of burning is not exactly the same each year although it is very similar and presumably accounts for a burning rotation. Some areas of burning are a cause for concern – for example frequent burning adjacent to intact forest blocks on Jebel Marra including the FNC managed softwood plantation (HTS, 1995a).

### 4.3. Woodfuel

Drigo (2005) presents the WISDOM methodology for a regional woodfuel assessment in East Africa, including Sudan. The following analysis uses the WISDOM methodology as first applied in East Africa to make a preliminary assessment of woodfuel supply and demand in both North and South Darfur. In addition it uses the other information products developed in the ELVM project to propose a more realistic assessment for this particular context.

The WISDOM methodology as first applied in East Africa follows five main steps:

- Definition of the minimum administrative spatial unit of analysis<sup>22</sup>.
- Development of the DEMAND module.
- Development of the SUPPLY module.
- Development of the INTEGRATION module.
- Selection of PRIORITY areas or “woodfuel hot spots”.

The input datasets for the analysis are both spatial and statistical and include:

- Ecological zones
- Africover land cover classification
- SRTM terrain data
- Oak Ridge National Laboratory LandScan population distribution
- Biomass stocking rates by woody land cover classes and ecological zone

<sup>22</sup> The WISDOM method uses a 9km grid as the spatial unit of analysis. The spatial unit of analysis used in this report is approximately 1km but is then generalised to 16km.

- Mean Annual Increment (MAI) of biomass
- Per capita total wood consumption for energy use

The main analytical steps of the methodology are shown in Figure 28, some of which may have been modified for this project. Caveats regarding the application of the method to woodfuel resources in Darfur are made in Section 4.3.4.

### Woodfuel Supply

On the supply side, the woody biomass reference statistics are assigned to land cover classes on the basis of ecological zone and canopy characteristics to give a map of woody biomass by land cover types and ecological zone. The mean annual increment of woody biomass is considered to be the sustainable extraction rate of the wood resource.

### Woodfuel Demand

On the demand side, the population distribution is assigned woodfuel consumption reference statistics to give a map of per capita woodfuel consumption. In the case of Darfur urban and rural consumption are assumed to be the same.

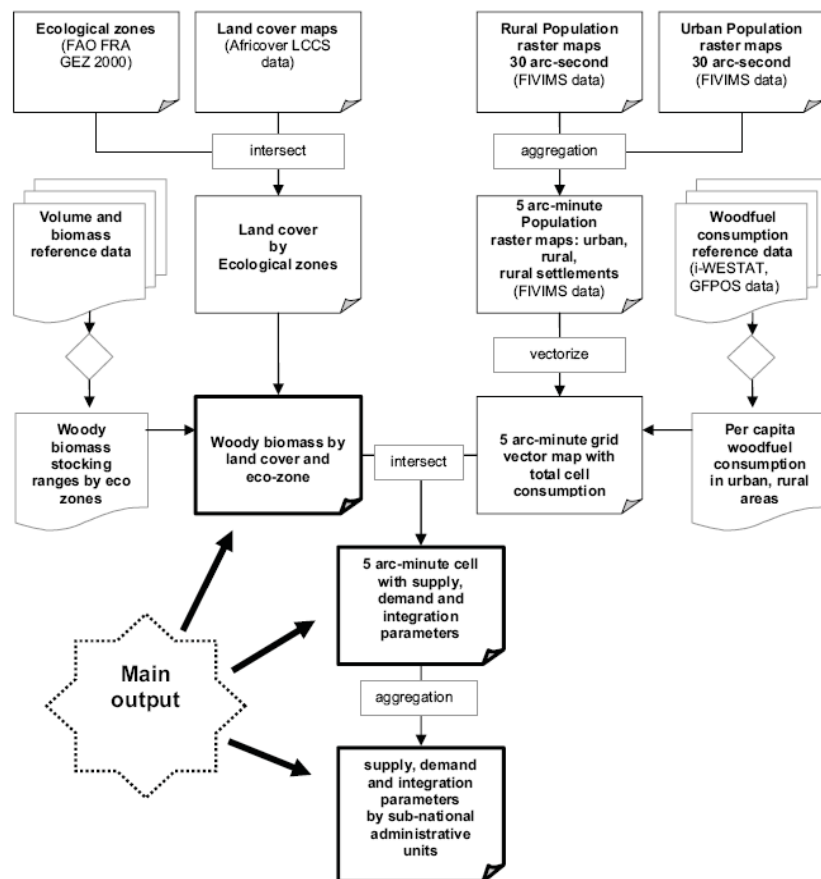


Figure 28. WISDOM's main analytical steps. (Source: Drigo, 2005).

The balance of woodfuel supply and woodfuel demand is then calculated, resulting in a map of woodfuel deficit and surplus.

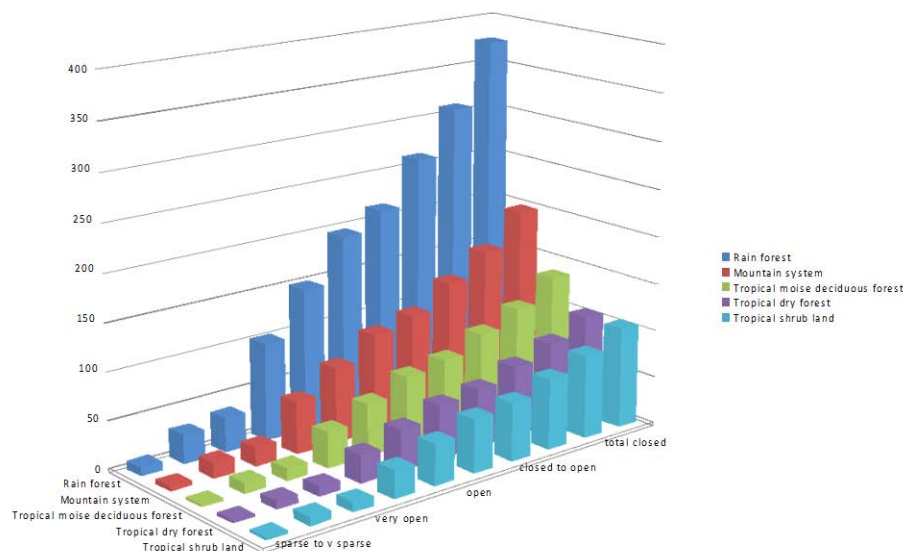
### 4.3.1. Darfur Wood Resources – Supply

Any methodology to assess woodfuel resources needs to estimate the quantity of biomass contained within the classes of land cover in the study area. WISDOM does this by using the Africover land cover data (*circa* 2000) in conjunction with estimates of wood biomass stocking by vegetation formation, ecological zone and canopy structure, using the best available information from the literature on stocking rates on the basis of each of these criteria. The WISDOM methodology as first applied in East Africa uses the following ecological zones from the FRA-2000 ecological zone map (described in FAO, 2000):

- Mountain system
- Rainforest
- Tropical moist deciduous forest
- Tropical dry forest
- Tropical shrub land

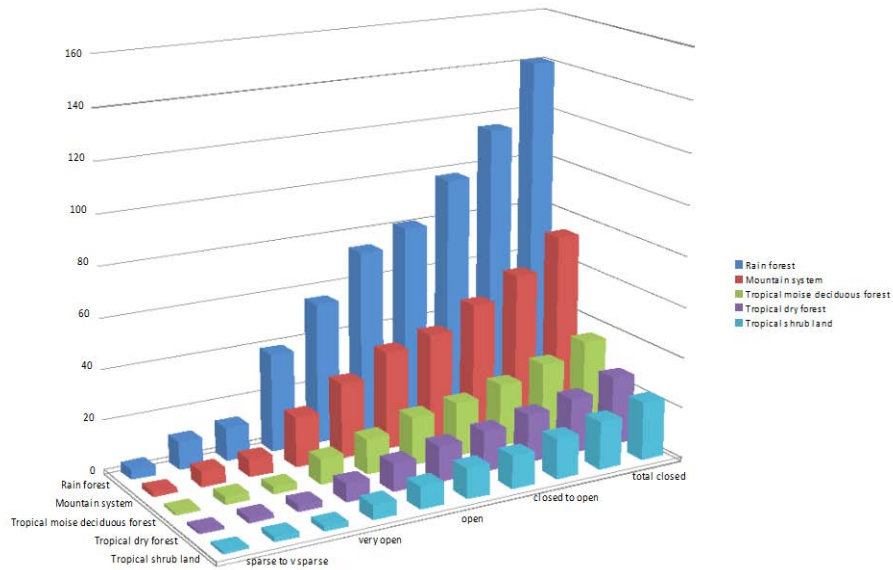
Natural and artificial formations are considered separately.

Within each of these ecological classes Drigo (2005) provides woody biomass estimates from the literature for 10 different canopy crown covers and 3 vegetation types which differ in the dominant plant form (*tree*, *shrub* and *woody*)<sup>23</sup>, see Figure 29 to Figure 31.

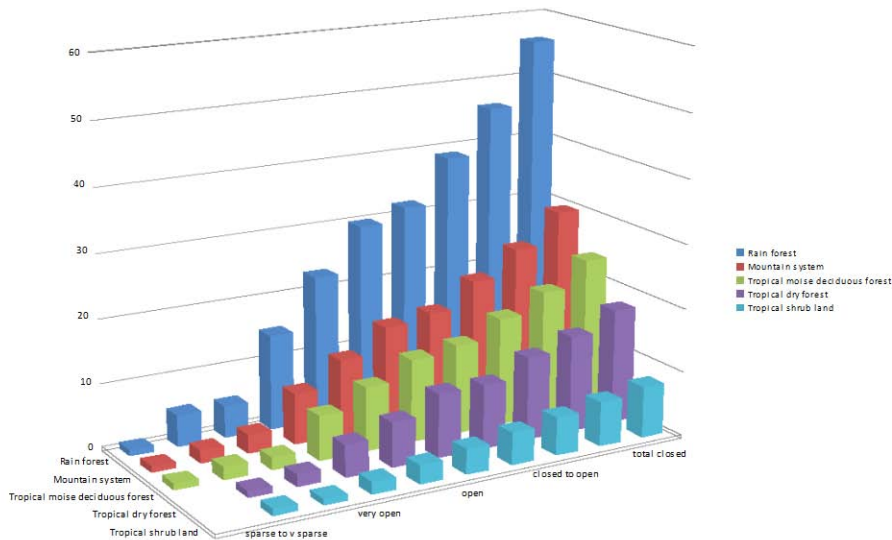


**Figure 29.** Woody biomass stocking (t/ha) in the TREE vegetation type (Taken from Drigo, 2005).

<sup>23</sup> Woody life forms include *trees* (higher than 5m tall) and *shrubs* (less than 5m tall). FAO and UNEP (2005) have defined a *woody* class for plants in the 2-7m range which are a mixture of both trees/shrubs or where it is not possible to distinguish between the two.



**Figure 30.** Woody biomass stocking (t/ha) in the WOODY vegetation type (Taken from Drigo, 2005).



**Figure 31.** Woody biomass stocking (t/ha) in the SHRUB vegetation type (Taken from Drigo, 2005).

These figures show the way in which woody biomass stocking increases:

1. with crown canopy closure and ecological zone (within the above Figures)
2. by vegetation type – Shrub, Woody, Tree (between the above Figures)

As the FRA-2000 ecological zones, described in FAO (2000), are very general it was considered that the eco-climatic zones produced by the ELVM project provide a more detailed representation of actual ecological boundary conditions in Darfur. Therefore, the following equivalence between the FRA-2000 ecological classification and the ELVM eco-climatic zonation was made:

- The ELVM 50-400mm zone was assigned to the FRA tropical shrub land;
- the 400-800mm ELVM zone was assigned to the FRA tropical dry forest class;

- the ELVM > 800mm zone was assigned to the FRA tropical moist deciduous forest class;
- the 1500m contour from the SRTM digital terrain model was taken to represent the Mountain systems class in the FRA classification.

The WISDOM methodology as first applied in East Africa (Drigo, 2005) assigns appropriate woody biomass stock values in t/ha to Africover land cover classes, according to the ecological/altitude zone, vegetation type and crown cover. Essentially this takes the information in Figure 29 to Figure 31 and spatialises it with Africover. These stocking rates should be cross referenced with data specific to Darfur (Elsiddig, 2007). Drigo (2005) does not provide any estimates for herbaceous biomass; however Ahlcrona (1988) has established a relationship between biomass of this type of vegetation and NDVI, which could potentially be used to address this gap in the future.

The woody biomass stock in tonnes per hectare is shown in Figure 32. This map represents the biomass stock at equilibrium. In productive systems an annual increment will be added to the stock each year. The mean annual increment (MAI) in the WISDOM model (as first applied in East Africa) is taken to be 2.5 percent of biomass stock for all formations. Drigo (2005) states that reliable field data in the region are difficult to find and that taking a simple positive relationship between biomass stock and MAI was the only practical solution for calculating MAI<sup>24</sup>.

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<sup>24</sup> The MAI is the proportion of stock that can be sustainably harvested for fuel and other purposes.

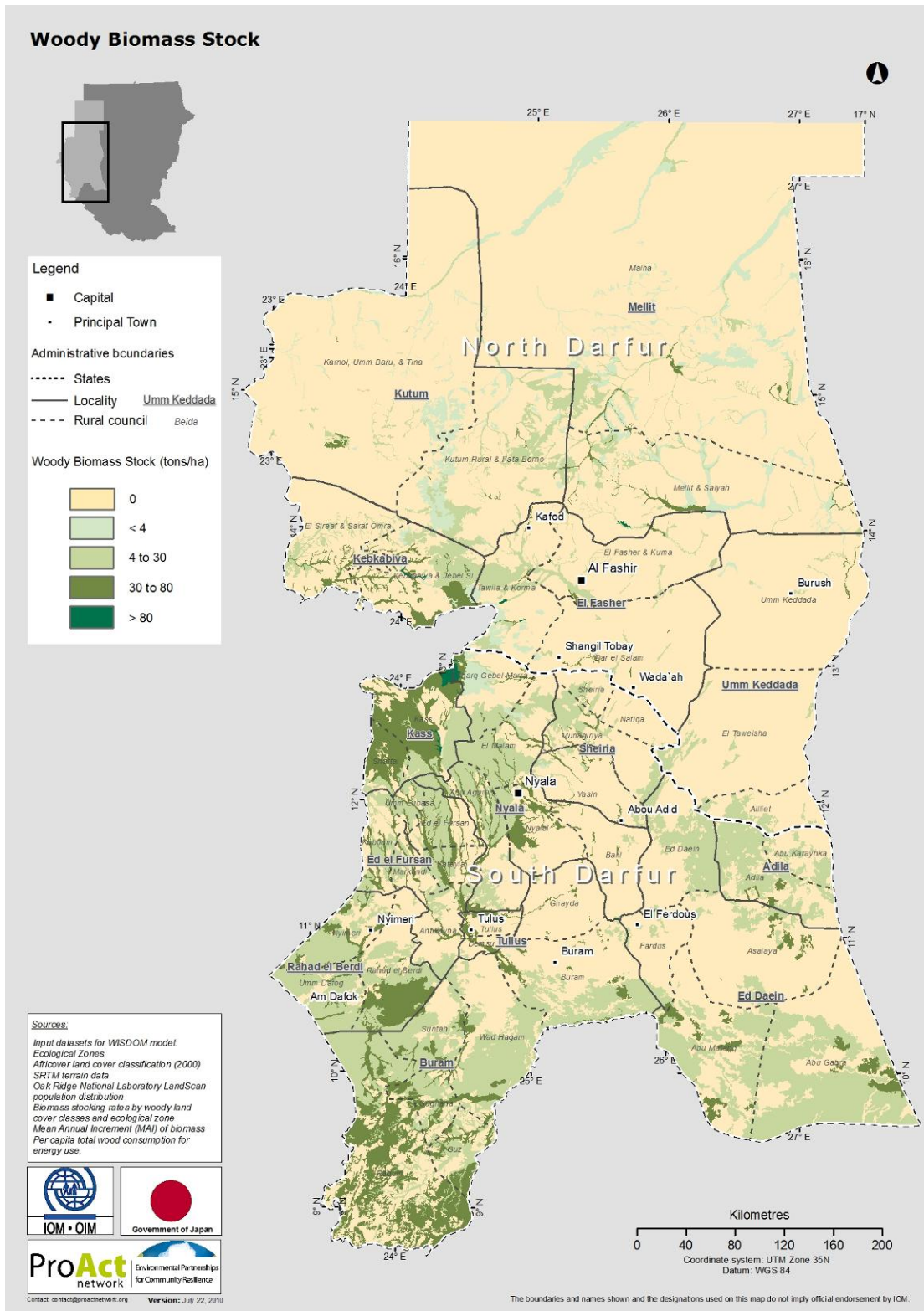


Figure 32. Yearly woodfuel biomass stock (t/ha).

### 4.3.2. Darfur Population Woodfuel Demand

In the absence of the latest census information or other population data, this project used the Oak Ridge National Laboratory (ORNL) LandScan product (2007) which provides an “ambient” population database derived from a complex spatial model. This product gives a measure of the number of people per cell and has a spatial resolution of 30 arc seconds, which is approximately 1km at the equator. The data were converted from 30 arc second geographic longitude / latitude coordinates to UTM Zone 35 N coordinates resulting in a pixel size of 0.933km. 0.933km is taken as the base resolution for calculation in the model and all other data are matched to this standard.

Each grid cell therefore represents  $(0.933 * 0.933) / 100 = 86.49\text{ha}$ . Because the pixel size has changed the population values need to be adjusted by the same factor.

Woodfuel demand per grid cell (t) is equal to:

$$\text{Population} \times \text{area adjustment factor} \times \text{per capita consumption} \times \text{wood density}$$

Where:

- Area adjustment factor – an adjustment factor to account for the change in pixel size between the population estimate on a longitude / latitude grid and UTM map projection<sup>25</sup>
- Per capita consumption – the average woodfuel consumption per person per year in cubic metres
- Wood density – the density of wood per cubic metre, used to convert from  $\text{m}^3$  to kg.

Drigo (2005) gives a per-capita woodfuel consumption rate for Sudan of  $1.09 \text{ m}^3$  per year for both rural and urban populations based on a wood density of  $725 \text{ Kg/m}^3$ . The demand for woodfuel is calculated as follows:

$$\text{Woodfuel demand per cell (t/ha)} = \text{population cell value} \times 0.8649 \times 1.09 \times 0.725$$

In Kordofan, Olsson (1985a) calculated the per capita woodfuel consumption to be 1.035t or  $1.428\text{m}^3$ .

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<sup>25</sup> The correction factor was added to account for the *Important Note* supplied with the LandScan data which states “Converting (including on-the-fly projections) a grid to other projections or coordinate systems causes population cells to be re-sampled, and hence population counts will be incorrect”

### **4.3.3. Darfur Woodfuel Balance**

Having calculated the demand and the supply the balance is simply the difference between the two (Figure 33) in which pink areas indicate a negative balance and green areas a positive woodfuel balance. It should be noted that the distribution is extremely skewed with negative values going down to -19,000 tonnes per hectare in Nyala where an intense peak of population occurs.

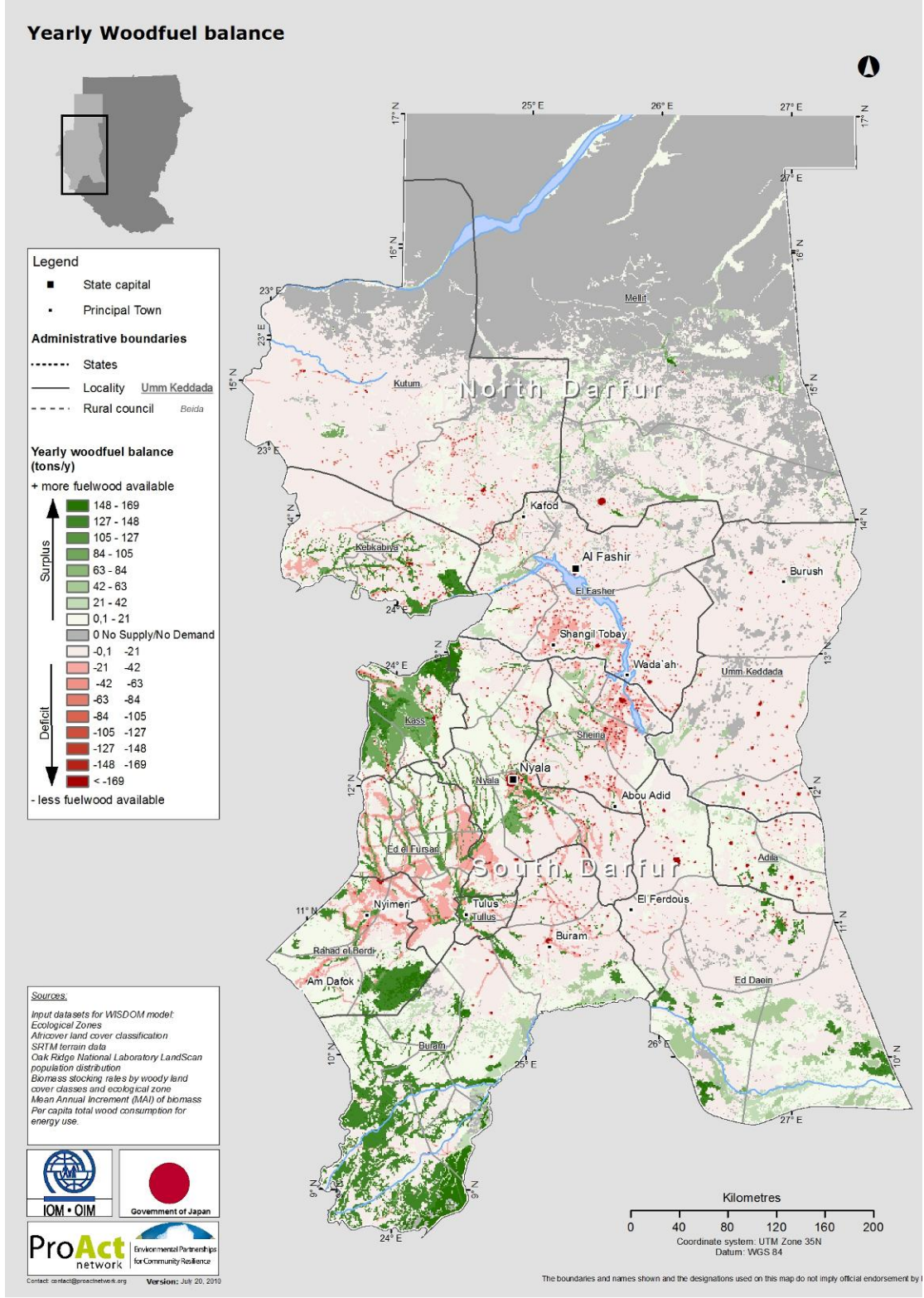


Figure 33. Annual woodfuel supply / demand balance.

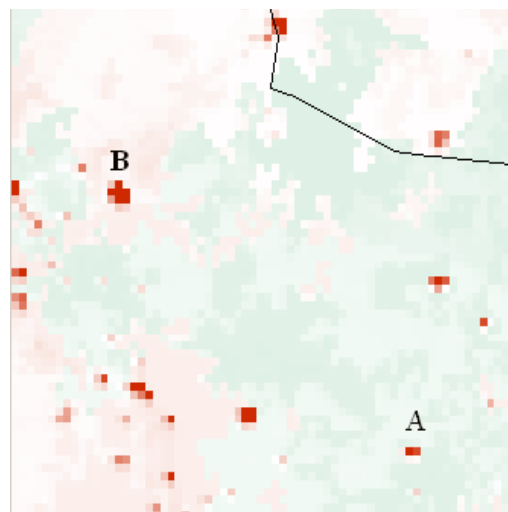
#### 4.3.4. Issues to Consider

There are a number of caveats to be made in relation to this map, as outlined below.

##### 4.3.4.1. Woodfuel Catchment

The methodology implemented above has a resolution of approximately 1km whereas the WISDOM methodology as first applied in East Africa is based on a 9 x 9km cell size. The WISDOM methodology as first applied in East Africa assumes that both demand and supply are contained within one grid cell, which is likely to be true at a 9km resolution but unlikely at a 1km resolution. The IOM Population Tracking and Village Assessment Project records people walking up to four hours to collect fuel in Umm Kaddada Rural Council (IOM, 2009). Therefore, a 1km resolution highlights demand hotspots but not necessarily the woodfuel collection catchment. The WISDOM approach of degrading to a 9km analysis cell generalises the catchment issue except that the cells are not necessarily aligned with village locations. The ELVM analysis developed later in this report generalises the woodfuel catchment to a 16km grid.

In Figure 34, at location **A** the collection hotspot (village) has a marked woodfuel deficit but is surrounded by areas of woodfuel surplus where fuel can easily be collected, whereas at location **B** the deficit hotspot is surrounded by areas that are already in woodfuel deficit. People at location **B** will have to either degrade the surrounding area further or travel a greater distance to find a sustainable source.



**Figure 34.** Woodfuel deficit hot spots.

The existing methodology could be extended to be more spatially explicit about the wood production areas necessary to satisfy the estimated woodfuel demand in the vicinity of populated places. Ideally this would require more accurate village locations and population data. Standardising the vulnerability framework on a 16km grid provides a workaround for the current version of the ELVM.

#### **4.3.4.2. Africover**

The Africover dataset is now ten years old and in places is out of date. Discrepancies between Africover and the 2010 DMC-2 imagery can be identified and it is understood that a new version of Africover is currently in preparation which should provide a more realistic assessment of wood resources when it is released.

#### **4.3.4.3. Mean Annual Increment**

Drigo (2005) notes the difficulty in obtaining reliable figures for mean annual increment and applies a blanket figure of 2.5 per cent. Olsson (1985a) also notes this difficulty and uses a figure of 7.2 per cent, derived from a study by Lamprey (1984) in arid rangelands in Kenya.

The NDVI is a function of the photosynthetic activity of plants and is correlated with biomass of herbaceous formations. There is therefore no direct relationship between NDVI and woody biomass - During the growing season woody plants accumulate biomass in their stems where it can be stored for many years- unless NDVI is measured every year from planting. For this reason albedo can be a better indicator of woody biomass than NDVI because of the effect of shadows cast on the ground by stems and branches (Olsson, 1985a).

NDVI is more correlated with productivity and the Mean Annual Increment; see for example González-Alonso *et al.* (2006). If the relationship between NDVI and MAI were known in this region then NDVI could potentially be used as a proxy for MAI which should improve the estimation of the sustainable extraction of woodfuel. This is probably an area for research rather than of operational relevance.

#### **4.3.4.4. Herbaceous Biomass**

Ahlcrona (1988) presents regression estimates of NDVI and wet grass biomass and field cover in White Nile Province using near contemporaneous field data and Landsat MSS and Landsat TM imagery. This relationship could be used to estimate biomass in the herbaceous formation of the Africover maps.

#### **4.3.4.5. Population Distribution and Consumption Rates**

According to LandScan (ORNL, 2007) population data, the population of Darfur is highly concentrated in villages and in particular the larger towns of Nyala and El Fasher. According to this dataset the total population for North and South Darfur is approximately 4,877,000 (2007) and is largely distributed around the Jebel Marra massif on the Basement Complex and across the *qoz* areas of South Darfur. The southern parts of South Darfur and the north-eastern parts of North Darfur are less populated (see Figure 45).

The displacement of people as a result of the conflict in Darfur has resulted in both a concentration of population in some locations (most notably in the large IDP camps) and

depopulation in places of origin. The concentration of people in IDP camps or the depopulation of areas would also alter the actual current availability of woodfuel at a given location and thus affect consumption rates. Despite the lack of available, quantitative, comparable, region-wide data on population distribution and wood fuel consumption, it can be expected that woodfuel consumption rates differ across the three Darfur states, differ between rural and camp populations and differ between different camps, (as noted by ProAct Network in a 2008 assessment of the effectiveness of fuel-efficient stove programming across Darfur). In the absence of sufficient data to map different consumption rates across the study area a single rate has been used in the WISDOM methodology as applied in the ELVM project. Furthermore, the WISDOM methodology, as applied in the ELVM framework does not take into account the local and regional trade in woodfuel (i.e. wood and charcoal) or timber. It should be noted that the WISDOM methodology has developed considerably since its first application in East Africa but these recent developments were not available during the project timeframe<sup>26</sup>.

#### **4.4. Quantifying Environmental and Livelihoods Vulnerability of the Study Area in North and South Darfur**

The available data provides measures of the following environmental factors which have a direct impact on livelihoods and which are available to construct an index of environmental and livelihoods vulnerability:

- potential rainfall water availability;
- rainfall variability;
- potential groundwater availability; and
- potential woodfuel sufficiency.

Anthropogenic factors required for estimating vulnerability are:

- adaptive capacity; and
- population.

Each of these factors deals with *potential* rather than the *actual* availability at a given place and time. For example a farmer pursuing a livelihood at a location with an average of 500mm of rainfall per year on the Nubian Sandstone aquifer cannot necessarily expect either 500mm of rainfall nor access to water in the aquifer. Access to these resources depends on actual rainfall during a given time period and access to a deep well or borehole at a specific site. Access to the natural water assets may only be available through physical assets such as boreholes. The infrastructure of physical and natural assets contributes to communities' adaptive capacity.

The following section attempts to use the available data to:

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<sup>26</sup> Additional WISDOM case studies at the FAO Wood Energy Programme web site: <http://www.fao.org/forestry/site/energy/en>. An updated version of the methodology will soon be available and will be implemented by FAO for Darfur.

- i) build a multi-hazard index;
- ii) modulate the multi-hazard index with a measure of adaptive capacity; and
- iii) calculate a vulnerability index that includes human population exposure to the multiple hazards.

To build the index each of the main parameters is re-coded in the range 0-1, with 0 representing poor conditions and 1 good conditions for production, and thus rural livelihood activities. This task is complicated by some of the data distributions being skewed and thus, data requiring statistical transformations to conform to the 0-1 scale. Data for each of the factors has been standardised on the 16km grid.

#### **4.4.1. Potential Rainfall Water Availability Index (PRA)**

A potential rainfall water availability index was created by averaging the rainfall values within each of the 16km x 16km grid cells and dividing this by 1,300 (the maximum annual rainfall occurring in Darfur) resulting in a scaled rainfall index with values from 0-1 (Figure 35).

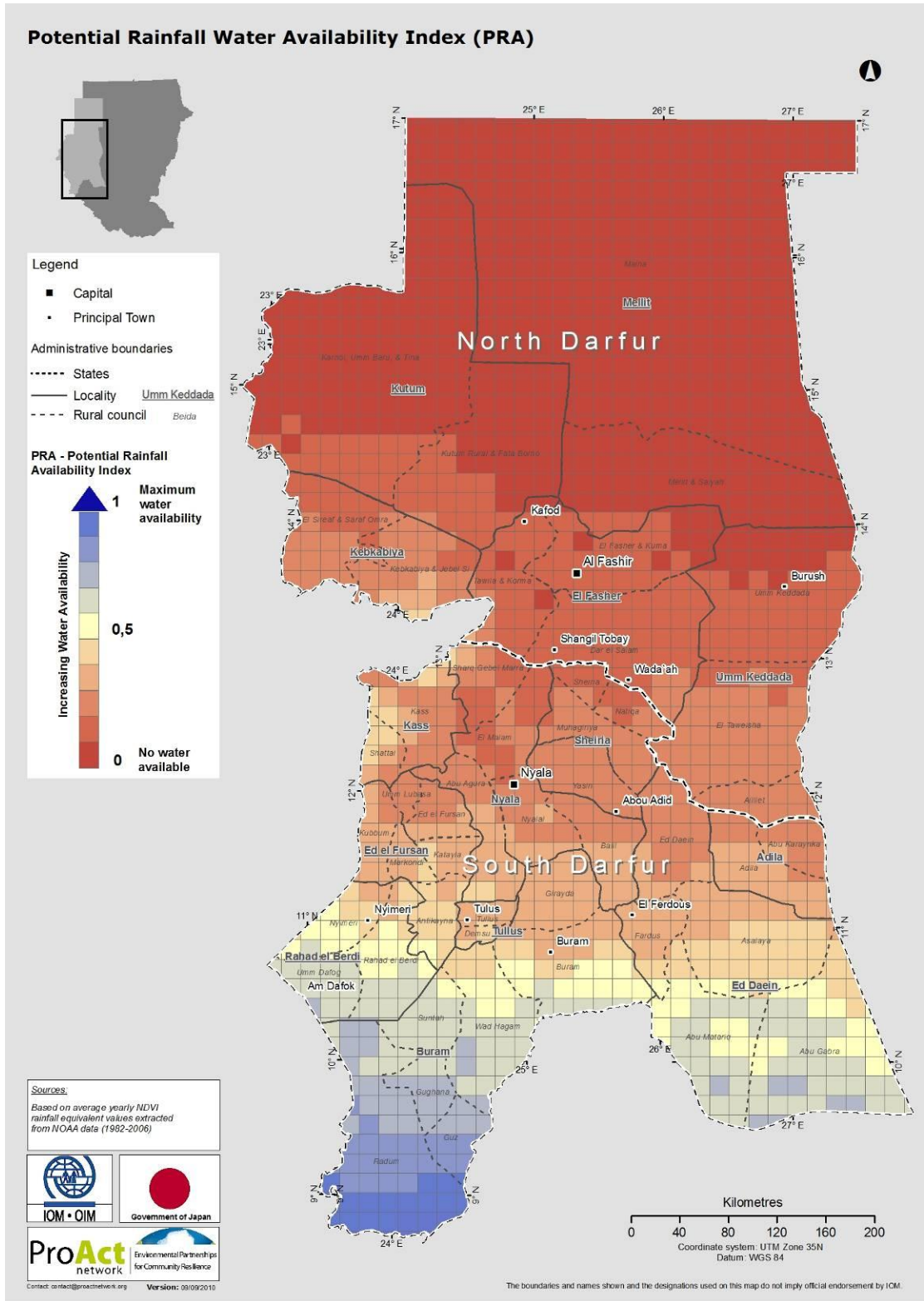


Figure 35. Potential rainfall water availability index.

#### 4.4.2. Potential Groundwater Availability Index (PGA)

The five main hydrogeological elements present in North and South Darfur were coded on a 1-5 scale of increasing groundwater availability potential - where a value of 1 was given to Basement Complex and 5 to Alluvium (see Figure 17). The potential groundwater availability for each 16 x 16km grid cell was then calculated as the average of the values assigned to the hydrogeological elements present in the cell area. To scale these cell values on a 0-1 range, they are divided by 5 in the potential groundwater availability index (PGA), see Figure 36.

#### 4.4.3. Rainfall Predictability Index (RP)

The rainfall predictability index is based on the coefficient of variation (CV) of the NDVI rainfall equivalent over a 25 year period. Because the distribution of CV values in the study area is very skewed and, towards the desert margin CV values increase exponentially -and are greater than one-, the desert margin was excluded from the index calculation.

A natural logarithm transformation was applied on the remaining values –which range between 0 and 1 – to make their distribution more normal. In the rainfall predictability index (RP) the ‘normalised’ CV values are subtracted from one. This gives RP a 0-1 range where high values represent high rainfall predictability, i.e. low year to year fluctuation in rainfall amounts. Figure 37 shows the rainfall predictability index.

$$\text{Rainfall Predictability Index (RP)} = 1 - [\ln (|CV| + 1)]$$

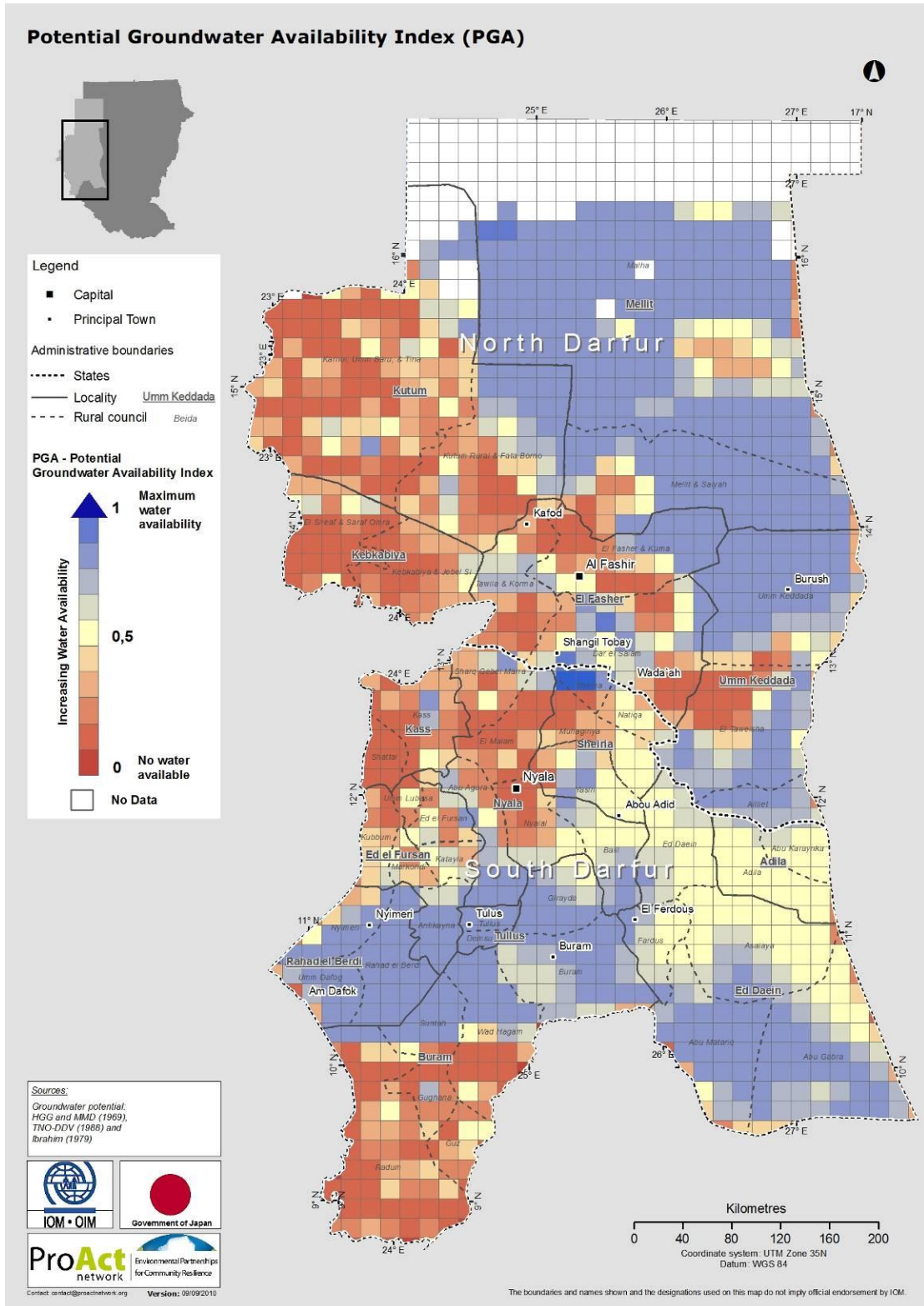


Figure 36. Potential groundwater availability index.

# Interannual Rainfall predictability Index (RP)

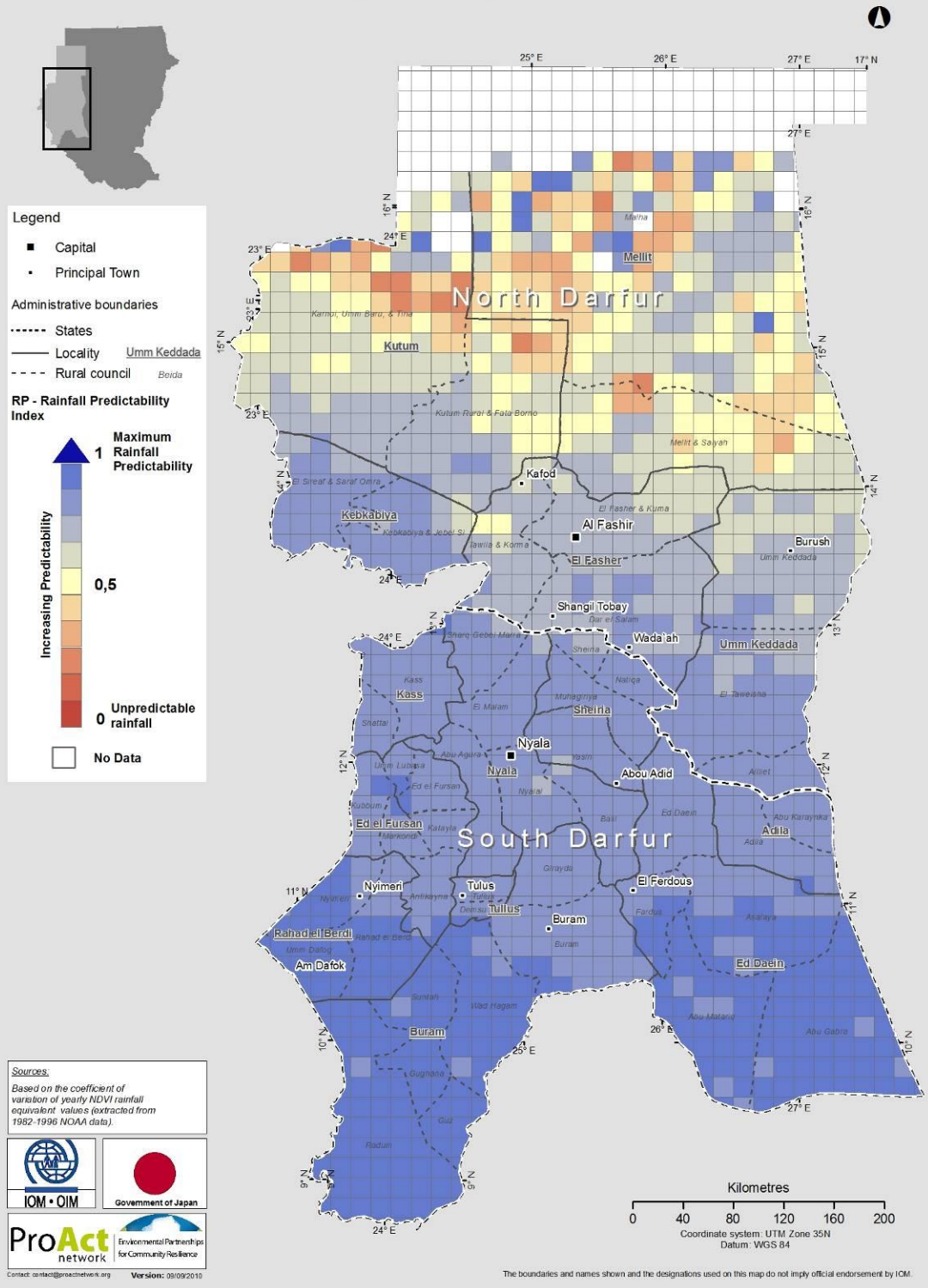


Figure 37. Potential rainfall predictability index.

#### 4.4.4. Potential Woodfuel Sufficiency (PWS)

The potential availability of woodfuel, sufficient to meet the energy needs of an area's population (woodfuel sufficiency) is the last environmental limiting factor evaluated in the project, with woodfuel insufficiency considered a hazard to livelihoods based on this natural resource. Woodfuel sufficiency varies with both woody biomass supply and population demand for fuel.

To create the woodfuel sufficiency index the following formula was used:

$$\text{Potential Woodfuel Sufficiency Index (PWS)} = 1 - [(\ln (|\text{grid cell deficit value}| + 1)) / 9.853]$$

Woodfuel deficit values are converted into absolute positive values and 1 is added. The natural logarithm is then taken and the result divided by 9.853<sup>27</sup>. Finally, the value obtained in the previous step is subtracted from one. This gives a set of positive values between zero and 1 which represent the sufficiency of woodfuel for local populations. Note that because this calculation was only applied to areas with an actual deficit of woodfuel (red shaded areas in Figure 33), all areas with a surplus of this energy form or where there is no demand (such as in the northern edge of the study area - green shades in Figure 33), are included in a single category -darkest blue - in the potential annual woodfuel sufficiency map (see Figure 38).

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<sup>27</sup> 9.853 =  $\ln (|-19,014| + 1)$ , where -19,014 is the maximum woodfuel deficit value in the study area.

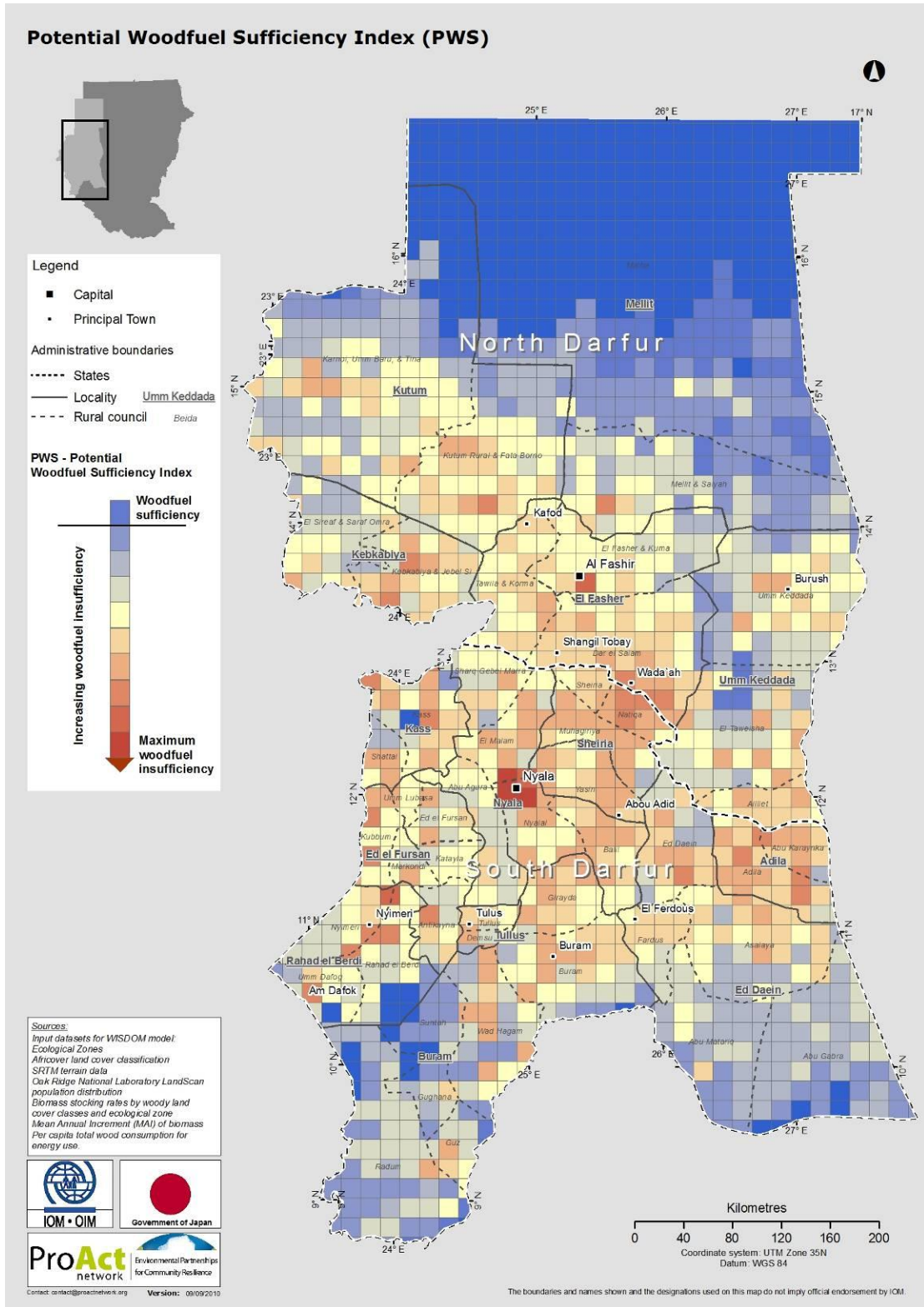


Figure 38. Potential annual woodfuel sufficiency index.

#### 4.4.5. Adaptive Capacity (AC)

The adaptive capacity component of the ELVM framework is based on people's accessibility to natural and physical assets and which can provide communities with the ability to both access natural assets more effectively, to sell their produce and to support community health and education.

Access to the following natural and physical assets is taken into account:

- access to surface water resources (not considered in the above water availability analysis);
- access to boreholes;
- access to hand pumps;
- access to important markets;
- access to health facilities;
- access to education; and
- access to IDP camps.

Accessibility to these assets implies knowledge of the distance from any point in the landscape to any of the above assets. However, in reality, accessibility is a function not just of distance but also ease of travel between the two places. Moving from one place to another implies a cost which might be in fuel or simply in human effort. Distance can therefore be considered in terms of *cost-distance* (Eastman, 1989), i.e. not just the distance from A to B but the cost (effort) of travelling from A to B, which will be influenced by other factors that determine how easy it is to move across the land surface. For example, it is much easier to walk along a track through thorn scrub than it is to walk directly through the thorn scrub. Knowing the location of the main roads and the land cover types it is possible to propose a friction surface that indicates difficulty/ease of movement across the land surface, relative to free movement.

Assuming that people will try to minimise the cost/effort of travel then a *cost-surface* can be constructed to indicate the cost of moving between any given location to the nearest asset of interest. A friction surface was compiled by assigning relative friction values to land cover classes and to road surfaces. This friction surface was then used to calculate the cost-distance of moving from each location to the nearest asset. A set of cost-distance maps was compiled in this way, one for each asset. The potential adaptive capacity was then taken to be one minus the added costs of access to all assets (standardised between 0 and 1) to give an overall cost to assets at each location, with resulting values closest to 1 reflecting the highest adaptive capacity.

In this initial version of the ELVM framework the assets were all given equal weight. This approach ignores all political and security constraints which may exist on the ground and could not include important components of local communities' financial and social capital – such as social networks or remittances – because of the lack of available spatial information.

All of the data on which the adaptive capacity is based is derived from the IMWG dataset (UNDP, 2009) and the Africover Surface Water Body Features layer (FAO, 2006).

The 16km x 16km grid cells which occur around the boundary of Darfur may cross into adjacent areas for which no information is available. For example, population data are available for other provinces of Sudan but not neighbouring countries. This can lead to edge effects along the international borders with the average values being under representations. Wherever possible these edge effects have been minimised or eliminated.

#### **4.4.5.1. Access to Surface Water**

Surface water flow in Darfur is dependent on the local geology and surface deposits as discussed in the section 4.1.2. For example, on *qoz* soils there is almost no surface drainage. The FAO Africover data and associated river layer gives some indication of perennial and ephemeral occurrence of surface water. A cost-surface to surface water was developed as an input to the adaptive capacity module.

#### **4.4.5.2. Access to Ground Water**

The analysis of potential groundwater resources indicates potential access rather than actual access. Accessibility is dependent not only on spatial location in relation to the aquifers but also on the depth of the aquifer which may be shallow in the case of alluvium or at considerable depth in the case of the Nubian Sandstone. Access to hand pumps and boreholes therefore gives a better indication of actual access to ground water. A cost surface to hand pumps and boreholes was developed as an input to the adaptive capacity module.

#### **4.4.5.3. Access to Support Services**

Access to markets is an important factor in the rural economy and to rural livelihoods, both to sell agricultural produce and to buy commodities. A cost-surface to traditionally – or historically – important markets has been developed as an input to the adaptive capacity module.

Access to health care facilities is a basic support mechanism to all communities. A cost-surface to known health care facilities was also developed as an input to the adaptive capacity module.

Finally, access to IDP camps has been included as an adaptive capacity of last resort, and a cost-surface to known IDP camps was developed as an additional input to the adaptive capacity module.

The map presented in Figure 39 shows the potential adaptive capacity calculated for North and South Darfur.

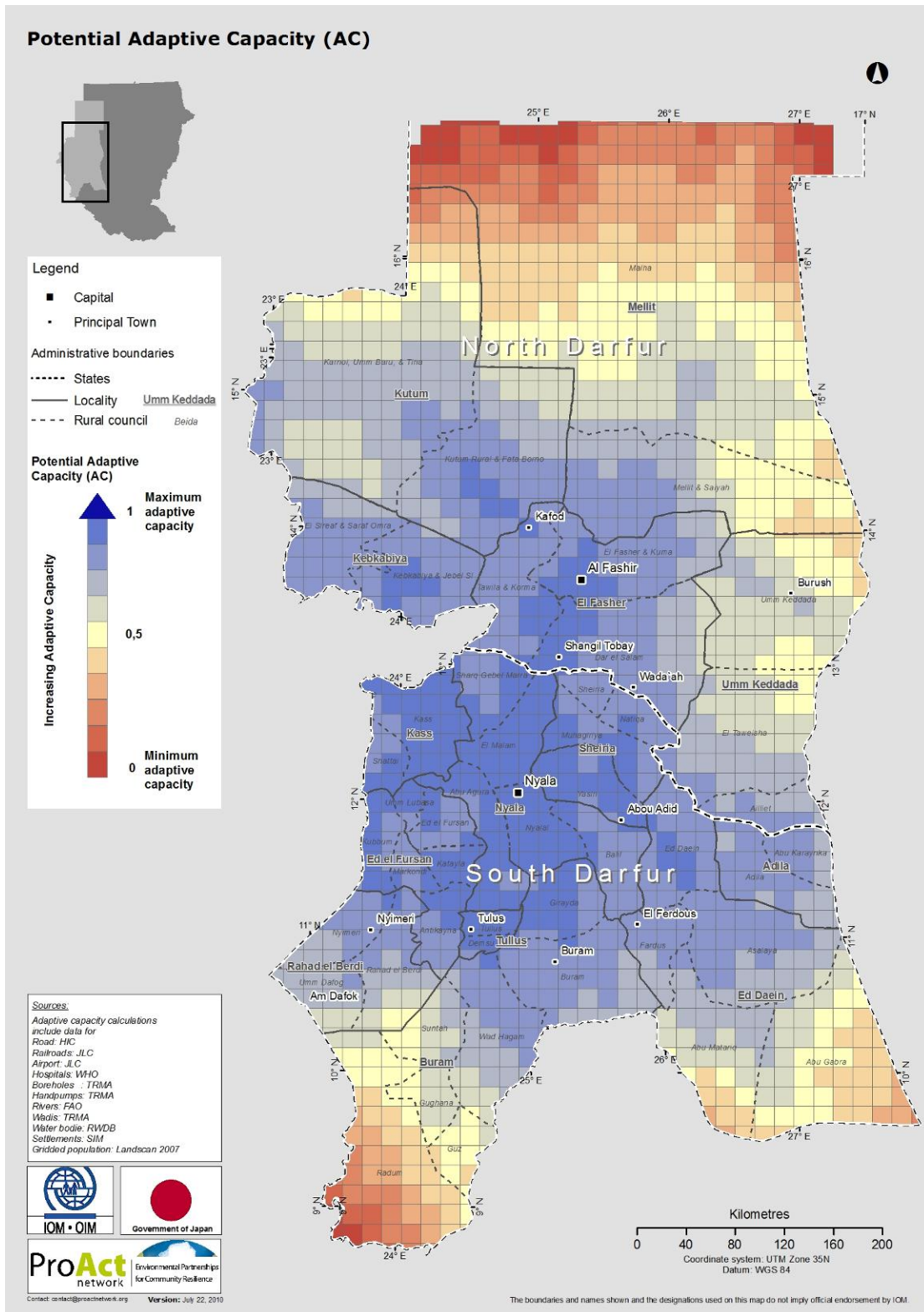


Figure 39. Potential adaptive capacity.

#### 4.4.6. MHVI, A Combined Index of Spatial Vulnerability to Multiple Hazards

Several steps were taken to estimate the vulnerability of rural livelihoods to environmental hazards in the study area.

Firstly, all indices described above were considered to be of equal weight –a debatable assumption – and were combined into a simple multi-hazard vulnerability index by adding adaptive capacity to the average of the multiple hazard values, using the following formula:

$$\text{MHVI} = [ (\text{PRA} + \text{RP} + \text{PGA} + \text{PWS}) / 4 + \text{AC} ] / 2.0$$

Where:

MHVI = Spatial vulnerability to multiple hazards index

PRA = Potential rainfall water availability

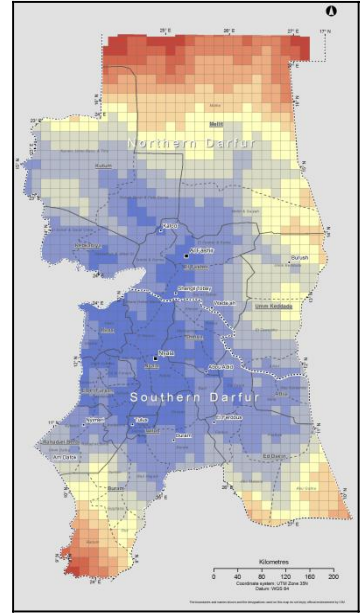
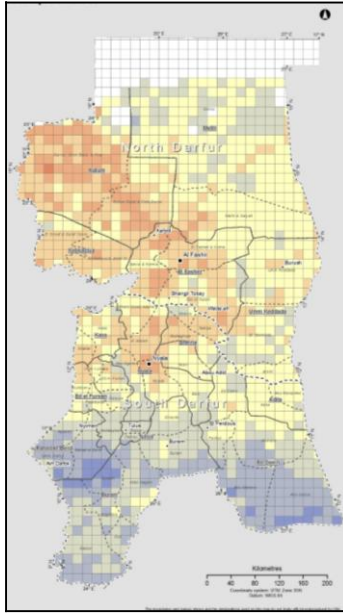
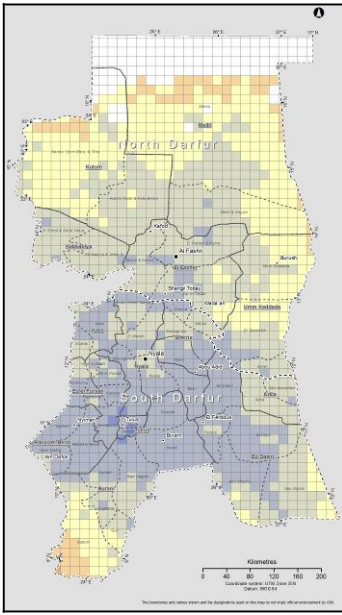
RP = Rainfall predictability

PGA = Potential groundwater availability

PWS = Potential woodfuel sufficiency

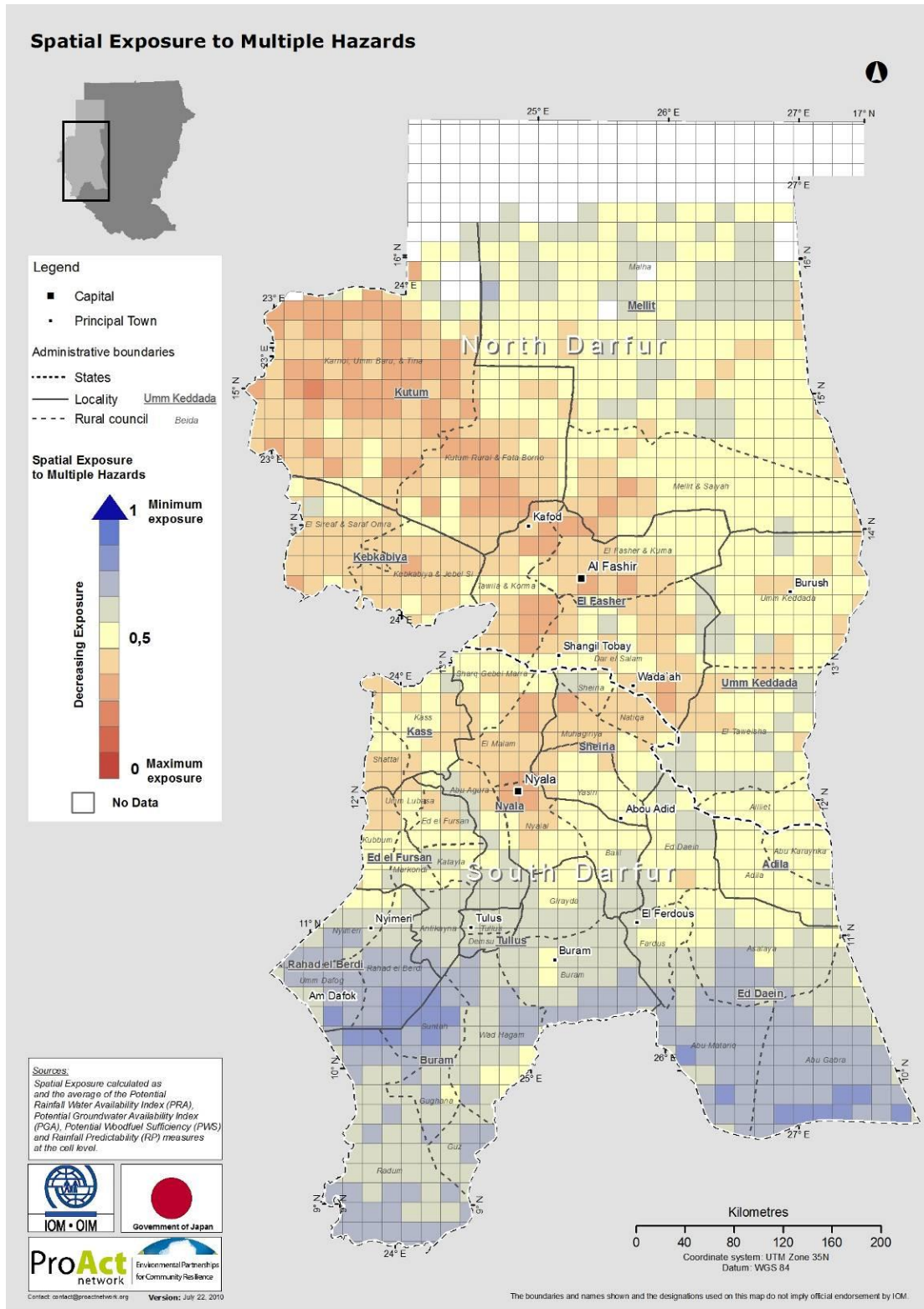
AC = Potential adaptive capacity.

The average of these indices  $[(\text{PRA} + \text{RP} + \text{PGA} + \text{PWS})/4]$  represents the degree to which the four combined environmental factors limit livelihood activities at a specific 16km x 16km grid cell (i.e. the cell's exposure to multiple hazards). In this context, low average values (driven for instance by low rainfall and groundwater availability) indicate rural livelihoods in the grid cell are highly limited by these environmental factors, i.e. the grid cell area is highly exposed to multiple environmental hazards (see Figure 41). However, in the MHVI calculation, negative environmental effects on livelihoods can be balanced by positive adaptations (adaptive capacity). The result is divided by 2.0 to bring the range of the MHVI values back into the 0-1 range, with MHVI values close to zero reflecting high vulnerability levels. The spatial vulnerability to multiple hazards in North and South Darfur is presented in Figure 42.



$$\text{MHVI} = [ (\text{PRA} + \text{RP} + \text{PGA} + \text{PWS}) / 4 + \text{AC} ] / 2$$

**Figure 40.** Construction of the spatial vulnerability to multiple hazards index (MHVI).



**Figure 41.** Spatial exposure to multiple environmental hazards.

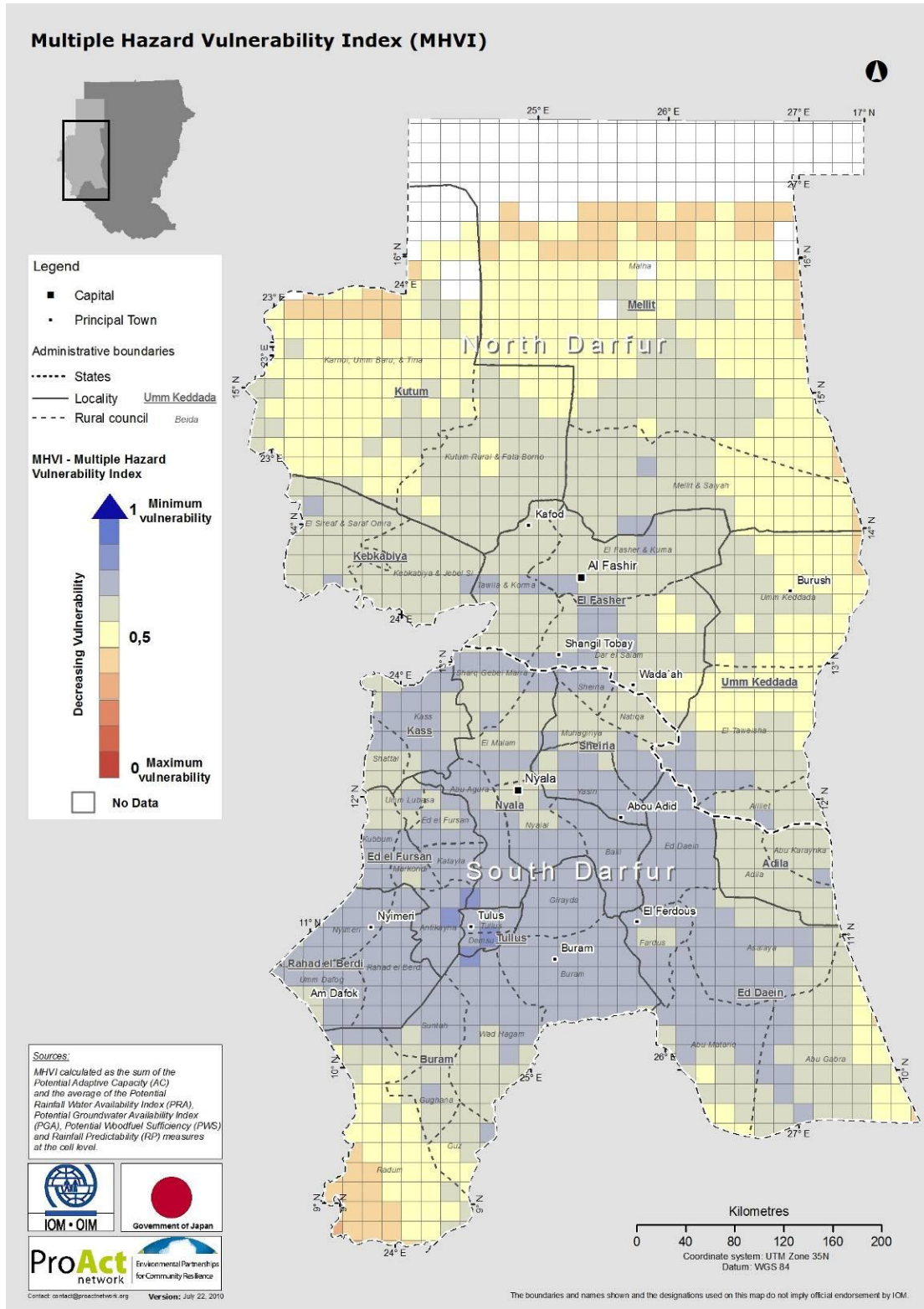


Figure 42. Spatial vulnerability to multiple hazards.

#### 4.4.7. Environmental and Livelihoods Vulnerability Index (ELVI)

This project's definition of vulnerability states that it is "the extent to which a system may be impacted by a hazardous event to which it is exposed, after accounting for the system's adaptive capacity". The system has been defined as the community and environment within a 16km x 16km grid cell. The vulnerability index therefore also needs to take into account the population within the 16km x 16km grid cell as well as the multi-hazard and adaptive capacity factors, according to the following formula:

$$\text{ELVI} = \text{MHVI} \times (1 - \text{RPOP})$$

Where:

ELVI = Environmental and Livelihoods Vulnerability Index

MHVI = Spatial vulnerability to multiple hazards index

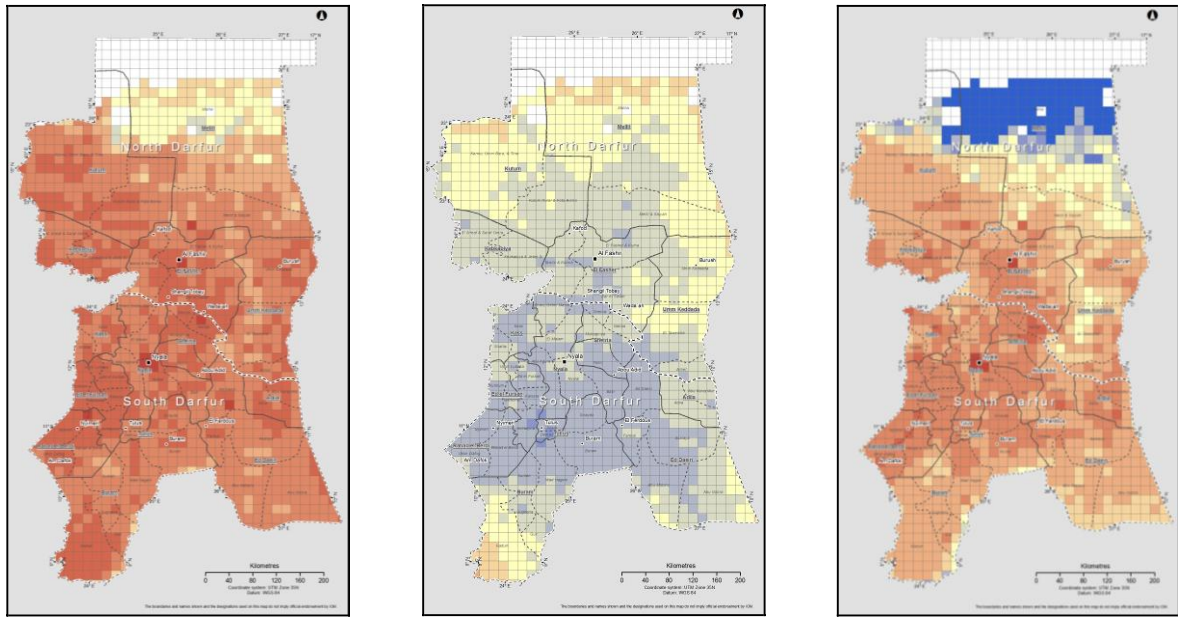
RPOP = Relative Population Distribution Index<sup>28</sup>.

MHVI and 1-RPOP are both on a scale of zero to one, so their multiplication will also result in the ELVI being on a scale from zero to one. ELVI values close to 0 reflect maximum vulnerability and ELVI values close to 1 denote low vulnerability levels.

The ELVI is a synthesis of many different data condensed into a single value at each 16km x 16km grid cell location. Figure 44 shows the spatial variation of the index, which permits generalized comparisons of vulnerability across the study area but does not provide information on the drivers of vulnerability at each site. To complement understanding and utility of the index the underlying factors are also presented in a graphical form in the next section.

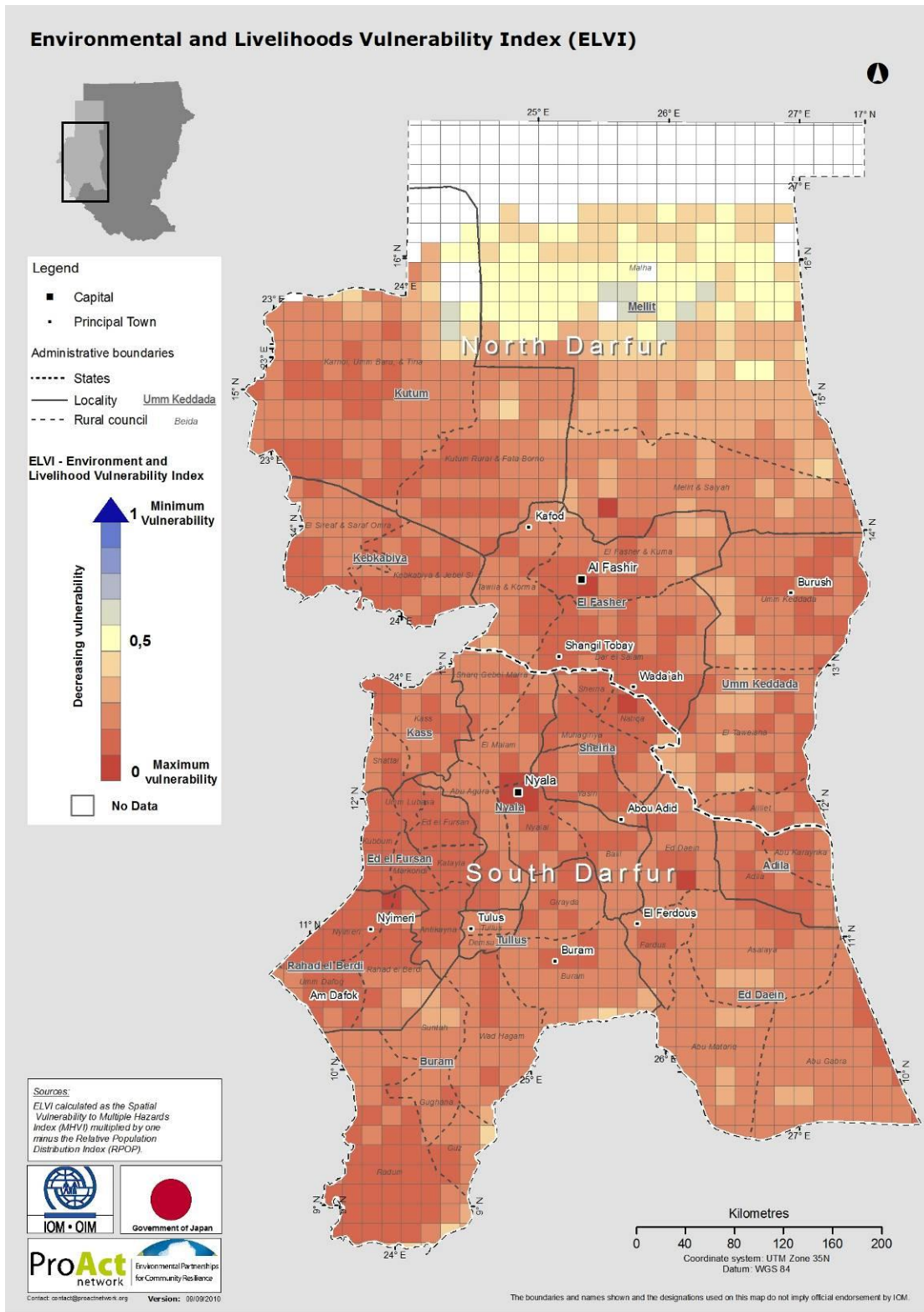
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<sup>28</sup> The Relative Population Distribution Index (RPOP) is defined as the natural logarithm of the normalised population of the grid cell + 1. The relative population of North and South Darfur present at each grid is presented in Figure 45.

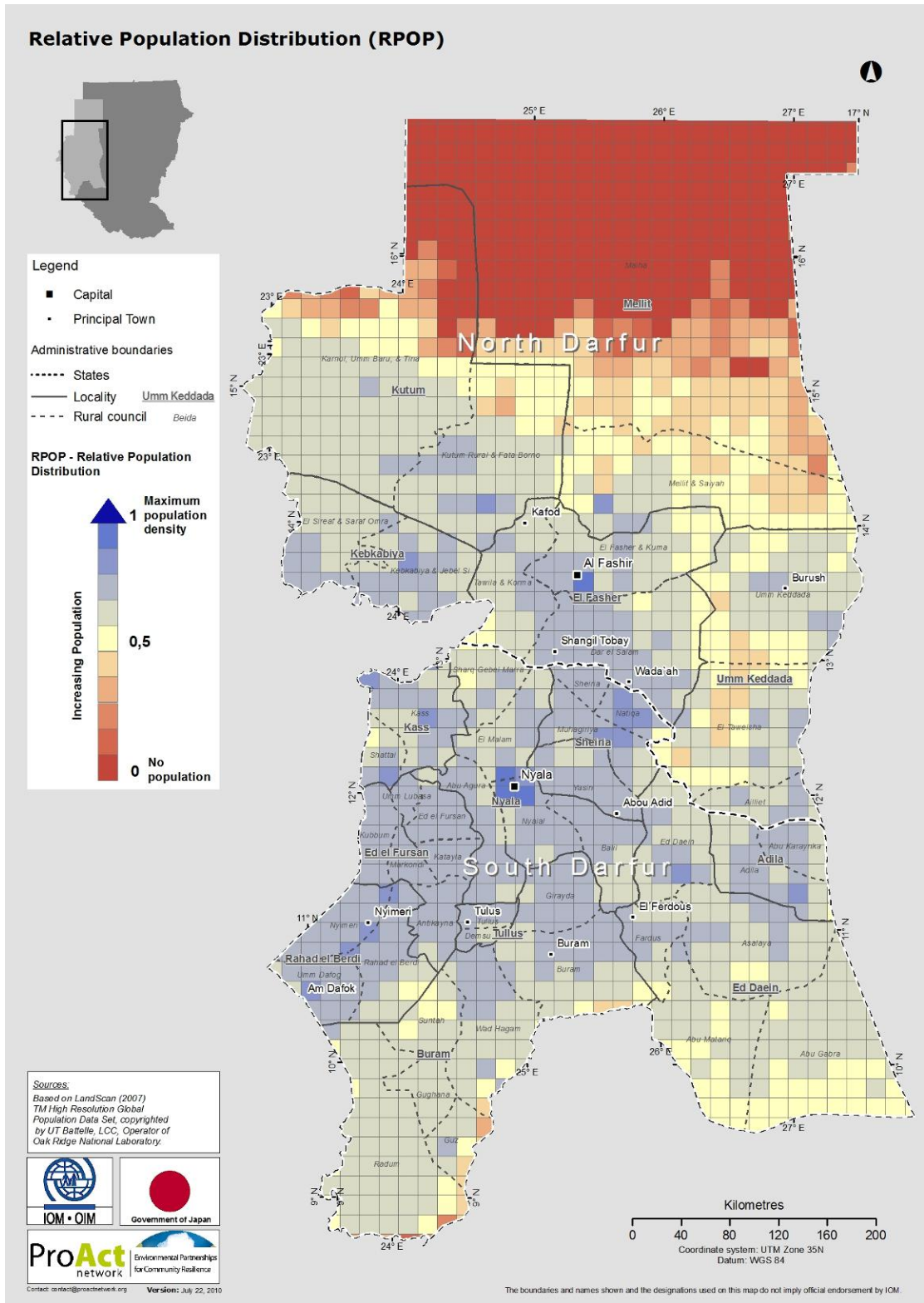


$$\text{ELVI} = \text{MHVI} \times 1\text{-RPOP}$$

**Figure 43.** Construction of the Environmental and Livelihoods Vulnerability Index (ELVI)



**Figure 44. Environmental and Livelihoods Vulnerability Index (ELVI).**



**Figure 45.** Relative population distribution in study area.

## 4.5. Graphical Presentation of the ELVI and MHVI

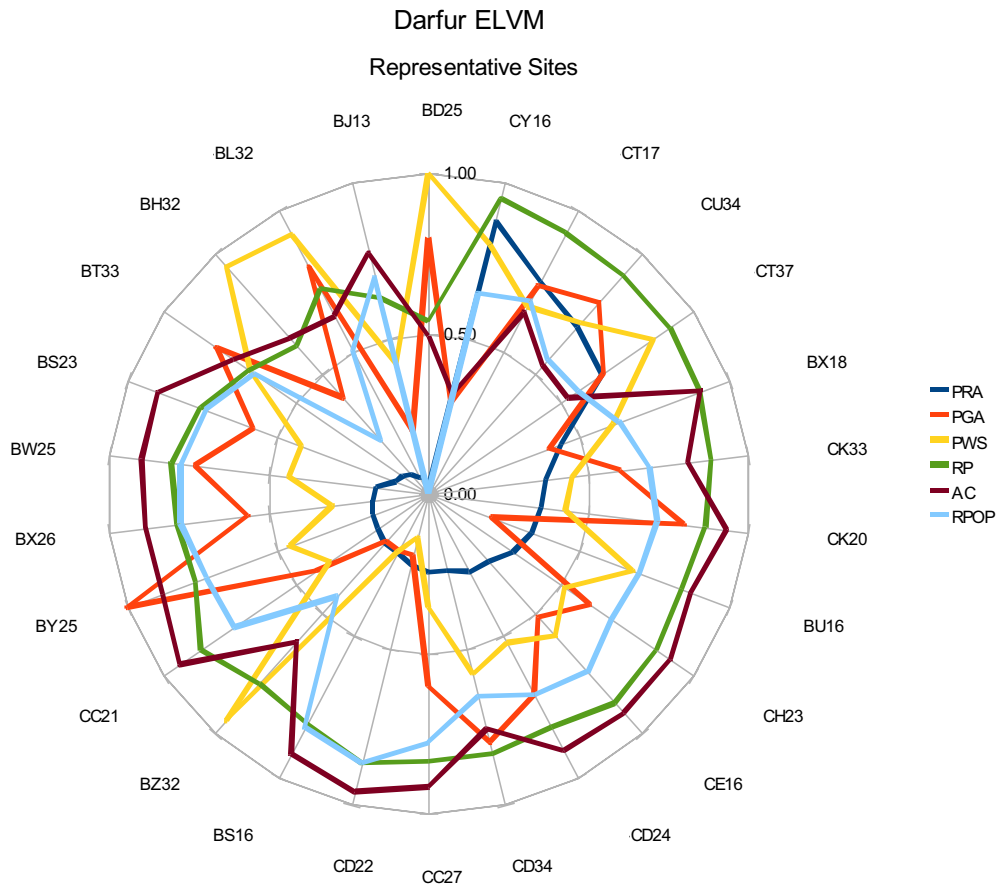
To understand the drivers of vulnerability at each 16 km x 16 km grid cell in the study area, the values of the components of vulnerability included in the MHVI and ELVI indices can be plotted along independent axis in radar charts – vulnerability diagrams – (see examples in Section 6). These types of diagrams have been used before to depict vulnerability (e.g. Downing *et al.* 2003).

A selection of representative sites for each of the water availability strata described in section 4 (16km x 16km grid cells marked in Figure 63), are represented by axes arranged as radial spokes in Figure 46, which allows for comparing the drivers of vulnerability at these sites. Here the values of the ELVI components for each sample site are presented on a scale of 0 to 1, with low values representing hazardous conditions and higher values (closer to 1) representing suitable conditions for livelihoods. The representative sites are ordered by rainfall where the increasing blue rainfall values spiral out from the centre of the plot in an anti-clockwise direction. For example, site BS 16 has low rainfall and groundwater potential, a bad woodfuel deficit, a high population and high adaptive capacity. Conversely, site CY 16 has high rainfall, moderate groundwater potential, moderate population a low woodfuel deficit and a stable climate.

The indices plotted on the diagrams are as follows:

- Potential Rainfall Water Availability (PRA)
- Potential Groundwater Availability (PGA)
- Relative Population Distribution (RPOP)
- Rainfall Predictability (RP)
- Potential Woodfuel Sufficiency (PWS)
- Adaptive Capacity (AC).

Since numerical values for each of these components are provided in Annex 10.4, vulnerability diagrams can be individually created for each 16km x 16km grid cell in the study area.



**Figure 46.** Vulnerability diagram for selected representative sites in North and South Darfur.

Each of the above sites can also be represented on site-based vulnerability diagrams. Four contrasting sites have been selected for a more complete description: BJ 13, CD 22, CC 27 and CT 17 and are discussed in Section 6.

#### 4.6 Notes on Data Quality and Chronology

One of the key challenges posed in developing an ELVM framework for a study area covering approximately 454,978km<sup>2</sup>, is the quality and coverage of the available data. Inevitably the different data sets used in the framework differ in terms of their completeness, precision, accuracy, consistency and currency. In order to achieve full coverage across North and South Darfur the project had to rely on data sets that were available for this full area, in some cases ignoring relevant data sets that were more complete or accurate, but which were only available for much smaller geographic units. In other cases better quality data was known to exist but it was not possible to obtain – for a variety of reasons – in the timeframe of the project, for example the recent population census would have been the most updated source of population data, but it was inaccessible to the project. In other instances there were pockets of comparatively high quality data that existed for certain areas, such as that

produced by IOM in its reports on rural councils (e.g. IOM, 2009), but this data was not representative for the entire study area.

An additional challenge related to the scale and latitudinal extent of North and South Darfur was the range of eco climatic zones within the study area. Integrating total water availability (i.e. a combination of potential rainfall and groundwater resources) reveals that at least 22 different zones (see Figure 20) exist within the study area. The wide variety of eco-climatic zones, as well as the disruption to traditional natural resource-based livelihoods and displacement – resulting in both localised concentration and depopulation of areas – caused by the conflict exacerbated the difficulties of using localised data sets as representative or indicative of other areas in Darfur

In light of the above constraints the project tried to use the best data available for its analytical purposes. However, the quality of the data used in the ELVM framework remains very variable and these variances are outlined below.

NOAA NDVI images were used as a rainfall proxy from 1982 to 2006 and SPOT VGT data were used up until 2009. This is an *inconsistency* in the NDVI data series. However, a more consistent data set is not thought to be available.

Meteorological information was obtained for the entire period of the NOAA data but it was generally unusable after 1993 because of incomplete reporting. This is a lack of *completeness* in the meteorological data.

Village locations were used from the IMWG UNDP project, but these suffered from imprecision of location with some villages being located correctly while others not. Some villages are recorded in multiple places and with slightly different names. Other villages are missing. This is a lack of precision, completeness and accuracy. Location errors were also noted in the geographical coordinates for villages noted by IOM field teams. These errors extend to the data as recorded in the UNDP TRMA project, which in turn incorporates the inaccuracies inherited from the UN-OCHA/ HIC datasets. These errors were readily apparent when comparing the various satellite images, in particular the 2009-2010 DCM imagery covering the entire study area project, high resolution images obtained from Google Earth® and SPOT images obtained by the project through the Planet Action Initiative.

Land cover data from the Africover project were used but this dataset is approximately 10 years old and will in places be out of date. This is a lack of data *currency*.

Hydrogeology data have been used from three different sources with slightly different legends and from different dates. This is a lack of *consistency*, although not currency, because the hydrogeology has not significantly changed.

Population census data were not available to the project and instead commercially obtained population data were used from the LandScan modelled population data source dated 2007. In turn, this dataset is based on imprecise data inputs and in places has significant data

artefacts. Further, its complete data sources are not known. This is a lack of *completeness, precision, accuracy, consistency and currency*.

In almost all respects the data quality therefore can be improved. The NDVI data used by the project is perhaps the most consistent data set utilised.

The Landsat imagery used was for numerous dates, circa 2000, representing an inconsistency in data currency.

In terms of the cumulative impacts of inaccurate or incomplete data those 16km x 16km grid cells that fall in the extreme northern portion of the study area (North of approximately 16.5 °N) are affected by data gaps in the interannual rainfall variability and groundwater availability, as well as subsequent analyses which rely on these data. In all ELVM maps those grid cells where there are data problems have been recorded in white. Annex 10.4, includes the numerical values for the six components of the ELVM Framework for all 16km x 16km grid cells for which complete data sets are available.

The nine DMC-2 images are entirely consistent apart from variations in look direction from image to image and a very slight difference in acquisition dates. The DMC-2 imagery was acquired with a view to a potential contemporary base mapping and land cover mapping, since it provides contemporaneous and contiguous coverage of the study area. The DMC imagery has played a key role in the analysis and comparison of different image sets and has been used throughout the project as a visual indicator of land cover, land use, landscape morphology and as a reference for other data sets, for example village locations. However, the imagery was not directly used for land cover mapping because the FAO Africover map became available during the project which enabled the WISDOM methodology to be rapidly developed and adapted to the project's purposes. Additionally, insufficient time and resources prevented the project to process the DMC imagery in accordance with the Africover land cover classes. The DMC image mosaic remains a very consistent and up-to-date source of data that would, with further time available, provide much additional information of interest. It also provides an extremely solid foundation for IOM's GIS Unit or other users to undertake further spatial analysis in North and South Darfur.

Many of the above-mentioned data quality problems are not new in Darfur although it is perhaps surprising that some of the problems – such as lack of accuracy of village locations recorded by GPS – persist.

One of the implications of the above variances in data sources used in the ELVM Framework is that there can be no single answer to the question “what is the date of the vulnerabilities estimates?”

Table 5 below presents the chronological range of the main components in the ELVM Framework.

Rainfall water availability	Derived from NDVI analysed from NOAA Dataset 1982 – 2006. Potentially this could be extended to 2009 if SPOT VGT data were used but there are difficulties in splicing the data sets together. The NDVI rainfall equivalent data was calibrated with rainfall statistics from meteorological stations available for 1982-1994.
Rainfall predictability	Calculated as the co-efficient of variation of the above NDVI 1982-2006 dataset.
Groundwater availability	These data are not very near-time dependent but the coverage for the entire study area was obtained from sources dated 1970, 1978 and 1988.
Woodfuel sufficiency	Known dates include those associated with the population estimate (see below) and the Africover Land cover dataset. However, two key components of the Wisdom model applied relate to assumptions of mean annual woody biomass increase and per capita woodfuel consumption. The validity of these assumptions has not been tested against the current situation in Darfur.
Population	The Oak Ridge National Laboratory LandScan population distribution product is dated 2007, but no metadata of the data inputs used in that estimate are known.
Adaptive capacity	Based on natural and physical asset data provided by the FAO Africover surface water layer and the IMWG CD-ROM, UNDP (compiled in 2009 but consisting of data collected at a wide variety of earlier dates).

**Table 5.** Chronological range of main ELVM components.

## **5. ELVM VALIDATION PROCEDURES**

### **5.1 FIELD VERIFICATION PROCESS**

As part of the ELVM and EPR projects, a field mission to North and South Darfur was conducted by ProAct Network between 18 January and 10 February 2010. This mission aimed to achieve the following three objectives. First, to obtain field level data to validate the ELVM model and calibrate recently acquired medium-resolution satellite imagery (DMC-2). The second objective was to support the EPR project by providing IOM staff initial training on tools and methods for community-based environmental management activities and by conducting rapid environmental assessments and interviews with community members at selected locations. These activities would then enable the team to identify suitable field sites to undertake the EPR work. The third objective was to test and improve environmental data collection methods, including field protocols designed for the ELVM and EPR projects, and amendments suggested to the environment and livelihoods form of IOM's PTP village assessments.

Despite security and logistical constraints which allowed only one ProAct team member to participate in the mission, all objectives were met. Baseline information on environmental and livelihood conditions was collected at Dar El Salaam and Donkey Shatta in North Darfur, and at Moraya Jangey and Baba in South Darfur. Four IOM staff received training on participatory approaches to community environmental management activities, which were then applied at two field sites.

Based on identified environmental issues and the level of the local community's commitment to resolve these, Baba was recommended as a potential site for the EPR project. After applying, testing and refining field questionnaires, an integrated field protocol that may be used for the ELVM and EPR projects was finalised. Finally, a tested and amended environment and livelihoods form was produced for IOM's PTP village assessments. The *Field Mission Report for the ELVM and EPR projects for the period 18 January - 10 February, 2010* by ProAct Network, details the development of the field mission and includes a narrative report of findings at each field site visited; this document also contains copies of the final questionnaires.

### **5.2 Satellite Imagery, Acquisition and Processing**

#### **5.2.1. Satellite Imagery Used in the Project**

The acquisition, processing and use of satellite imagery in the ELVM project are summarized in Table 6 and detailed below. Additional sources of geo-referenced and spatial data used in the project are presented in Annex 10.3.

<b>Sensor</b>	<b>Spatial resolution</b>	<b>Temporal resolution</b>	<b>Acquisition Window</b>	<b>Category</b>	<b>Main Information extracted</b>
<b>NOAA</b>	8 km	15 days	1982 - 2006	Low Resolution	NDVI , Rainfall
<b>SPOT VGT</b>	1 km	10 days	1998 - 2009	Low Resolution	NDVI, Rainfall
<b>Landsat</b>	15 - 80 m	Single date	1999 - 2002	Medium Resolution	Land cover classes
<b>DMC</b>	22 m	Single date	Dec 2009- Jan 2010	Medium Resolution	Land cover classes and terrain features
<b>GoogleEarth</b>	61 cm to 2,5 m	Multi date	2000 - 2010	High Resolution	Objects: Assets
<b>QuickBird</b>	61 cm	Single date		High resolution	Objects: Assets

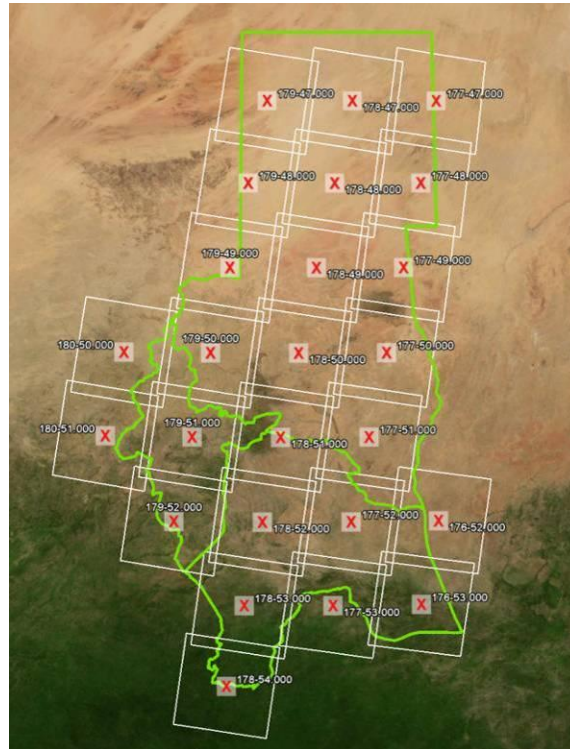
**Table 6.** Satellite imagery used during the project

#### **Landsat Mosaic**

Since 1972, Landsat satellites have been routinely acquiring images of Earth. These images are freely available from public websites<sup>29</sup>. The Landsat scenes are presented in paths and rows; a unique path and row combination exists for each scene covering a specific area of the Earth's surface. Darfur is covered with approximately 25 scenes, corresponding to 25 Paths and Rows (See Figure 47).

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<sup>29</sup> Landsat imagery may be acquired from: U.S. Geological Survey, Global Visualization Viewer (GLOVIS) (<http://glovis.usgs.gov/>).



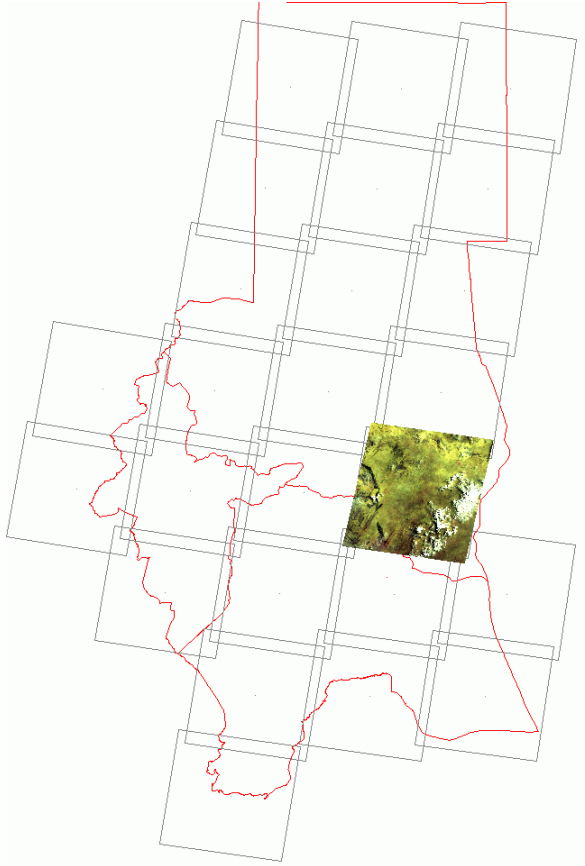
**Figure 47.** Landsat coverage of Darfur.

For this project, a natural colour composite has been produced using a set of 13 Landsat scenes acquired between 1999 and 2002. Scenes have been merged using linear regression analysis to achieve quasi-seamless junctions. Where the radiometry difference was visible, an artificial mask line was drawn across the overlay area between the adjacent scenes.

The resulting mosaic was used as a reference baseline for the project and as an insurance against delays in acquiring the DMC imagery ahead of the field verification mission.

Its main uses were:

- Field mission planning and logistics: a set of space maps were produced for the field mission.
- Historical reference baseline: to detect changes between the current DMC imagery and the historical baseline provided by Landsat.
- Quality control of the land cover datasets (Africover and Globcover).



**Figure 48.** Landsat scene used in the historical data study.

#### **Landsat coverage study**

In parallel, a Landsat coverage analysis was undertaken in order to assess the possibilities of using Landsat for NDVI analysis. For that purpose, only one Landsat Path and Row was studied (See Figure 48), which involved the study of 91 images, acquired since 1972:

- 18 by the MSS instrument (on board Landsat 1 to Landsat 4)
- 9 by the TM instruments (on Board Landsat 5)
- 64 by the ETM+ instrument (on board Landsat-7).

#### **DMC imagery**

DMC scenes were acquired between December 2009 and January 2010. All scenes were processed and merged using a linear regression analysis to create a Mosaic. When the radiometry difference was too visible, an artificial mask line was drawn across the overlay area between the adjacent scenes (see Figure 49).

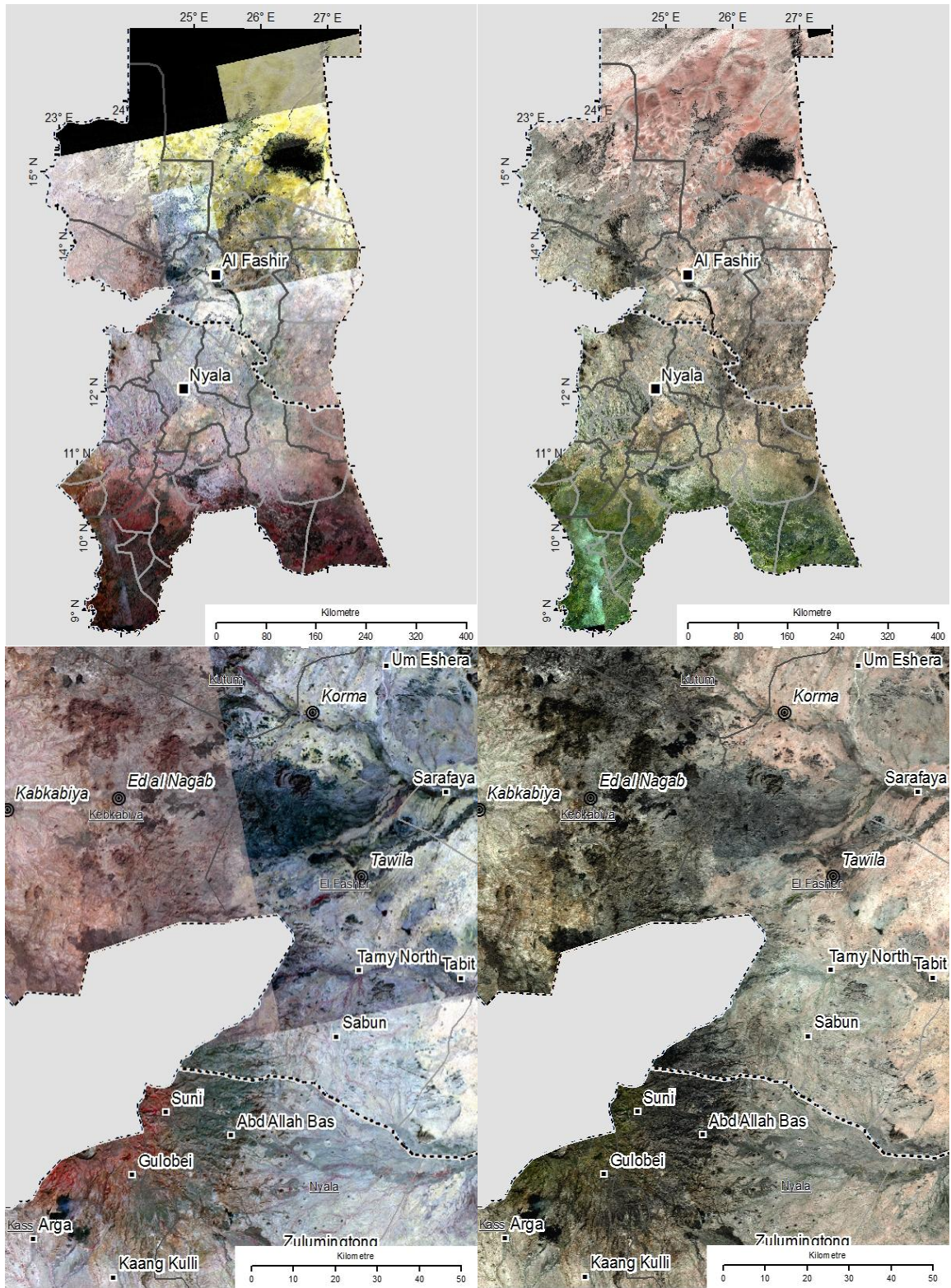


Figure 49. DMC imagery merging process.

### Very High Resolution Imagery- Google Earth®

GoogleEarth® (GE) is a virtual globe, map and geographic information program. It maps the earth by overlaying images obtained from satellite imagery and aerial photography and has been widely used during the project, primarily as a source of freely available Very High Resolution Imagery. GE was also used to process change detection analysis over time on some specific areas as well as visualizing geo-referenced photos taken during the IOM/ ProAct Field Mission (see Figure 50 for GE coverage of Darfur).

Darfur is particularly well covered with very high resolution imagery. In Figure 51, the brighter areas are covered with very high resolution imagery. Until recently the areas that were not covered with high resolution imagery were covered with Landsat imagery. Recently, these have been replaced by a Spot mosaic at 2.5 m spatial resolution. (1 pixel = 2.5 m).

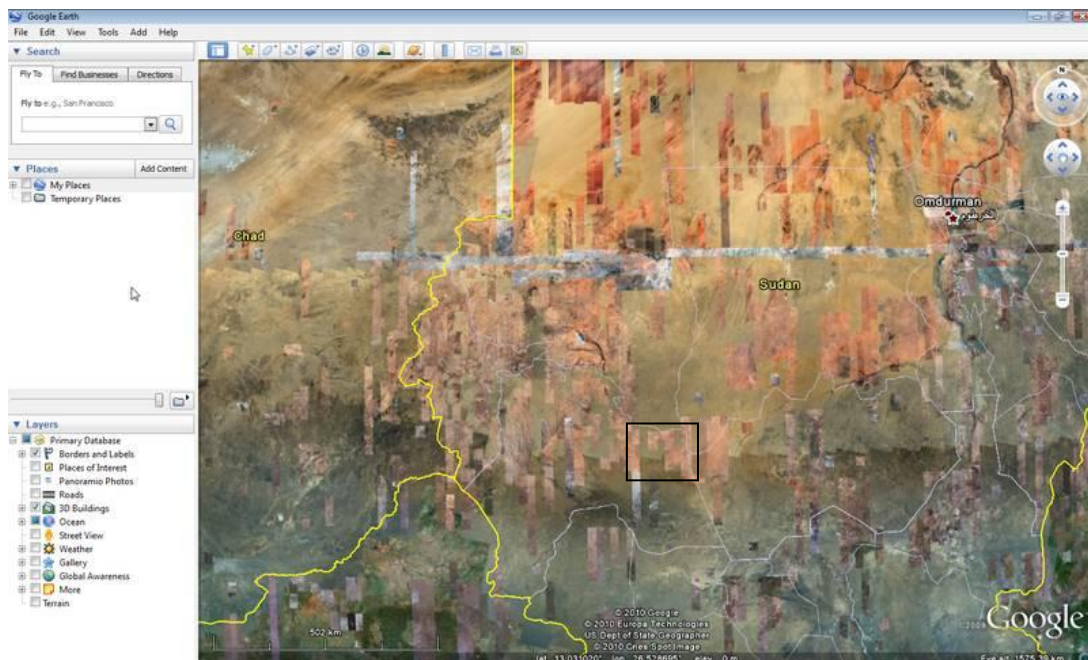
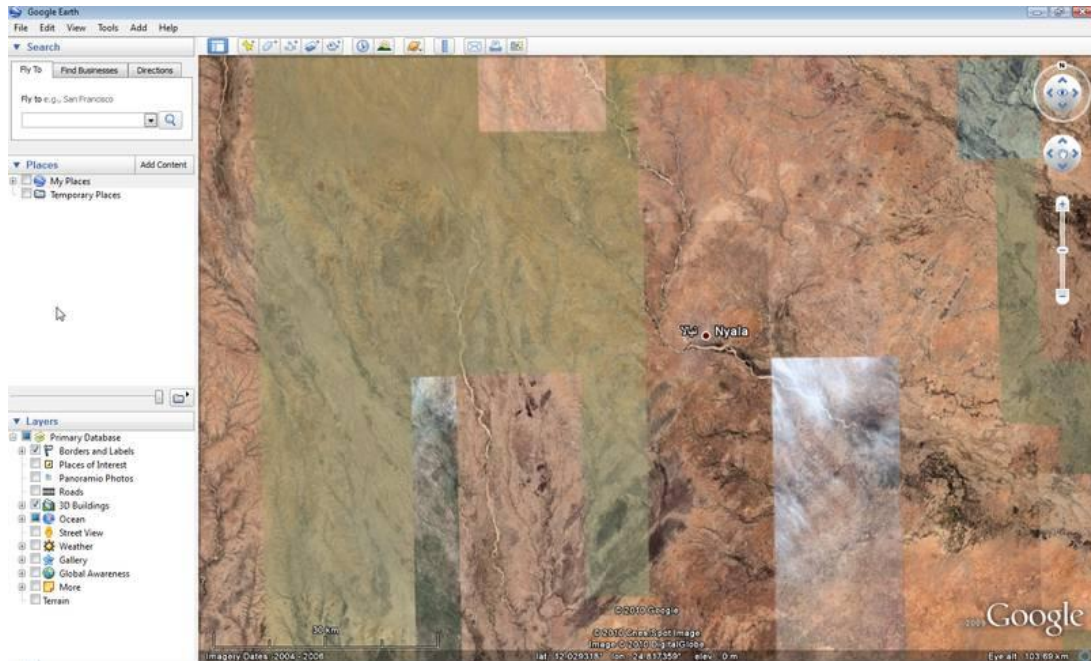


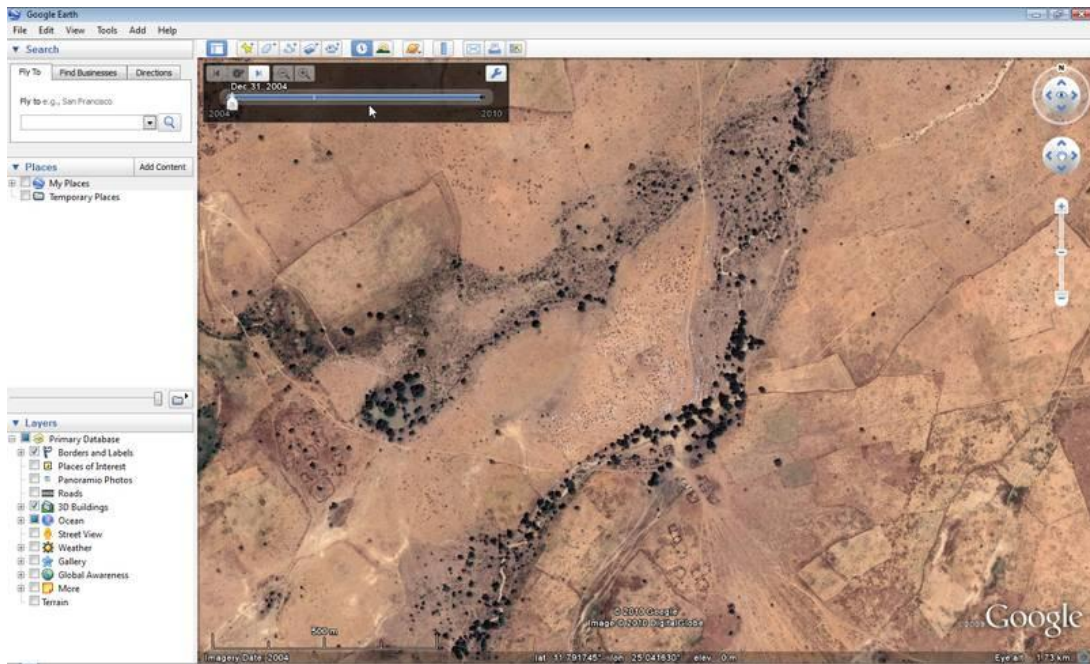
Figure 50. Google Earth® coverage of Darfur.



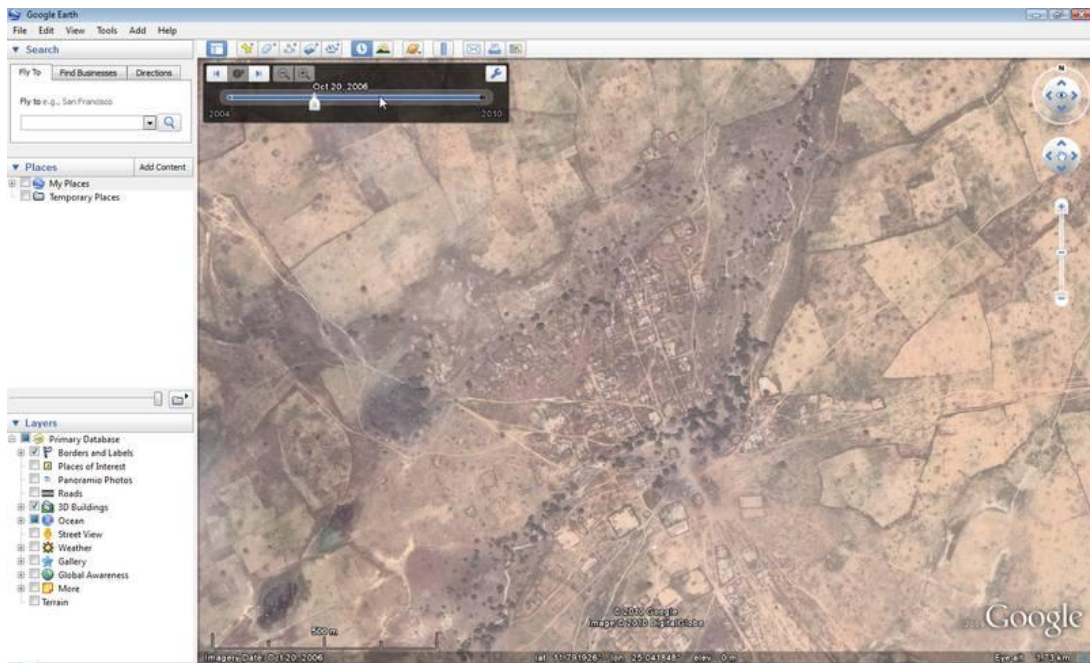
**Figure 51.** Heterogeneity of overlaid images in Google Earth's© coverage of Darfur.

### **Multi-temporal analysis**

In 2009, Google gave access to historical imagery. It is hence possible to access historical imagery for some areas, as demonstrated in the example below. Figure 52 and Figure 53 show land cover changes between December 2004 and October 2006 in a specific site of South Darfur. From these images, it is possible to infer that between 2004 and 2006, temporary tents installed for displaced persons were replaced by new traditional houses (see Figure 54 and Figure 55).



**Figure 52.** Representative area in South Darfur (Image acquired in December 2004).



**Figure 53.** Representative area in South Darfur (Image acquired in October 2006).



**Figure 54.** Temporary tents are clearly visible in December 2004.



**Figure 55.** In October 2006, traditional houses have replaced the temporary tents.

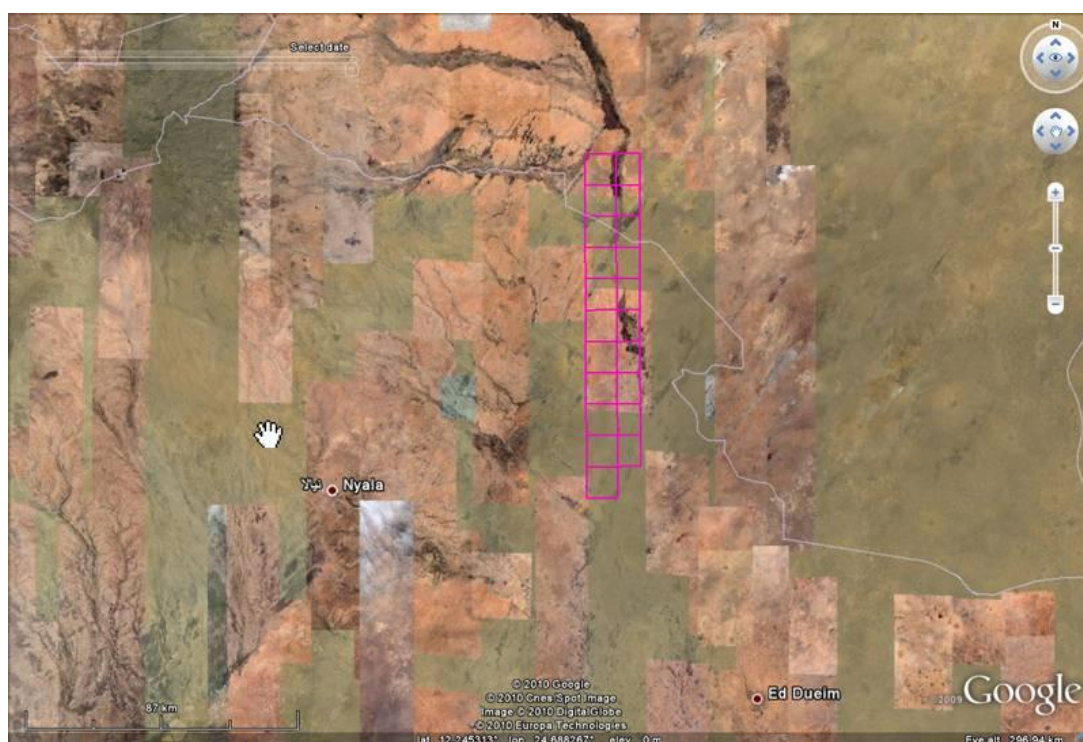
## Photo-Interpretation Key Manual

All the useful information extracted from GoogleEarth imagery during the project was assembled into a Photo-Interpretation Key Manual (PIK Manual). This document is a compilation of detected and clearly identified features which can provide important information on areas of interest and be used at various stages of a humanitarian operation. The interpretation key identifies features such as different levels and types of agricultural activity (e.g. dry land, *wadi* bank or terrace agriculture,) livestock enclosures, forests and plantations, water bodies (permanent water sources, wells, boreholes, oases, land use and settlement patterns. It provides easier analysis of imagery from anywhere within the study area.

## Planet Action

Planet Action is a non-profit initiative launched in 2007 which supports climate change-related projects led by organizations (including NGOs), government and academic institutions in partnership with local organizations. Planet Action shares its remote sensing analysis capacity and donates images from satellites such as the SPOT constellation, Formosat2, Komsat2, and Quickbird, as well as providing processing tools to extract and interpret the data.

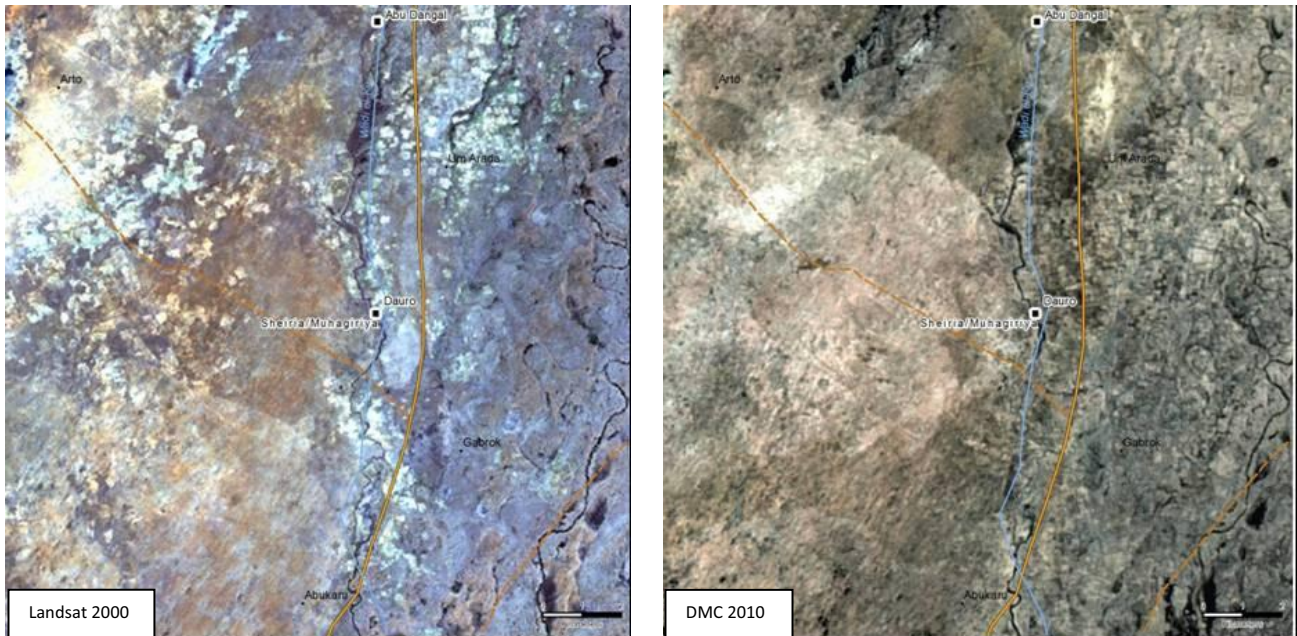
Planet Action provided the project with 21 QuickBird images acquired in 2009 as shown in violet on Figure 56. However, the images were received too late in the project timeframe to allow for a full analysis, therefore only one image was used to analyse an identified IOM priority return site, Um Arada.



**Figure 56.** Footprint of satellite images Planet Action provided to the ELVM project.

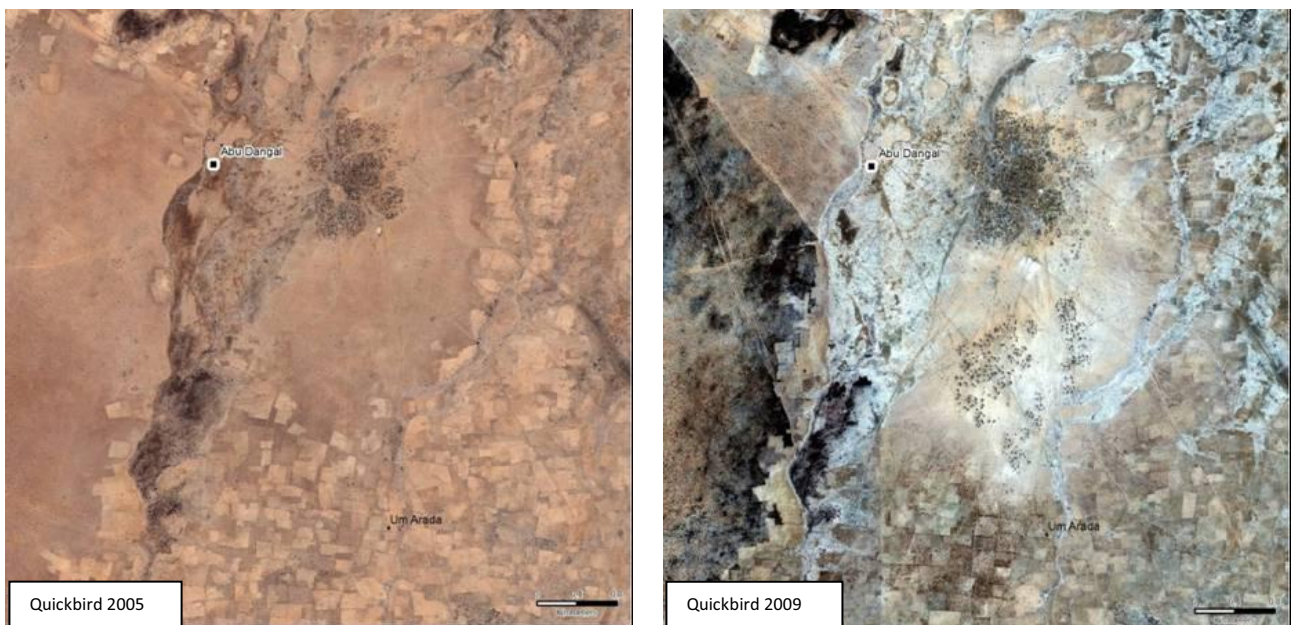
### Use of High Resolution imagery

The following illustrations (Figure 57 to Figure 61) exemplify how high resolution imagery can provide detailed information at selected locations. The examples below are an analysis of spatial changes in a 16x16 km grid cell which includes the IOM Priority site of Um Arada.



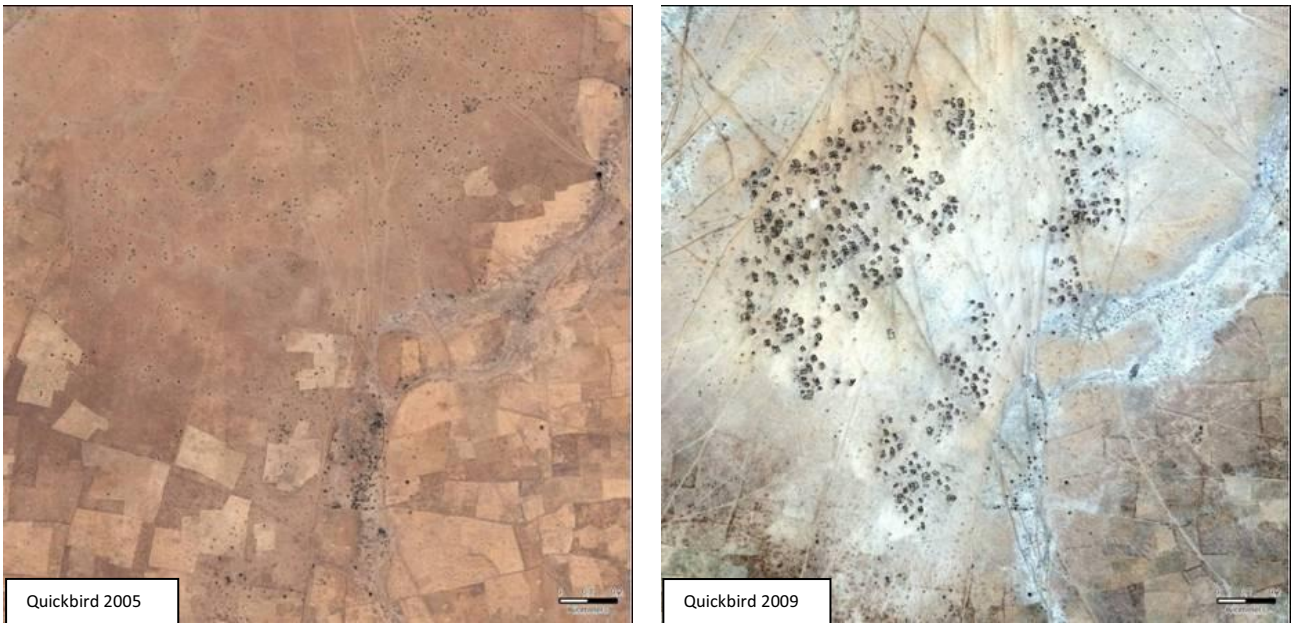
**Figure 57.** Comparison of Landsat 2000 (left) and DMC 2010 (right) imagery.

Over a 10 year period, changes have occurred in landscape patterns, including changes in agricultural patterns in the west.



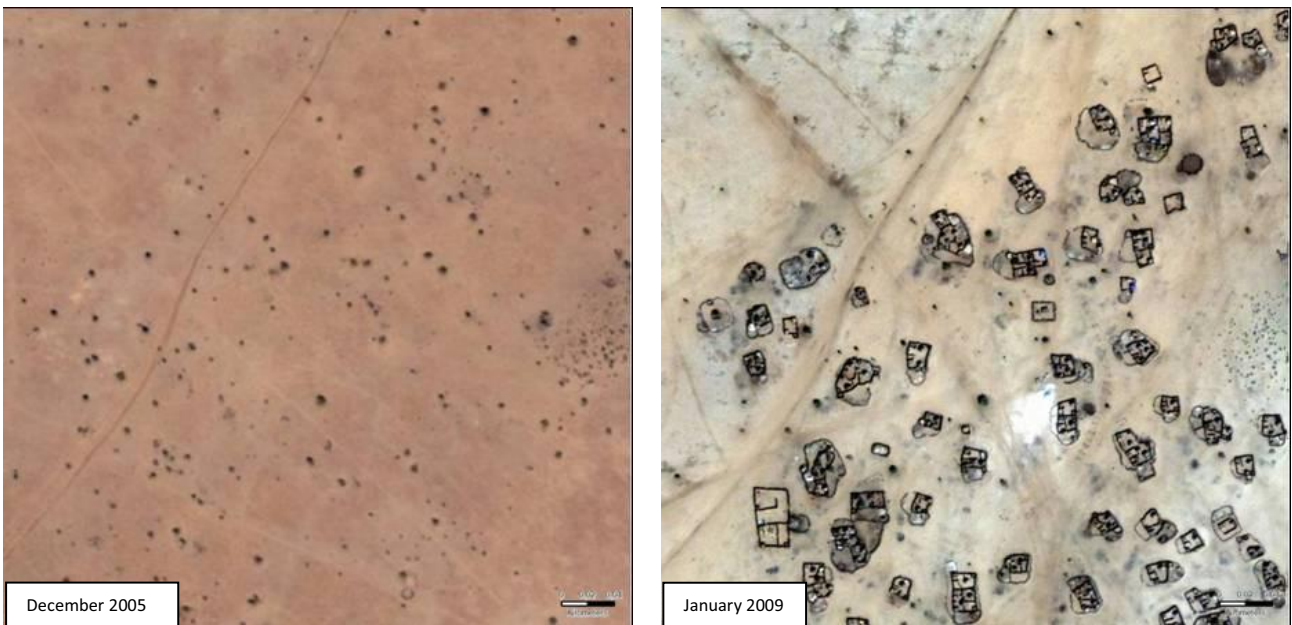
**Figure 58.** Comparison of QuickBird images: December 2005 - January 2009.

These 7x7 km extracts cover exactly the same area as the previous figures. Here, using higher resolution imagery, new settlements are apparent in the south of Abu Dangai village, explaining the changes in agricultural patterns.



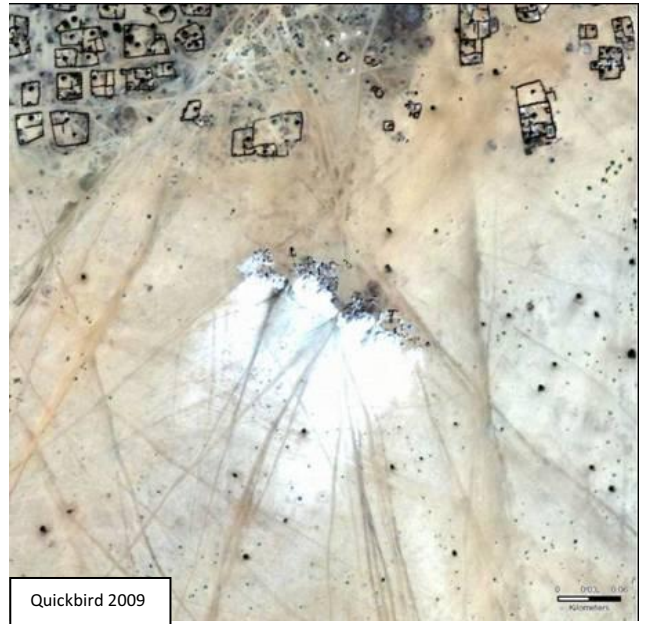
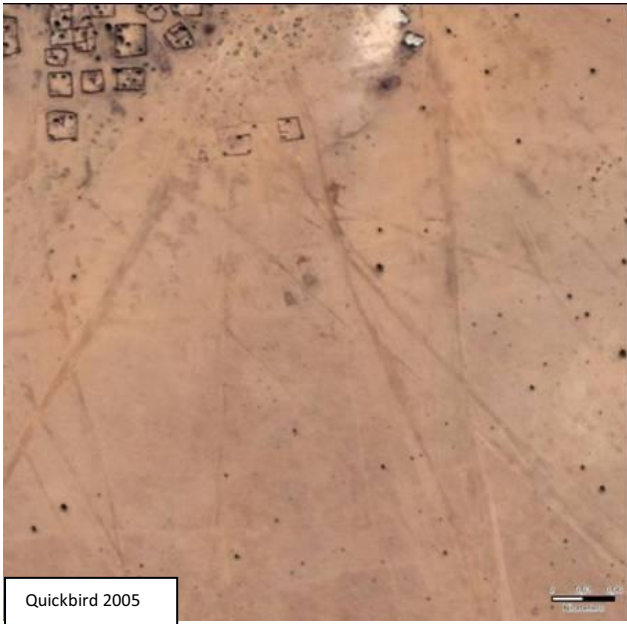
**Figure 59.** Comparison of Quickbird images: December 2005 - January 2009.

In 2009 there were approximately 300 new houses compared to 2005.



**Figure 60.** Comparison of Quickbird images: December 2005 - January 2009.

This detail zoom shows clearly the changes occurring over a 4 year period at the same location. Physical infrastructure has increased – In 2005 one track is apparent, whereas in 2009 there are several new roads and tracks as well as houses.

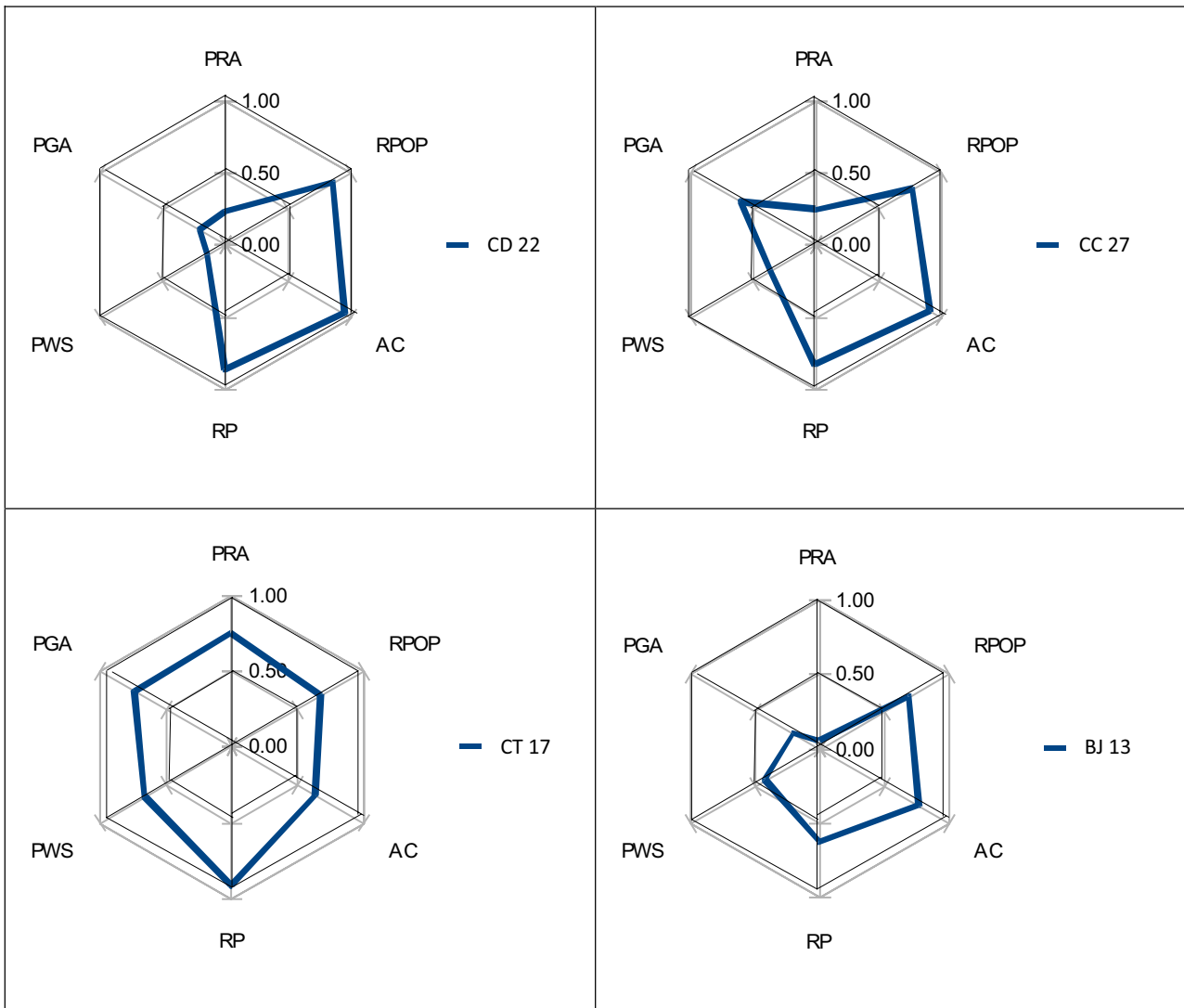


**Figure 61.** Comparison of Quickbird images: December 2005 - January 2009.

The main change in these images is the appearance of a dumping site to the Southern edge of the settlement in 2009.

## 6. REPRESENTATIVE APPLICATIONS OF THE ELVM FRAMEWORK

As noted in Section 4.5, four 16km x 16km grid cells have been selected to provide comparative illustrations of the different components of vulnerability. As the 16km x 16km grid cells all occupy different water availability strata their vulnerability diagrams are quite distinct. The location of the four sites below, as well of the other representative sites noted in Section 4.5 can be found in Figure 63.



**Figure 62.** Vulnerability diagrams for four sites of contrasting environmental conditions across North and South Darfur.

These plots (Figure 62) are of four diverse water availability classes. In the diagrams, the individual indices are the radial spokes and each representative site has its own diagram. Again, the centre of the diagram represents low index values which – with the exception of population, expressed with the RPOP index – represent poor conditions. The edge of the plot (1.00) represents the best conditions for each of the indices. For example, for the 16km x 16km grid cell CD 22 (Baba) the Potential Ground Water Availability (PGA) is low and so are the Potential Rainfall Availability (PRA) and the Potential Woodfuel Sufficiency (PWS);

Rainfall Predictability (RP) is high and so is the Adaptive Capacity (AC). Relative Population Distribution (RPOP) is also high. A simple interpretation of this information permits an assessment of appropriate interventions for returnees.

Ground water potential is low because the site is on the Basement Complex so boreholes are inappropriate but wells into fracture zones or alluvium may be appropriate. The low groundwater potential is a function of the impervious rocks which, in turn, imply high surface run-off and rapid recharge of localised alluvial aquifers. The Potential Woodfuel Sufficiency (PWS) is low whilst Relative Population Distribution (RPOP) is high – implying a high demand for woodfuel. Adaptive Capacity (AC) is high.

Suitable interventions to support the returns process at site CD 22 may include protecting existing woodfuel resources and strengthening new ones, using surface water run-off for agriculture and forestry and identifying localised aquifers.

Site CC 27 is relatively close (80km) to CD 22 and has very similar characteristics in terms of Potential Rainfall Availability, Relative Population, Adaptive Capacity, Rainfall Predictability and Potential Woodfuel Sufficiency. However, it differs by being located on different subsurface geology and its Potential Groundwater Availability is higher than site CD 22. At site CC 27 ground water potential is moderately high because it is located on Nubian Sandstone. Surface water is therefore likely to be limited because of high infiltration rates with little surface runoff, but ground water may be available given access to a deep borehole.

Suitable interventions to support the returns process at site CC 27 may include protecting existing woodfuel resources and strengthening new ones, identifying if borehole is required for the extraction of ground water.

In contrast site CT 17 has moderate Relative Population Distribution; moderate Adaptive Capacity; good Potential Woodfuel Sufficiency; good Potential Groundwater Availability and Potential Rainfall Availability and Predictability. However the site has only moderate Relative Population Distribution and Adaptive Capacity. At this site water is not in short supply from either groundwater or rainfall and the major limiting factor to livelihoods is Adaptive Capacity.

Suitable interventions to support the returns process at site CT 17 may include protecting existing woodfuel and water resources and identifying suitable adaptive capacity requirements of the communities such as health and veterinary support services and education.

Lastly, site BJ 13 is located in the North West and has low Potential Rainfall and Groundwater Availability, moderate Potential Woodfuel Sufficiency, low Rainfall Predictability and moderate Adaptive Capacity. At this site water is a limiting factor from both rainfall and groundwater sources, so rainwater concentrating techniques and localised

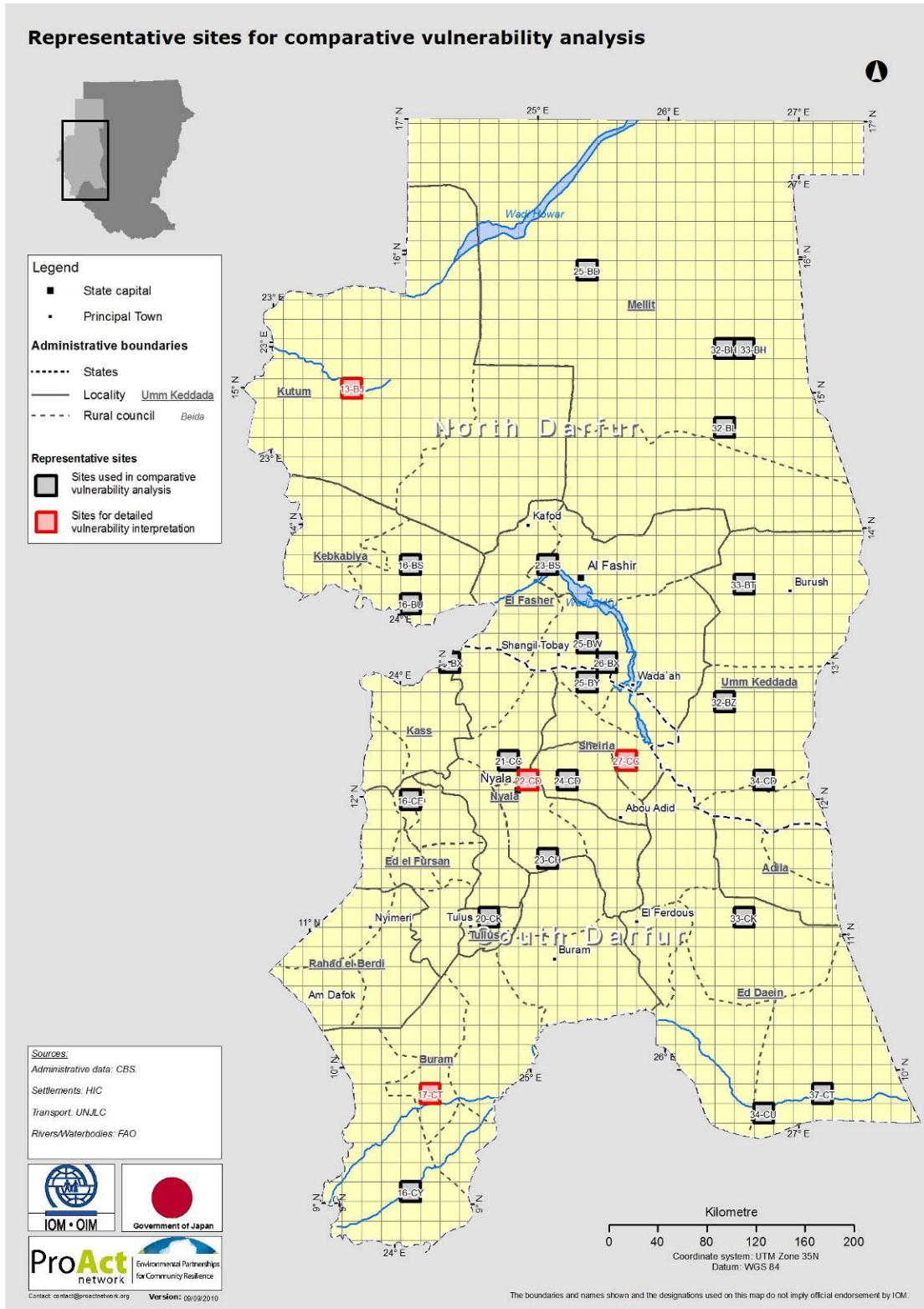
aquifers in fracture zones are likely to be important. These limiting environmental factors are offset by moderately high Adaptive Capacity.

Suitable interventions to support the returns process at site BJ 13 may include protecting existing woodfuel resources and strengthening new ones, identifying localised aquifers in fracture zones which can be exploited, strengthening water concentration techniques for rainwater harvesting, developing adaptive capacity.

If additional hazards or components of adaptive capacity need to be added then these can be accommodated by adding additional spokes to the diagram, for example suitability for cultivation of particular crops or livestock stocking rates.

It should be noted that the above vulnerability diagrams can be generated for every 16km x 16km grid cell across North and South Darfur. This allows:

- rapid, non-technical assessments of environmental and livelihood vulnerability;
- a readily understandable representation of the drivers of vulnerability at any location (in a 16km x 16km grid cell) across North and South Darfur;
- comparative evaluations to be made of vulnerability at different locations;
- possible identification of potential appropriate interventions at the community level;
- improvements to be made to the levels of spatial environmental and livelihood information available to IOM, the Government of Sudan and other actors on which to base future decisions; and
- for IOM in particular, the framework provides environmental and livelihood information to assist in planning interventions to support returning communities.



**Figure 63.** Representative sites across the study area.

## 7. FURTHER APPLICATIONS OF DATA SOURCED AND PROCESSED IN THE ELVM PROJECT

### 7.1 CLASSIFICATION OF POTENTIAL LIVESTOCK PRODUCTION SYSTEMS

The ephemeral nature of livestock herding, the lack of contemporary data and the difficulty of conducting livestock surveys – especially during a time of conflict – means that it is impossible to get an up-to-date picture of livestock in Darfur. Livestock surveys have been undertaken in Darfur (Watson *et al.* 1977) but these will not reflect the current livestock situation given the disruption caused by the recent conflict. However, in the same way that the NDVI has been used in section 4 to create a potential water availability maps and eco-climatic zones, the same NDVI data have been used to create a livestock potential map based on the livestock eco-climatic zones presented by Simpkin (2005) see Table 7, Figure 64 and Figure 65.

Zone	Climate Type	Rainfall (mm/y)	Characteristic Vegetation	Potential Production System	Stocking Rate
I	Humid	>1,500	Rainforest	Only limited potential for livestock production, mainly forests	
II	Sub-humid	1,000 – 1,500	Dry forest or evergreen bush	Intensive milk and meat production with purebred exotic cattle, wool and mutton production with purebred exotic sheep; goat milk production	1 TLU/0.25 ha
III	Dry sub-humid	800 – 1,000	Deciduous bush or thin woodlands	Intensive ranching with crossbred and pure bred exotic cattle, also dairy ranching; wool and mutton production with purebred exotic sheep; goat milk production	1 TLU/1.25 ha
IV	Semi-arid	500 – 800	Deciduous thin woodlands	Extensive beef ranching with crossbred and indigenous cattle; meat production with crossbred and indigenous sheep and goats; goat milk production	1 TLU/2 ha
V	Arid	200 – 500	Deciduous thorn bush	Extensive ranching with indigenous cattle, sheep and goats; semi-sedentary pastoralism with cattle, sheep, goats and dromedaries	1 TLU/7.5 ha
VI	Very arid desert climate	< 200	Dwarf shrubs or halophytic species	Migratory subsistence pastoralism with cattle, sheep, goats, dromedaries; sale of immature cattle for fattening and sheep and goats for slaughter; sales of hides and skins	1TLU/20 ha

**Table 7.** Potential livestock production systems by eco-climatic zones. From Simpkin (2005). NB: TLU = Tropical Livestock Unit is equivalent to a 250kg animal or one cow, 6 goats or sheep, or 0.8 camels.

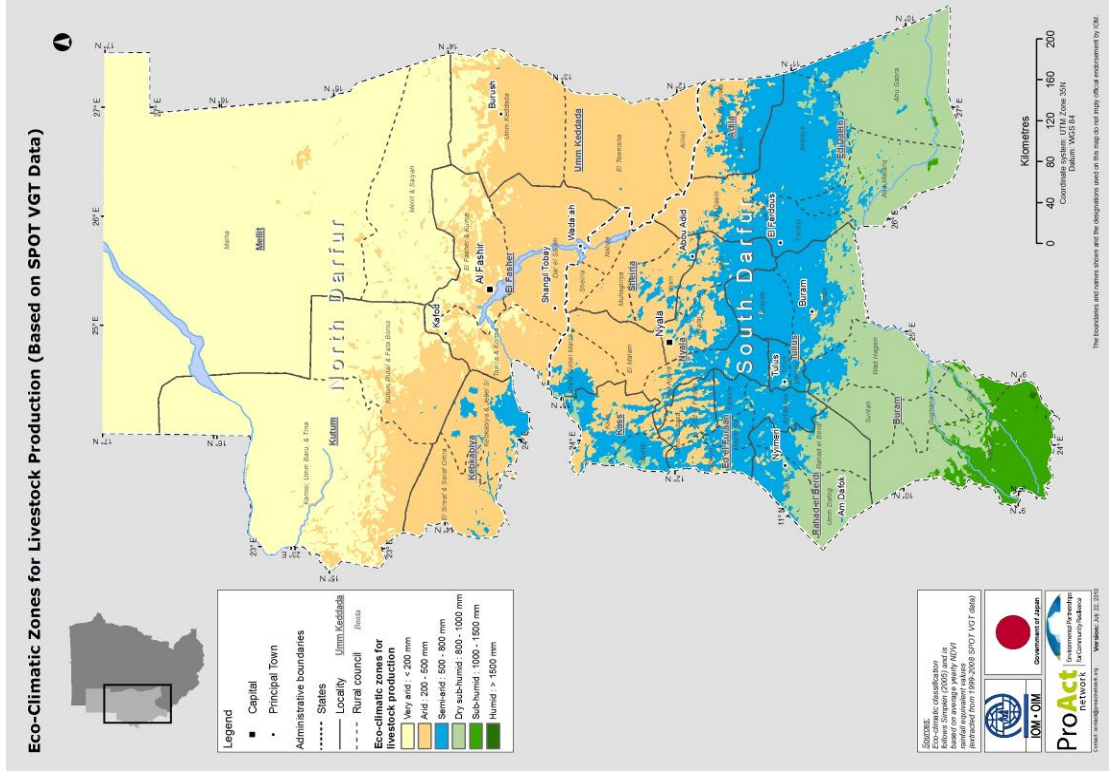


Figure 65. SPOT VGT derived eco-climatic zones for livestock production.

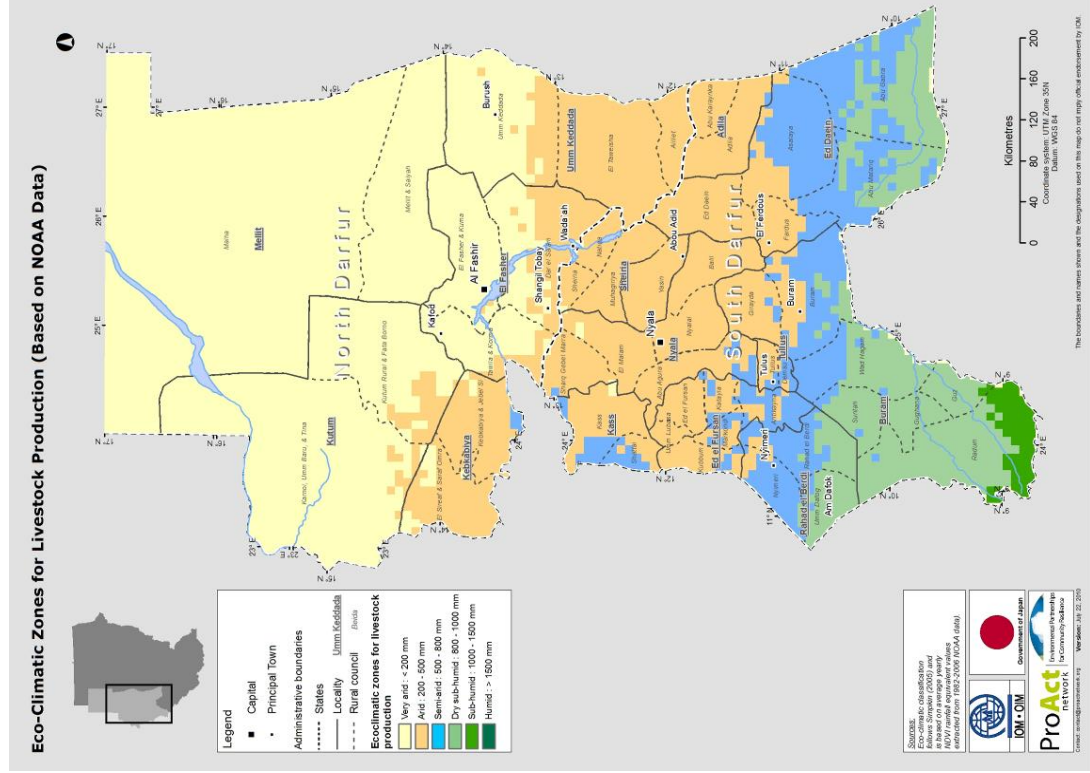


Figure 64. NOAA derived eco-climatic zones for livestock production.

A potential livestock map could readily be combined with the stocking rates in Table 7 to produce a map of livestock carrying capacity which, in turn, could be used to estimate the number of people who could be sustained by those stocking densities. This would need to take into account agricultural and non-agricultural areas and the balance of reliance on livestock as part of livelihood strategies. Extending the approach used for the woodfuel analysis, it should be possible to estimate the biomass available to livestock as fodder.

## **7.2. The Agronomic Dry Boundary: The Limits of Sustainable Millet Production**

Agriculture in Darfur is predominantly rainfed and agricultural systems are closely related not just to rainfall but also to the local terrain and soil conditions (HTS, 1995b; Elsiddig, 2007). Taking water availability as the primary limiting factor some authors have considered the northern limits of rainfed agriculture in Darfur (Ibrahim, 1978; HTS, 1994) and neighbouring Kordofan (Olsson, 1985b). However, defining an agricultural limit on a map is largely impractical because of the highly variable nature of rainfall. These authors instead have identified more practical approaches by identifying zones within which marginal and in particular millet, rainfed agriculture may be practiced.

Ibrahim (1978) uses the term “agronomic dry boundary” to identify the boundary beyond which agriculture should not be practiced in order to prevent the Darfur environment becoming degraded. He defines this as the meteorological boundary of eight arid months in the year and states that in Darfur this is approximately the same as the 600mm isohyet, adding that in Darfur rainfed millet farming actually occurs up to the 250mm isohyet. Ibrahim (1978) therefore considers rainfed cultivation on *qoz* soils in the zone between the 600mm and 250mm isohyets to be inherently unsustainable.

Ibrahim (1978) does not expand on the logic for this definition but it is presumably because more than 600mm (or more than four humid months) of rainfall provides sufficient vegetative material to enable the development of a sustainable humic soil horizon, which is otherwise lacking in the upper *qoz* profile but which does occur below 2m as a result of a formally more humid period (Parry and Wickens, 1981).

Olsson (1985b) notes that Ibrahim’s (1978) definition would exclude much of the existing *qoz* cultivation in Kordofan and suggests an alternative approach to calculate the probability of an area receiving, say, 300mm of annual rainfall to support millet production, although he does not offer a method to do this. The drought monitoring approach proposed by Abdel-Muttalib (1986) does offer the possibility of mapping rainfall probabilities, although in 1986 this would have been very labour intensive and is not thought to have been adopted, however the method is used for drought monitoring in Australia. HTS (1994) also used a 300mm threshold to calculate an annual rainfall probability map of Sudan with a view to identifying drought risk zones for rainfed agriculture.

These studies all focus on a 300mm annual rainfall threshold for rainfed farming at the desert margin and have identified the need to take into consideration the variability of rainfall and its probability.

Olsson (1985b) quotes Dancette and Hall (1979) who specify a minimum quantity of water for an adequate millet crop as being 80 per cent of the 300mm<sup>30</sup> water requirement of a well watered crop, i.e. 240mm, effectively the same as Ibrahim's (1978) 250mm threshold, assuming that in the northern areas of Darfur the growing season is very short and the rainfall received during this period is almost the same as the annual figure.

Taking the HTS/NDDU probability zones approach, JRC/SOAS (2001) extended the methodology to focus only on the crop growing season within the year rather than the annual figure – i.e. the effective rainfall for crop growth. Unfortunately time did not permit a growing season based approach to be adopted in this project.

Using the available NOAA data as a proxy for rainfall, a probability map of 250mm rainfall can be generated which indicates the probability of successfully growing a millet crop according to the above logic.

The procedure to produce these maps is quite simple. For each NDVI annual rainfall equivalent map between 1982 and 2006 an appropriate threshold (250mm) is applied to isolate those areas which exceed the threshold and those which do not. The 25 binary (more-than/less-than) maps are then added together to give a count of the number of years when the threshold was exceeded. From this map it is simple to calculate the probability of rainfall occurring at the threshold level. This type of map is different from an average rainfall map because it shows the full range of probabilities, not just the mean. So, assuming that 250mm of annual rainfall is required to grow a millet crop then the map shows the probability of achieving that objective. The map (Figure 66) shows where 250mm were achieved each and every year during the 25 year period – millet planting offers no risk – through all combinations down to where it was achieved in only one year out of 25 –where millet planting is a very risky activity.

In Figure 66, the dark blue in the south indicates that an equivalent of 250mm of rainfall occurs every year or 100 per cent of the time. Similarly, yellow indicates those areas where 250mm of rainfall occurs up to 20 per cent of the time. The 100 per cent probability boundary is roughly equivalent to the annual rainfall 350-500mm isohyet.

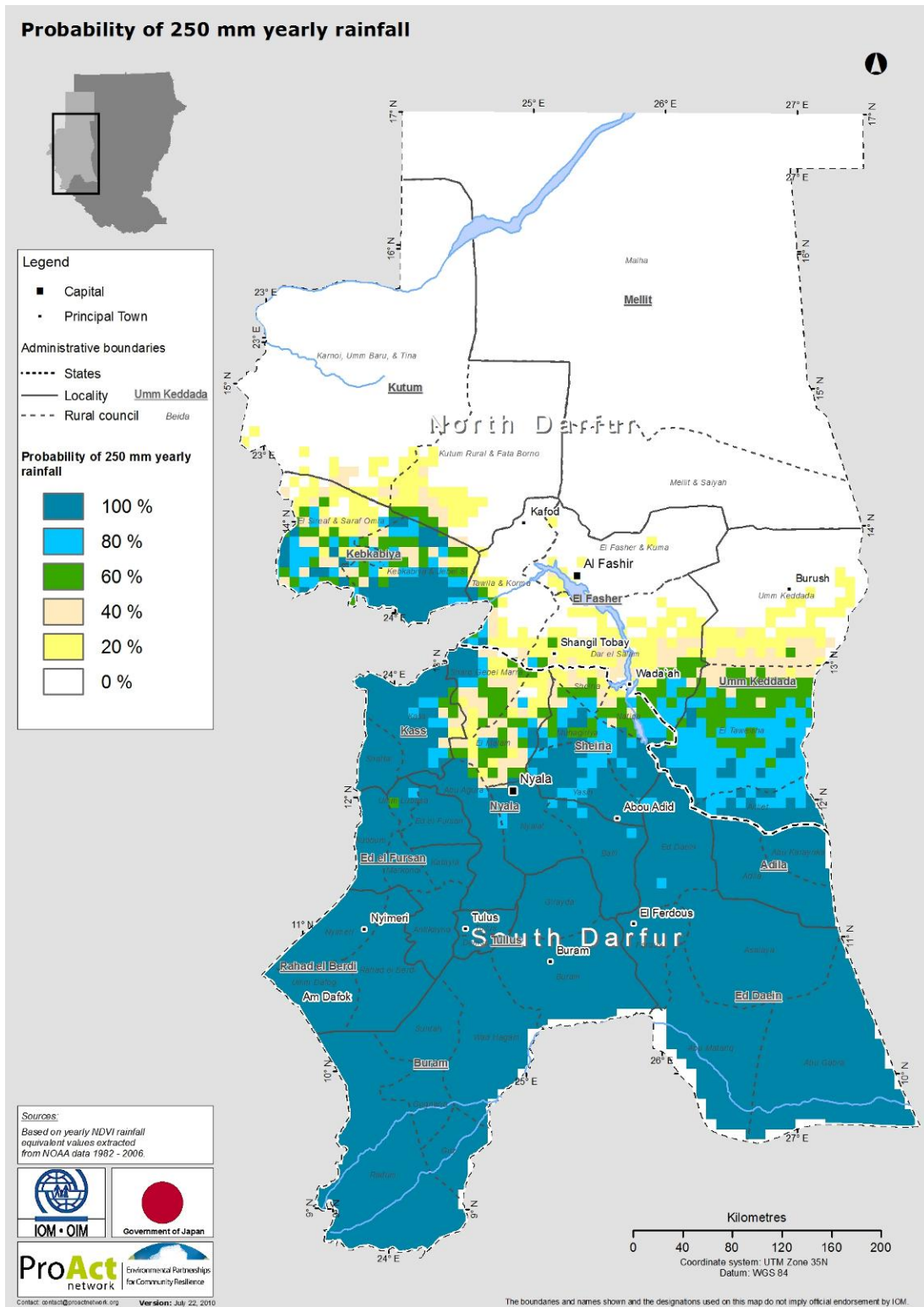
The FAO LocClim database states that the average rainfall at Umm Kaddada in North Darfur is 233mm – interpolated from surrounding stations. The NOAA analysis (1982-2006) indicates somewhat lower values with 250mm occurring only up to 20 per cent of the time at Umm Kaddada. Rainfed millet farming would therefore seem to be a very marginal livelihood activity at Umm Kaddada with the southern part of the rural council experiencing

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<sup>30</sup> Olsson (1985b) quotes both 300mm and 320mm but his result for 80 per cent of the water requirement is 240mm. He must therefore mean 300mm, not 320mm.

rainfall of 250mm per year up to 40 per cent of the time, and to the north considerably less. Inspection of the DMC-2 imagery bears out this north-south divide of the rural council with the majority of the rainfed farming taking place in the south. Umm Kaddada is highlighted because IOM has been working in this Rural Council and a lot is known about the area, further it is towards the northern limit of millet production on *qoz*. Umm Rakuba is highlighted because it is in a much more humid zone than Umm Kaddada but is also on *qoz* soils, although other crops such as groundnuts may be being cultivated. Further historical information on the land cover of Umm Rakuba is available for future investigation.

At Umm Kaddada the growing season is very short, only 38 days between 21 July and 27 August (FAO LocClim). Conversely at Umm Rakuba in South Darfur (on *Qoz Ma Alyia*) the growing season's moist period is 83 days between 28 June and 18 September with 370mm of average rainfall (FAO LocClim) and a 100 per cent chance of receiving in excess of 250mm of rainfall (NOAA analysis). Millet farming on *qoz* is therefore a very different proposition in Umm Rakuba compared to Umm Kaddada – with corresponding implications for how risk and uncertainty are managed in the context of a natural resource-based rural livelihood and how intensively the land may be utilised.



**Figure 66.** NDVI equivalent rainfall probability map for the 250mm threshold.

## 7.3 Maps and Datasets Developed During the ELVM Project

As part of its data acquisition and analysis the ELVM project collected a large amount of data that has been processed to provide a number of mapping products for each 16km x 16km grid cell in the study area. For each grid cell it is possible to generate the following:

- a location map that places each 16km x 16km grid cell into overall ELVI strata;
- a terrain map (showing elevation and topography) based on SRTM V4;
- a vegetation negative trends map extracted from SPOT VGT imagery acquired between 1999 and 2010 that shows relative measures (in six classes) of negative trends in NDVI;
- a Landsat Mosaic acquired in the 1999 -2001 that can be used as a base map reference layer for space maps, georeferencing other data sources, and the digitization of data;
- a DMC-2 Mosaic acquired in January 2010 that can be used as a base map reference layer for space maps, georeferencing others data sources, and the digitization of data. It can also be used for checking the location of villages, and land use patterns;
- two DMC-2 False colour composites acquired in January 2010 which can be used to provide a better understanding of the active vegetation at the time of data acquisition;
- a breakdown of land cover classes according to the Africover land cover classifications that were used in the project's calculations using the WISDOM methodology as first applied in East Africa;
- an indication of those areas within the 16km x 16km grid cell that have experienced cumulative burning between 2001 - 2008; including an indication of the number of burn events (refer to section 4.2.2 for more information on burned areas);
- an Asset Map that identifies settlements, infrastructure (including health facilities, boreholes and hand pumps) that occur within the 16km x16km grid cell and which were used in the calculation of adaptive capacity;
- three NDVI profiles from over a 25 year period: 1984 (a drought and famine year), 1988 (a wet year with flooding), 1993 (a relatively normal year).

## 8. RECOMMENDATIONS

Given the scale and complexity of assessing environmental and livelihood vulnerability across Darfur it was agreed at the outset of the current project that recommendations would be made for a possible Phase II which would extend and improve the coverage of the ELVM Framework across the three Darfur States. This section presents some initial recommendations for activities that could be undertaken in a subsequent phase of the project. Broadly speaking, they are presented from the simplest to the more complex.

1. The first recommendation is to **extend the coverage of the existing iteration of the Framework to include coverage of West Darfur**. Some, but not all, of the prerequisite data have been gathered, but not processed.
2. **Undertake consultations with Darfuri and Darfur experts**: time constraints and related complications prevented the team from presenting the Framework to Darfur and Darfuri experts based in Nyala and El Fasher. It is suggested that before a proposed Phase II is undertaken the current version of the Framework is presented to Darfuri livelihoods and environmental experts in Sudan, with a similar expert workshop outside of the country for international experts on Darfur. The purpose of these workshops would be to provide an additional verification opportunity and supplement the analysis of the satellite imagery and literature survey which has formed the backbone of the current project. Similarly, these consultations would provide the opportunity to prioritize and weight the different components within the current version of the ELVM Framework.
3. **Undertake consultations with government and other agencies** at both central (Khartoum) and state levels. In particular the Sudan Meteorological Authority, the Sudanese Drought and Desertification Unit, the Ministries of Agriculture, Livestock, Environment and Planning with a view to improving the data sets used in the Framework.
4. **Undertake community consultations and mapping in Darfur**: information obtained from community consultations and mapping exercises across the different eco-climatic zones would be a valuable addition to the data already assembled by the project and would, for example, offer insights into community adaptive capacities and strategies not otherwise obtainable.
5. **Refine the data used in the existing ELVM Framework** by improving the accuracy of spatial data a more robust Framework could be developed. Consideration should be given to improving the quality of GPS usage and data recorded by IOM and other agencies active in Darfur. Moving from NOAA derived data to data obtained from newer generation sensors and using updated population data and the soon to be released Africover land cover database, along with improved estimates of per capita woodfuel usage and vegetation regeneration rates would give a more accurate, and up-to-date, woodfuel balance.

- 6. Undertake additional work on data already gathered but not completely analysed by the project:** Further digitisation and spatialisation of historical maps to improve the hydrogeological information. More information can be extracted from the existing maps and interpretation of imagery, for example by using additional software such as the SRTM terrain model and the EcoCognition tool which could allow additional adaptive capacity data to be extracted.
- 7. Refine the ELVM Framework:** Undertake an analysis of end user requirements of the Framework from IOM and other potential users to improve the access to and use of environmental and livelihood information in their respective decision making processes. Within IOM this could potentially include using the ELVM Framework as the foundation for a platform for the spatial capture and presentation of information collected by IOM's PTP and VMU teams.
- 8. Capacity Building and Replicability:** The current Framework is a static tool that is based on time bound data. Obviously it can be refined as soon as new data or more accurate data becomes available but to ensure that the ELVM Framework, *and the underlying principles of taking environmental factors into account in the return process*, are understood and meaningfully applied by decision makers, a capacity building and awareness raising programme should be considered both within IOM and other potential users of the Framework, particularly at national and regional (i.e. Darfur State) levels, as initially anticipated in the project proposal.

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## 10. ANNEXES

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### 10.3. Sources of Geo-Referenced and Spatial Data Used in the Project

	Data	Source	Contact number or Website	Scale	Resolution	Year/Last updated	Data Format
Administrative boundaries	International boundaries	CBS	TRMA +249 183 783765 ext 1723				vector
	State boundaries	CBS	TRMA +249 183 783765 ext 1723				vector
	Localities	CBS	TRMA +249 183 783765 ext 1723				vector
	Rural councils	CBS	TRMA +249 183 783765 ext 1723				vector
	Settlements	SIM	TRMA +249 183 783765 ext 1723				
Population	Gridded population	Landscan	<a href="http://www.ornl.gov/sci/landscan/">http://www.ornl.gov/sci/landscan/</a>		1km	2007	raster
Transportation	Roads	HIC	TRMA +249 183 783765 ext 1723				vector
	Railroads	JLC	TRMA +249 183 783765 ext 1723				vector
	Airports	JLC	TRMA +249 183 783765 ext 1723				vector
	Health facilities	WHO	TRMA +249 183 783765 ext 1723				vector
	Boreholes	TRMA	TRMA +249 183 783765 ext 1723				vector
Hydrographic data	Handpumps	TRMA	TRMA +249 183 783765 ext 1723				vector
	Rivers	FAO					vector
	Wadis	TRMA	TRMA +249 183 783765 ext 1723			2004	vector
	Water bodies	RWDB_SWB-Py	<a href="http://www.fao.org/geonetwork/srv/en/metadata.s how?id=29046&amp;currTab=simple">http://www.fao.org/geonetwork/srv/en/metadata.s how?id=29046&amp;currTab=simple</a>				vector
	Watersheds	alcomwaf	<a href="http://www.fao.org/geonetwork/srv/en/metadata.s how?id=15750&amp;currTab=simple">http://www.fao.org/geonetwork/srv/en/metadata.s how?id=15750&amp;currTab=simple</a>				vector
Land cover	Globcover	ESA	<a href="http://ionia1.esrin.esa.int/images/GLOBCOVER_Product_Specification_v2.pdf">http://ionia1.esrin.esa.int/images/GLOBCOVER_Product_Specification_v2.pdf</a>		350m		raster
	Africover	FAO	<a href="http://www.africover.org/">http://www.africover.org/</a>			1999-2000	raster

Data	Source	Contact number or Website	Scale	Resolution	Year/Last updated	Data Format
DMC-2	DMC-2	<a href="http://www.dmcii.com/">http://www.dmcii.com/</a>		23m	2010	raster
Landsat	NASA	<a href="http://landsat.gsfc.nasa.gov/">http://landsat.gsfc.nasa.gov/</a>		30m	1999-2000	raster
QuickBird	Digital Globe/Planet Action	<a href="http://www.digitalglobe.com/">http://www.digitalglobe.com/</a>		62cm	2007	raster
NOAA NDVI	Global Land Cover Facility	<a href="http://www.landcover.org/data/gimms/">http://www.landcover.org/data/gimms/</a>		8km	1984-2006	raster
Spot VGT NDVI	SPOT/VEGETATION program	<a href="http://free.vgt.vito.be/">http://free.vgt.vito.be/</a>		1km	1998-2010	raster
MODIS	NASA	<a href="http://rapidfire.sci.gsfc.nasa.gov/">http://rapidfire.sci.gsfc.nasa.gov/</a>		1km		raster
Shuttle Radar Topographic Mission (SRTM)	CGIAR / NASA	<a href="http://srtm.csi.cgiar.org/">http://srtm.csi.cgiar.org/</a>		90m	2000	raster
Hunting Geology & Geophysics	R.M. Munro	Rural Water & Development Corporation, Khartoum	1:500,000		1970	
TNO-DGV Institute for Applied Geoscience	R.M. Munro	Rural Water & Development Corporation, Khartoum	1:1,000,000		1988	
Ibrahim	R.M. Munro	Published book	1:1,000,000		1978	
Global Historical Climatology Network (GHCN)	NOAA	<a href="http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php">http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php</a>		N/A		point data
FAOLocClim	FAO	<a href="http://www.fao.org/sd/locclim/srv/locclim.home">http://www.fao.org/sd/locclim/srv/locclim.home</a>		N/A		point data
WorldClim	Uni California, CIAT, CRC-TREM	<a href="http://www.worldclim.org/">http://www.worldclim.org/</a>		1km		raster
IOM		PTP Database				

## 10.4 Data Values per 16km x 16km Grid Cell

The table below contains the numerical values of the components of the EIVM Framework for each 16km x 16km grid cell in the study area for which complete datasets are available.

PRA - Potential Rainfall Water Availability Index  
 PGA - Potential Groundwater Availability Index  
 PWS - Potential Woodfuel Sufficiency Index  
 RP - Rainfall Predictability Index  
 AC - Potential Adaptive Capacity  
 RPOP - Relative Population Distribution Index

Water availability ranking – *not directly used in the final version of the EIVM Framework but indicates the ranking of water availability taking into account both Potential Rainfall Water Availability and Potential Groundwater Availability*

Spatial Vulnerability to Multiple Hazards Index (MHVI)  
 Environmental and Livelihoods Vulnerability Index (ELVI)

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
DA 14	0.9785	0.3882	0.6535	0.6625	0.3375	21	0.4260	0.1438
DA 15	0.9772	0.2997	0.6535	0.6764	0.3236	21	0.4751	0.1538
DA 16	1.0051	0.2000	0.8003	0.6137	0.3863	21	0.5063	0.1956
DA 17	1.0415	0.2775	0.8003	0.5341	0.4659	21	0.5668	0.2640
CZ 13	0.9096	0.2000	0.8003	0.6435	0.3565	21	0.4257	0.1518
CZ 14	0.9228	0.2000	0.8003	0.6389	0.3611	21	0.4426	0.1598
CZ 15	0.9102	0.2000	0.7911	0.6639	0.3361	21	0.4651	0.1563
CZ 16	0.9628	0.2000	0.6535	0.6761	0.3239	21	0.5011	0.1623
CZ 17	0.9797	0.2000	0.6656	0.6676	0.3324	21	0.5367	0.1784
CZ 18	0.9883	0.2000	0.5807	0.5210	0.4790	21	0.5760	0.2759
CU 32	0.6246	0.7582	0.8346	0.5873	0.4127	19	0.5961	0.2460

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CS 34	0.5701	0.8000	0.7024	0.6595	0.3405	19	0.7100	0.2418
CS 35	0.6172	0.8000	0.7373	0.5970	0.4030	19	0.7052	0.2842
CS 38	0.6345	0.8000	0.7748	0.5974	0.4026	19	0.6344	0.2554
CS 39	0.6124	0.8000	0.8346	0.5990	0.4010	19	0.6230	0.2498
CY 13	0.8624	0.2000	0.8003	0.6478	0.3522	21	0.4514	0.1590
CY 14	0.8399	0.2000	0.8003	0.6421	0.3579	21	0.4679	0.1675
CY 15	0.8868	0.4657	0.8003	0.6468	0.3532	21	0.5212	0.1841
CY 16	0.8757	0.2913	0.8003	0.6453	0.3547	21	0.5254	0.1863
CY 17	0.9193	0.2083	0.7062	0.6442	0.3558	21	0.5611	0.1997
CY 18	0.9379	0.4118	0.8003	0.5827	0.4173	21	0.6354	0.2652
CX 14	0.8259	0.2000	0.6709	0.6448	0.3552	21	0.4843	0.1720
CX 15	0.8235	0.3107	0.7228	0.6466	0.3534	21	0.5246	0.1854
CX 16	0.8101	0.3107	0.6535	0.6712	0.3288	21	0.5416	0.1781
CX 17	0.8503	0.4381	0.3932	0.6932	0.3068	21	0.5662	0.1737
CX 18	0.8882	0.2706	0.4119	0.6876	0.3124	21	0.5860	0.1831
CW 14	0.8001	0.2443	0.6535	0.6682	0.3318	21	0.5002	0.1659
CW 15	0.8119	0.2498	0.6535	0.6585	0.3415	21	0.5270	0.1799
CW 16	0.8100	0.2000	0.6582	0.6550	0.3450	21	0.5408	0.1866
CW 17	0.8077	0.2000	0.6142	0.6822	0.3178	21	0.5622	0.1787
CW 18	0.8101	0.3412	0.3746	0.7201	0.2799	21	0.5706	0.1597
CV 14	0.8446	0.3772	0.8003	0.6242	0.3758	21	0.5638	0.2119
CV 15	0.7751	0.3993	0.6656	0.6643	0.3357	21	0.5707	0.1915
CV 16	0.7654	0.2028	0.6582	0.6723	0.3277	21	0.5654	0.1853
CV 17	0.7612	0.4242	0.8003	0.6262	0.3738	21	0.6203	0.2319
CV 18	0.7807	0.2000	0.6631	0.6668	0.3332	21	0.6005	0.2001
CV 19	0.7843	0.5986	0.6558	0.6614	0.3386	25	0.6701	0.2269
CU 14	0.7693	0.3464	0.6469	0.6785	0.3215	21	0.5565	0.1789
CU 15	0.7919	0.5948	0.6656	0.6733	0.3267	25	0.6210	0.2029
CU 16	0.7490	0.2183	0.6535	0.6776	0.3224	21	0.5924	0.1910
CU 17	0.7117	0.2837	0.7228	0.6412	0.3588	21	0.6283	0.2254

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CU 18	0.7278	0.2099	0.6535	0.6772	0.3228	21	0.6222	0.2008
CU 19	0.7522	0.2471	0.8003	0.6112	0.3888	21	0.6377	0.2479
CU 33	0.6549	0.7477	0.7427	0.5346	0.4654	24	0.6201	0.2886
CU 34	0.6970	0.8000	0.7141	0.5595	0.4405	24	0.6572	0.2895
CU 35	0.6979	0.7856	0.8492	0.5684	0.4316	24	0.6853	0.2958
CT 14	0.7040	0.2000	0.8003	0.6379	0.3621	21	0.5604	0.2029
CT 15	0.7413	0.3550	0.6558	0.6686	0.3314	21	0.5898	0.1954
CT 16	0.7548	0.2000	0.7274	0.6427	0.3573	21	0.6043	0.2159
CT 17	0.7483	0.7343	0.6606	0.6796	0.3204	25	0.7029	0.2252
CT 18	0.7236	0.2366	0.4962	0.6925	0.3075	21	0.6291	0.1934
CT 19	0.6901	0.5986	0.6919	0.6658	0.3342	25	0.6752	0.2257
CT 32	0.7215	0.7689	0.8105	0.5101	0.4899	24	0.6467	0.3168
CT 33	0.6895	0.8000	0.7323	0.6595	0.3405	24	0.6734	0.2293
CT 34	0.6360	0.8000	0.7184	0.6094	0.3906	24	0.6878	0.2687
CT 35	0.7205	0.7467	0.7748	0.5752	0.4248	24	0.7160	0.3042
CT 36	0.7082	0.7052	0.8346	0.5412	0.4588	24	0.6934	0.3182
CT 37	0.6544	0.6602	0.8492	0.5660	0.4340	23	0.6478	0.2811
CT 38	0.6631	0.7588	1.0000	0.5891	0.4109	24	0.6513	0.2676
CT 39	0.6867	0.8000	0.8346	0.5933	0.4067	24	0.6075	0.2470
CT 40	0.6635	0.8000	0.7141	0.6324	0.3676	24	0.5920	0.2177
CS 14	0.6915	0.2000	0.8003	0.6201	0.3799	21	0.5926	0.2251
CS 15	0.6848	0.2000	0.6558	0.6752	0.3248	21	0.5718	0.1857
CS 16	0.6897	0.2000	1.0000	0.6439	0.3561	21	0.6229	0.2218
CS 17	0.6989	0.2000	0.8003	0.6416	0.3584	21	0.6408	0.2297
CS 18	0.6968	0.2000	0.8003	0.6356	0.3644	21	0.6772	0.2468
CS 19	0.7113	0.2000	0.8003	0.6241	0.3759	21	0.6654	0.2501
CS 20	0.6942	0.2000	0.3518	0.7055	0.2945	21	0.6300	0.1855
CS 31	0.6529	0.8000	0.4180	0.6111	0.3889	24	0.5905	0.2296
CS 32	0.6555	0.8000	0.8105	0.5467	0.4533	24	0.6766	0.3067
CS 33	0.6157	0.8000	0.7323	0.6894	0.3106	24	0.6904	0.2145

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CS 36	0.6842	0.8000	0.6988	0.6311	0.3689	24	0.6722	0.2480
CS 37	0.6477	0.8000	0.8003	0.6314	0.3686	24	0.6438	0.2373
CS 40	0.5823	0.7972	0.8219	0.5875	0.4125	19	0.6069	0.2504
CR 13	0.7055	0.2000	1.0000	0.6334	0.3666	21	0.6434	0.2359
CR 14	0.7209	0.4242	0.7704	0.6643	0.3357	21	0.6511	0.2186
CR 15	0.6616	0.4990	0.7704	0.6352	0.3648	21	0.6262	0.2284
CR 32	0.5919	0.8000	0.6823	0.6091	0.3909	19	0.6925	0.2707
CR 33	0.5804	0.8000	0.6641	0.6528	0.3472	19	0.7160	0.2486
CR 34	0.5484	0.8000	0.7483	0.6536	0.3464	19	0.7312	0.2533
CR 35	0.5604	0.8000	0.7323	0.6076	0.3924	19	0.6992	0.2744
CR 36	0.6127	0.8000	0.7062	0.6157	0.3843	19	0.6752	0.2595
CR 37	0.6132	0.8000	0.7024	0.6447	0.3553	19	0.6541	0.2324
CR 38	0.5946	0.8000	0.7323	0.6349	0.3651	19	0.6372	0.2326
CR 39	0.5839	0.7377	0.6823	0.6309	0.3691	19	0.5928	0.2188
CQ 29	0.5361	0.8000	0.7373	0.6136	0.3864	19	0.6916	0.2673
CQ 30	0.6123	0.8000	0.5658	0.6596	0.3404	19	0.7015	0.2388
CQ 32	0.5673	0.8000	0.7141	0.5992	0.4008	19	0.7157	0.2868
CQ 34	0.6543	0.8000	0.7373	0.6238	0.3762	19	0.7412	0.2789
CQ 39	0.5956	0.6000	0.7323	0.6262	0.3738	18	0.5859	0.2190
CP 20	0.5964	0.8000	0.3053	0.7367	0.2633	19	0.7405	0.1950
CP 21	0.5932	0.8000	0.7062	0.6880	0.3120	19	0.7970	0.2486
CP 22	0.6280	0.8000	0.5535	0.6925	0.3075	19	0.7898	0.2428
CP 29	0.5313	0.7003	0.7323	0.6212	0.3788	19	0.7051	0.2671
CP 30	0.5313	0.8000	0.5639	0.6744	0.3256	19	0.7081	0.2305
CP 31	0.6158	0.8000	0.6794	0.6510	0.3490	19	0.7428	0.2592
CP 35	0.6272	0.8000	0.7748	0.5864	0.4136	19	0.7238	0.2994
CP 37	0.5493	0.6048	0.7101	0.6294	0.3706	18	0.6282	0.2328
CP 38	0.5108	0.6000	0.7184	0.6006	0.3994	18	0.6074	0.2426
CP 39	0.4927	0.5709	0.6736	0.6596	0.3404	18	0.5787	0.1970
CR 16	0.6532	0.5176	1.0000	0.6173	0.3827	24	0.6497	0.2486

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CR 17	0.6823	0.2187	1.0000	0.6217	0.3783	21	0.6574	0.2487
CR 18	0.6907	0.2000	0.6582	0.6501	0.3499	21	0.6604	0.2311
CR 19	0.7126	0.2000	0.7141	0.6308	0.3692	21	0.6814	0.2516
CR 20	0.6804	0.2000	0.8105	0.6108	0.3892	21	0.6910	0.2690
CR 21	0.6410	0.2000	0.8105	0.6131	0.3869	21	0.7194	0.2783
CR 31	0.6805	0.8000	0.7373	0.5785	0.4215	24	0.6940	0.2926
CQ 13	0.7388	0.8000	0.7860	0.6468	0.3532	24	0.7236	0.2556
CQ 14	0.7211	0.8000	0.7704	0.6585	0.3415	24	0.7138	0.2437
CQ 15	0.6764	0.8000	1.0000	0.6078	0.3922	24	0.7002	0.2746
CQ 16	0.6498	0.8000	0.8105	0.5970	0.4030	24	0.6645	0.2678
CQ 17	0.6817	0.8000	0.8105	0.6041	0.3959	24	0.7062	0.2796
CQ 18	0.6701	0.8000	0.7911	0.6002	0.3998	24	0.7452	0.2979
CQ 19	0.6835	0.5010	0.6709	0.6208	0.3792	24	0.7267	0.2755
CQ 20	0.6664	0.4824	0.3486	0.6389	0.3611	24	0.6889	0.2487
CQ 21	0.6239	0.7626	0.7141	0.6815	0.3185	24	0.7920	0.2522
CQ 31	0.6045	0.8000	0.7141	0.6526	0.3474	24	0.7260	0.2522
CQ 33	0.5868	0.8000	0.7101	0.6057	0.3943	24	0.7479	0.2949
CQ 35	0.6513	0.8000	0.7323	0.6368	0.3632	24	0.7139	0.2593
CQ 36	0.6299	0.8000	0.7062	0.6431	0.3569	24	0.6921	0.2470
CQ 37	0.6683	0.7446	0.6794	0.6180	0.3820	24	0.6535	0.2496
CQ 38	0.6263	0.6412	0.7294	0.6419	0.3581	23	0.6124	0.2193
CP 12	0.6977	0.8000	1.0000	0.7287	0.2713	24	0.7741	0.2100
CP 13	0.6997	0.8000	0.5933	0.7604	0.2396	24	0.7206	0.1726
CP 14	0.6887	0.8000	0.6667	0.6782	0.3218	24	0.7123	0.2293
CP 15	0.6791	0.8000	1.0000	0.6211	0.3789	24	0.7223	0.2737
CP 16	0.6571	0.8000	1.0000	0.6032	0.3968	24	0.7112	0.2822
CP 17	0.6698	0.8000	0.8105	0.5698	0.4302	24	0.7207	0.3100
CP 18	0.6912	0.8000	0.8003	0.5959	0.4041	24	0.7648	0.3090
CP 19	0.6684	0.8000	0.3469	0.7034	0.2966	24	0.7391	0.2192
CP 32	0.6194	0.8000	0.7748	0.5895	0.4105	24	0.7601	0.3120

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CP 33	0.6515	0.8000	0.7483	0.6093	0.3907	24	0.7762	0.3033
CP 34	0.6745	0.8000	0.7323	0.6063	0.3937	24	0.7556	0.2975
CP 36	0.6031	0.7343	0.6823	0.6576	0.3424	24	0.6683	0.2288
CO 15	0.6213	0.8000	1.0000	0.6857	0.3143	19	0.7534	0.2368
CO 18	0.5930	0.8000	0.8003	0.6275	0.3725	19	0.7705	0.2870
CO 19	0.5458	0.8000	0.6953	0.7092	0.2908	19	0.7857	0.2285
CO 20	0.5141	0.8000	0.4340	0.7400	0.2600	19	0.7624	0.1982
CO 21	0.5389	0.8000	0.6367	0.7256	0.2744	19	0.7969	0.2187
CO 22	0.5764	0.6444	0.3999	0.6961	0.3039	18	0.7540	0.2291
CO 23	0.6032	0.6405	0.5732	0.6886	0.3114	18	0.7633	0.2377
CO 24	0.5721	0.7843	0.5435	0.6458	0.3542	19	0.7591	0.2689
CO 25	0.5896	0.8000	0.6458	0.6652	0.3348	19	0.7587	0.2540
CO 26	0.5612	0.8000	0.6480	0.6470	0.3530	19	0.7597	0.2681
CO 27	0.5286	0.8000	0.6823	0.6430	0.3570	19	0.7447	0.2658
CO 28	0.5424	0.8000	0.8346	0.5928	0.4072	19	0.7493	0.3051
CO 29	0.5587	0.8000	0.6988	0.5999	0.4001	19	0.7432	0.2973
CO 30	0.5063	0.7373	0.6448	0.6745	0.3255	19	0.7344	0.2390
CO 31	0.5226	0.6809	0.7101	0.6715	0.3285	18	0.7430	0.2441
CO 36	0.5320	0.6039	0.7062	0.6399	0.3601	18	0.6664	0.2400
CO 37	0.5018	0.6000	0.7141	0.6203	0.3797	18	0.6527	0.2478
CO 38	0.4636	0.6000	0.7141	0.6292	0.3708	18	0.6347	0.2353
CN 13	0.6374	0.8000	0.5494	0.7672	0.2328	19	0.7743	0.1803
CN 14	0.5974	0.8000	0.6886	0.7341	0.2659	19	0.7659	0.2036
CN 15	0.5824	0.8000	0.6375	0.7127	0.2873	19	0.7356	0.2114
CN 16	0.6139	0.8000	0.5848	0.6647	0.3353	19	0.7388	0.2477
CN 17	0.5821	0.8000	0.8003	0.6214	0.3786	19	0.7612	0.2882
CN 18	0.4886	0.8000	0.7101	0.6563	0.3437	19	0.7626	0.2621
CN 19	0.4569	0.8000	0.7024	0.7133	0.2867	19	0.7892	0.2263
CN 20	0.4486	0.8000	0.3659	0.7424	0.2576	19	0.7615	0.1961
CN 21	0.5088	0.6900	0.5311	0.7090	0.2910	18	0.7751	0.2256

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CN 22	0.5778	0.6021	0.5360	0.6374	0.3626	18	0.7551	0.2738
CN 23	0.4911	0.6242	0.3832	0.7179	0.2821	18	0.7427	0.2095
CN 24	0.4517	0.7792	0.6469	0.6816	0.3184	19	0.7728	0.2461
CN 25	0.5988	0.8000	0.4240	0.7067	0.2933	19	0.7609	0.2232
CN 26	0.5533	0.8000	0.5435	0.6511	0.3489	19	0.7515	0.2622
CN 27	0.5081	0.7758	0.6631	0.6475	0.3525	19	0.7376	0.2600
CN 28	0.4634	0.6927	0.6919	0.6602	0.3398	18	0.7213	0.2451
CN 29	0.4277	0.6118	0.6794	0.6698	0.3302	18	0.7213	0.2381
CN 30	0.4327	0.6035	0.6490	0.6716	0.3284	18	0.7207	0.2367
CN 31	0.4601	0.6261	0.5678	0.6007	0.3993	18	0.7251	0.2895
CN 35	0.4599	0.6042	0.7024	0.6525	0.3475	18	0.7119	0.2474
CN 36	0.4776	0.6000	0.5872	0.6377	0.3623	18	0.6743	0.2443
CN 37	0.4745	0.6000	0.4284	0.6232	0.3768	18	0.6480	0.2441
CN 38	0.4631	0.6000	0.7141	0.6184	0.3816	18	0.6574	0.2509
CM 11	0.6126	0.8000	0.6886	0.7477	0.2523	19	0.7518	0.1897
CM 12	0.6000	0.8000	0.6535	0.7401	0.2599	19	0.7631	0.1984
CM 13	0.5636	0.8000	0.2576	0.8060	0.1940	19	0.7331	0.1422
CM 14	0.5789	0.8000	0.5803	0.7666	0.2334	19	0.7806	0.1822
CM 15	0.5891	0.8000	0.6512	0.7409	0.2591	19	0.7611	0.1972
CM 16	0.5489	0.8000	0.5814	0.7498	0.2502	19	0.7566	0.1893
CM 17	0.5161	0.8000	0.6558	0.6860	0.3140	19	0.7653	0.2403
CM 18	0.4624	0.8000	0.4274	0.7151	0.2849	19	0.7444	0.2121
CM 19	0.4378	0.8000	0.7062	0.7060	0.2940	19	0.8008	0.2355
CM 20	0.4767	0.8000	0.3252	0.7471	0.2529	19	0.7717	0.1951
CM 21	0.4659	0.6962	0.7323	0.6322	0.3678	19	0.7930	0.2916
CM 22	0.4324	0.7156	0.5848	0.6581	0.3419	19	0.7626	0.2607
CM 23	0.3714	0.7834	0.3612	0.7897	0.2103	19	0.7469	0.1571
CM 24	0.3533	0.8000	0.3834	0.7490	0.2510	19	0.7455	0.1872
CM 25	0.3984	0.8000	0.3842	0.7419	0.2581	19	0.7427	0.1917
CM 26	0.4313	0.8000	0.4330	0.7081	0.2919	19	0.7416	0.2165

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CM 27	0.4070	0.7931	0.4297	0.7039	0.2961	19	0.7143	0.2115
CM 28	0.3774	0.6415	0.5668	0.7089	0.2911	18	0.7072	0.2058
CM 29	0.3743	0.6000	0.6919	0.6911	0.3089	18	0.7256	0.2242
CM 30	0.4098	0.6000	0.5427	0.7056	0.2944	18	0.7241	0.2132
CM 31	0.4442	0.6000	0.5639	0.6513	0.3487	18	0.7381	0.2574
CM 32	0.4488	0.7412	0.7323	0.6496	0.3504	18	0.7708	0.2701
CM 34	0.4408	0.6526	0.3744	0.6816	0.3184	18	0.6993	0.2227
CM 35	0.4601	0.6000	0.4287	0.7053	0.2947	18	0.6957	0.2050
CM 36	0.4338	0.6000	0.7826	0.6084	0.3916	18	0.7185	0.2814
CM 37	0.4620	0.6000	0.4289	0.6537	0.3463	18	0.6567	0.2274
CL 28	0.3373	0.6471	0.4789	0.7176	0.2824	18	0.6956	0.1964
CL 29	0.3553	0.6000	0.4289	0.7215	0.2785	18	0.6979	0.1944
CL 30	0.3709	0.6000	0.4768	0.7091	0.2909	18	0.7251	0.2110
CL 31	0.3722	0.6000	0.5271	0.7133	0.2867	18	0.7365	0.2111
CL 32	0.3822	0.6913	0.4414	0.7108	0.2892	18	0.7257	0.2099
CL 33	0.4056	0.6505	0.5183	0.6922	0.3078	18	0.7193	0.2214
CL 34	0.4327	0.6000	0.4814	0.6837	0.3163	18	0.7109	0.2248
CL 35	0.4371	0.6000	0.4277	0.7225	0.2775	18	0.7046	0.1955
CL 36	0.4224	0.6000	0.5053	0.6696	0.3304	18	0.7048	0.2329
CL 37	0.4081	0.6000	0.4703	0.6416	0.3584	18	0.6801	0.2438
CK 29	0.3382	0.6000	0.4680	0.6874	0.3126	18	0.7091	0.2217
CK 30	0.3347	0.6000	0.4814	0.6998	0.3002	18	0.7223	0.2168
CK 31	0.3474	0.6000	0.4809	0.6973	0.3027	18	0.7252	0.2195
CK 32	0.3519	0.6000	0.7024	0.6827	0.3173	18	0.7314	0.2321
CK 33	0.3690	0.6000	0.4507	0.6921	0.3079	18	0.6937	0.2136
CK 34	0.3783	0.6000	0.3433	0.7440	0.2560	18	0.6862	0.1757
CK 35	0.3736	0.6000	0.4411	0.7163	0.2837	18	0.6917	0.1962
CK 36	0.3517	0.6000	0.4124	0.7155	0.2845	18	0.6725	0.1913
CK 37	0.3140	0.6000	0.6765	0.6879	0.3121	13	0.6883	0.2148
CJ 14	0.3738	0.4554	0.4330	0.7574	0.2426	16	0.7114	0.1726

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CJ 17	0.4180	0.6339	0.6512	0.7435	0.2565	16	0.7786	0.1997
CJ 24	0.3357	0.7204	0.4843	0.7272	0.2728	18	0.7534	0.2055
CJ 25	0.3530	0.6647	0.5575	0.7257	0.2743	18	0.7338	0.2013
CJ 29	0.3062	0.6138	0.5318	0.6946	0.3054	13	0.7158	0.2186
CJ 30	0.3056	0.6000	0.5474	0.6925	0.3075	13	0.7341	0.2257
CJ 31	0.3301	0.6000	0.5466	0.6923	0.3077	18	0.7331	0.2256
CJ 32	0.3302	0.6000	0.4896	0.6561	0.3439	18	0.6961	0.2394
CJ 33	0.3336	0.6000	0.3900	0.7123	0.2877	18	0.6792	0.1954
CJ 34	0.3244	0.6000	0.4289	0.7136	0.2864	18	0.6785	0.1943
CJ 35	0.3244	0.6000	0.4076	0.7156	0.2844	18	0.6788	0.1930
CJ 36	0.3068	0.6000	0.2406	0.8128	0.1872	13	0.6553	0.1227
CJ 37	0.3020	0.5958	0.4537	0.6980	0.3020	13	0.6702	0.2024
CI 14	0.3338	0.4879	0.5814	0.7636	0.2364	16	0.7370	0.1742
CI 16	0.3776	0.4720	0.3106	0.7818	0.2182	16	0.6980	0.1523
CI 17	0.4050	0.3045	0.5896	0.7666	0.2334	16	0.7267	0.1696
CI 23	0.3341	0.7301	0.3421	0.7194	0.2806	18	0.7459	0.2093
CI 24	0.3437	0.6083	0.4078	0.7344	0.2656	18	0.7319	0.1944
CI 25	0.3299	0.6000	0.3890	0.7534	0.2466	18	0.7092	0.1749
CI 30	0.2821	0.6000	0.2394	0.8598	0.1402	13	0.7046	0.0988
CI 31	0.3007	0.6000	0.4500	0.7181	0.2819	13	0.7233	0.2039
CI 32	0.3232	0.6000	0.3692	0.6989	0.3011	18	0.6882	0.2072
CI 33	0.3124	0.6000	0.3410	0.7414	0.2586	13	0.6685	0.1729
CI 34	0.3112	0.6000	0.3137	0.7601	0.2399	18	0.6640	0.1593
CI 35	0.3142	0.6000	0.4805	0.6533	0.3467	13	0.6876	0.2384
CI 36	0.2944	0.6000	0.2902	0.7256	0.2744	13	0.6608	0.1813
CI 37	0.2972	0.5647	0.7274	0.6465	0.3535	13	0.7000	0.2474
CH 14	0.3898	0.4928	0.2838	0.7960	0.2040	16	0.7073	0.1443
CH 16	0.3778	0.2941	0.6512	0.7503	0.2497	16	0.7023	0.1754
CH 17	0.4059	0.5294	0.6337	0.7525	0.2475	16	0.7584	0.1877
CH 18	0.3580	0.6247	0.5872	0.7735	0.2265	16	0.7666	0.1736

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CH 19	0.3427	0.3026	0.5985	0.7738	0.2262	16	0.7264	0.1643
CH 23	0.3201	0.6098	0.5153	0.6922	0.3078	18	0.7443	0.2291
CH 24	0.3097	0.6000	0.3938	0.7491	0.2509	18	0.7208	0.1809
CH 25	0.3102	0.6000	0.3545	0.7797	0.2203	18	0.7148	0.1575
CH 26	0.3155	0.6163	0.4428	0.7254	0.2746	18	0.7286	0.2000
CH 28	0.3076	0.6791	0.4753	0.6856	0.3144	13	0.7296	0.2294
CH 29	0.2774	0.6131	0.3866	0.7262	0.2738	13	0.7233	0.1980
CH 30	0.2680	0.6000	0.3386	0.7541	0.2459	13	0.7145	0.1757
CH 31	0.2972	0.6000	0.4620	0.6943	0.3057	13	0.7015	0.2145
CH 32	0.3116	0.6000	0.4959	0.6876	0.3124	18	0.6911	0.2159
CH 33	0.3048	0.6000	0.2680	0.7679	0.2321	13	0.6648	0.1543
CH 34	0.3040	0.6000	0.4907	0.7027	0.2973	18	0.6897	0.2051
CH 35	0.3005	0.6000	0.4964	0.7048	0.2952	18	0.6889	0.2034
CH 36	0.2988	0.6000	0.3201	0.7231	0.2769	13	0.6624	0.1834
CH 37	0.2847	0.5647	0.4414	0.6670	0.3330	13	0.6561	0.2185
CG 14	0.3387	0.4242	0.5407	0.7605	0.2395	16	0.7243	0.1735
CG 15	0.3185	0.3993	0.5814	0.7484	0.2516	16	0.7074	0.1780
CG 18	0.3345	0.2941	0.6456	0.7395	0.2605	16	0.7139	0.1859
CG 19	0.3242	0.4630	0.5584	0.7723	0.2277	16	0.7316	0.1665
CG 21	0.3024	0.2221	0.6988	0.6997	0.3003	16	0.7265	0.2182
CG 22	0.2887	0.2332	0.5318	0.7153	0.2847	11	0.7098	0.2021
CG 23	0.2970	0.3564	0.5346	0.7216	0.2784	13	0.7166	0.1995
CG 24	0.2979	0.5336	0.5339	0.7036	0.2964	18	0.7268	0.2154
CG 25	0.2994	0.6000	0.3545	0.7821	0.2179	13	0.7152	0.1558
CG 26	0.2905	0.6000	0.3825	0.7202	0.2798	13	0.7025	0.1965
CG 27	0.2905	0.6000	0.3845	0.7307	0.2693	13	0.7014	0.1889
CG 28	0.2879	0.6000	0.4797	0.7029	0.2971	13	0.7242	0.2152
CG 29	0.2837	0.6000	0.4945	0.6882	0.3118	13	0.7342	0.2289
CG 30	0.2724	0.6000	0.7373	0.6623	0.3377	13	0.7463	0.2520
CG 31	0.2774	0.6000	0.7373	0.6777	0.3223	13	0.7184	0.2316

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CO 12	0.6875	0.8000	0.5553	0.7513	0.2487	24	0.7414	0.1844
CO 13	0.6735	0.8000	0.6118	0.7367	0.2633	24	0.7455	0.1963
CO 14	0.6660	0.8000	0.5920	0.7382	0.2618	24	0.7255	0.1899
CO 16	0.6466	0.8000	1.0000	0.5708	0.4292	24	0.7482	0.3211
CO 17	0.6669	0.8000	0.8105	0.5797	0.4203	24	0.7416	0.3117
CO 32	0.5212	0.8000	0.7062	0.6723	0.3277	19	0.7594	0.2489
CO 33	0.5065	0.8000	0.7024	0.6068	0.3932	19	0.7540	0.2965
CO 34	0.4888	0.8000	0.5678	0.6302	0.3698	19	0.7237	0.2677
CO 35	0.5203	0.7307	0.6631	0.6441	0.3559	19	0.7051	0.2510
CN 10	0.6507	0.7779	0.7343	0.7283	0.2717	24	0.7574	0.2058
CN 11	0.6300	0.8000	0.4559	0.7501	0.2499	24	0.7254	0.1813
CN 12	0.6474	0.8000	0.5427	0.7873	0.2127	24	0.7552	0.1606
CN 32	0.4707	0.7758	0.7323	0.6037	0.3963	19	0.7657	0.3034
CN 33	0.4577	0.8000	0.7323	0.5923	0.4077	19	0.7473	0.3047
CN 34	0.4493	0.7668	0.7228	0.5868	0.4132	19	0.7413	0.3063
CM 33	0.4437	0.7855	0.6953	0.6079	0.3921	19	0.7504	0.2942
CL 12	0.5208	0.8000	0.6097	0.7450	0.2550	19	0.7491	0.1910
CL 13	0.5290	0.8000	0.5764	0.7610	0.2390	19	0.7683	0.1836
CL 14	0.4656	0.8000	0.2599	0.8067	0.1933	19	0.7357	0.1422
CL 15	0.5260	0.8000	0.2713	0.7904	0.2096	19	0.7350	0.1541
CL 16	0.4816	0.8000	0.5688	0.7730	0.2270	19	0.7663	0.1739
CL 17	0.4286	0.8000	0.4938	0.7784	0.2216	19	0.7570	0.1678
CL 18	0.4045	0.8000	0.5075	0.7496	0.2504	19	0.7736	0.1937
CL 19	0.3991	0.8000	0.3910	0.7314	0.2686	19	0.7710	0.2071
CL 20	0.4513	0.8000	0.6257	0.6712	0.3288	19	0.8119	0.2669
CL 21	0.3957	0.8000	0.5482	0.6825	0.3175	19	0.7821	0.2483
CL 22	0.3773	0.8000	0.6794	0.6491	0.3509	19	0.7815	0.2743
CL 23	0.3627	0.8000	0.3832	0.7099	0.2901	19	0.7449	0.2161
CL 24	0.3437	0.8000	0.5113	0.7193	0.2807	19	0.7667	0.2152
CL 25	0.3427	0.8000	0.4122	0.7656	0.2344	19	0.7450	0.1747

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CL 26	0.3683	0.8000	0.4368	0.7171	0.2829	19	0.7414	0.2097
CL 27	0.3572	0.8000	0.4103	0.7015	0.2985	19	0.7180	0.2143
CK 13	0.4796	0.7170	0.5908	0.7513	0.2487	19	0.7589	0.1888
CK 14	0.4636	0.8000	0.4194	0.7971	0.2029	19	0.7574	0.1537
CK 15	0.3945	0.8000	0.5860	0.7605	0.2395	19	0.7782	0.1864
CK 16	0.4273	0.8000	0.5814	0.7329	0.2671	19	0.7752	0.2071
CK 17	0.4271	0.8000	0.2854	0.7879	0.2121	19	0.7498	0.1590
CK 18	0.4038	0.8000	0.6407	0.7645	0.2355	19	0.8092	0.1906
CK 19	0.3971	0.8000	0.4333	0.7356	0.2644	19	0.7850	0.2076
CK 20	0.3544	0.8000	0.4292	0.7165	0.2835	19	0.7733	0.2192
CK 21	0.3389	0.8000	0.5239	0.7180	0.2820	19	0.7788	0.2196
CK 22	0.3593	0.8000	0.3940	0.7396	0.2604	19	0.7603	0.1980
CK 23	0.3799	0.8000	0.4733	0.7326	0.2674	19	0.7648	0.2045
CK 24	0.3680	0.8000	0.4154	0.7613	0.2387	19	0.7657	0.1828
CK 25	0.3646	0.8000	0.5271	0.7303	0.2697	19	0.7652	0.2063
CK 26	0.3736	0.8000	0.5584	0.7108	0.2892	19	0.7526	0.2176
CK 27	0.3527	0.8000	0.5639	0.7039	0.2961	19	0.7427	0.2199
CK 28	0.3423	0.7343	0.4592	0.6992	0.3008	19	0.7218	0.2171
CJ 15	0.3661	0.8173	0.1554	0.8678	0.1322	19	0.7338	0.0970
CJ 16	0.4062	0.8000	0.5698	0.7580	0.2420	19	0.7786	0.1884
CJ 18	0.3743	0.6922	0.6469	0.7515	0.2485	19	0.7983	0.1984
CJ 19	0.4256	0.8000	0.5189	0.7728	0.2272	19	0.8012	0.1820
CJ 20	0.4055	0.8000	0.5933	0.7539	0.2461	19	0.7963	0.1959
CJ 21	0.3652	0.8000	0.6142	0.6932	0.3068	19	0.7882	0.2418
CJ 22	0.3630	0.8000	0.5698	0.6780	0.3220	19	0.7775	0.2503
CJ 23	0.3425	0.8000	0.3801	0.7460	0.2540	19	0.7595	0.1929
CJ 26	0.3423	0.7896	0.5760	0.6944	0.3056	19	0.7416	0.2267
CJ 27	0.3309	0.8000	0.5639	0.6994	0.3006	19	0.7504	0.2256
CJ 28	0.3279	0.7668	0.7062	0.6632	0.3368	19	0.7662	0.2581
CI 15	0.3756	0.6789	0.5814	0.7517	0.2483	20	0.7675	0.1905

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CI 18	0.3850	0.5817	0.5606	0.7480	0.2520	20	0.7702	0.1941
CI 19	0.3720	0.6983	0.5271	0.7742	0.2258	19	0.7816	0.1764
CI 20	0.3805	0.8000	0.4236	0.7847	0.2153	19	0.7675	0.1653
CI 21	0.3713	0.8000	0.6469	0.7202	0.2798	19	0.7788	0.2179
CI 22	0.3501	0.8000	0.4317	0.7203	0.2797	19	0.7497	0.2097
CI 26	0.3238	0.7398	0.3952	0.6964	0.3036	19	0.7314	0.2220
CI 27	0.3343	0.8000	0.4411	0.6775	0.3225	19	0.7541	0.2432
CI 28	0.3151	0.8000	0.6765	0.6899	0.3101	19	0.7744	0.2402
CI 29	0.2907	0.6471	0.4764	0.7011	0.2989	19	0.7227	0.2160
CH 15	0.3603	0.5294	0.5860	0.7481	0.2519	20	0.7301	0.1839
CH 20	0.3338	0.7150	0.4414	0.7849	0.2151	19	0.7615	0.1638
CH 21	0.3393	0.6667	0.6682	0.7026	0.2974	19	0.7683	0.2285
CH 22	0.3369	0.6627	0.3027	0.7606	0.2394	19	0.7241	0.1734
CH 27	0.3151	0.7320	0.5325	0.6852	0.3148	19	0.7383	0.2324
CG 16	0.3291	0.5488	0.5265	0.7550	0.2450	20	0.7195	0.1763
CG 17	0.3364	0.6014	0.3138	0.7714	0.2286	20	0.7148	0.1634
CG 20	0.3169	0.7260	0.6348	0.7234	0.2766	20	0.7811	0.2160
CG 32	0.2769	0.6000	0.3479	0.6918	0.3082	13	0.6556	0.2021
CG 33	0.2910	0.6000	0.4809	0.6796	0.3204	13	0.6868	0.2201
CG 34	0.2871	0.6304	0.2703	0.7288	0.2712	13	0.6721	0.1823
CG 35	0.2741	0.6415	0.3350	0.7687	0.2313	13	0.6790	0.1570
CG 36	0.2898	0.6000	0.3716	0.7402	0.2598	13	0.6705	0.1742
CF 15	0.2972	0.2000	0.5825	0.7487	0.2513	11	0.6880	0.1729
CF 16	0.2948	0.2581	0.5553	0.7475	0.2525	11	0.6931	0.1750
CF 17	0.2856	0.5073	0.6558	0.7333	0.2667	11	0.7463	0.1991
CF 18	0.2851	0.2471	0.5896	0.7305	0.2695	11	0.6858	0.1848
CF 19	0.3080	0.8284	0.4848	0.7519	0.2481	15	0.7559	0.1875
CF 20	0.3313	0.5017	0.6311	0.7063	0.2937	16	0.7505	0.2204
CF 21	0.2821	0.2277	0.6988	0.6768	0.3232	11	0.7222	0.2334
CF 22	0.2950	0.2000	0.3956	0.7711	0.2289	11	0.6894	0.1578

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CF 23	0.3100	0.3163	0.3931	0.7706	0.2294	11	0.6931	0.1590
CF 24	0.2727	0.7246	0.5318	0.7119	0.2881	15	0.7508	0.2163
CF 25	0.2701	0.6627	0.4454	0.7183	0.2817	13	0.7255	0.2043
CF 26	0.2914	0.6000	0.3958	0.7129	0.2871	13	0.7027	0.2017
CF 27	0.2786	0.6000	0.4865	0.7148	0.2852	13	0.7301	0.2083
CF 28	0.2613	0.6000	0.4651	0.7304	0.2696	13	0.7243	0.1953
CF 29	0.2628	0.6000	0.3071	0.7449	0.2551	13	0.7021	0.1791
CF 30	0.2637	0.6062	0.6988	0.6612	0.3388	13	0.7365	0.2495
CF 31	0.2626	0.6353	0.7373	0.6101	0.3899	13	0.7205	0.2809
CF 32	0.2664	0.6353	0.5085	0.6672	0.3328	13	0.6859	0.2282
CF 33	0.2727	0.7100	0.4722	0.6429	0.3571	13	0.6996	0.2498
CF 34	0.2770	0.7792	0.4169	0.6977	0.3023	14	0.7019	0.2122
CF 35	0.2606	0.7931	0.4094	0.7211	0.2789	14	0.6983	0.1948
CF 36	0.2610	0.7412	0.4592	0.7037	0.2963	14	0.6914	0.2049
CD 21	0.1992	0.2000	0.0302	0.9794	0.0206	6	0.6449	0.0133
CC 20	0.1957	0.2388	0.5615	0.6727	0.3273	6	0.7082	0.2318
CC 21	0.1896	0.4242	0.3733	0.7346	0.2654	6	0.7004	0.1859
CC 22	0.2109	0.2000	0.6448	0.6801	0.3199	6	0.7106	0.2273
CB 19	0.1745	0.2000	0.5544	0.6592	0.3408	6	0.6922	0.2359
CB 20	0.1808	0.2000	0.3912	0.6890	0.3110	6	0.6636	0.2064
CA 20	0.1802	0.2000	0.7826	0.6688	0.3312	6	0.7035	0.2330
CA 22	0.1933	0.2000	0.3540	0.7557	0.2443	6	0.6707	0.1638
BZ 22	0.1732	0.2000	0.3506	0.7496	0.2504	6	0.6672	0.1671
BZ 23	0.1647	0.2000	0.6512	0.6650	0.3350	6	0.6856	0.2297
BZ 26	0.1906	0.3246	0.3547	0.7510	0.2490	6	0.6458	0.1608
BY 21	0.1831	0.3495	0.3954	0.7375	0.2625	6	0.6790	0.1782
BY 22	0.1820	0.6235	0.5153	0.6799	0.3201	6	0.7327	0.2345
BY 27	0.1740	0.6422	0.2786	0.7875	0.2125	9	0.6745	0.1434
BY 28	0.1698	0.3633	0.3328	0.7717	0.2283	6	0.6312	0.1441
BY 29	0.2001	0.2000	0.3121	0.7212	0.2788	6	0.5879	0.1639

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BY 36	0.1834	0.8000	0.6988	0.5783	0.4217	9	0.5857	0.2470
BX 22	0.1818	0.4740	0.5482	0.6390	0.3610	6	0.7061	0.2549
BX 24	0.1624	0.9059	0.4180	0.7313	0.2687	9	0.7373	0.1981
BX 26	0.1728	0.5654	0.3008	0.7755	0.2245	6	0.6707	0.1506
BX 27	0.1704	0.6588	0.4009	0.7455	0.2545	9	0.6919	0.1761
BX 28	0.1672	0.7253	0.3548	0.7724	0.2276	9	0.6811	0.1551
BX 29	0.1880	0.2664	0.4699	0.6919	0.3081	6	0.6151	0.1895
BX 31	0.1842	0.4824	0.8346	0.5681	0.4319	9	0.6234	0.2692
BX 34	0.1791	0.2000	0.7101	0.4566	0.5434	6	0.5258	0.2857
BX 35	0.1784	0.2374	0.6988	0.5827	0.4173	6	0.5117	0.2135
BW 21	0.1467	0.2304	0.4699	0.6650	0.3350	6	0.6447	0.2160
BW 22	0.1469	0.2000	0.4030	0.6791	0.3209	6	0.6426	0.2062
BW 23	0.1577	0.3073	0.4294	0.7586	0.2414	6	0.6693	0.1616
BW 24	0.1561	0.5550	0.4264	0.7900	0.2100	6	0.6983	0.1466
BW 25	0.1617	0.7307	0.4383	0.7749	0.2251	9	0.7156	0.1611
BW 28	0.1532	0.6111	0.4425	0.6693	0.3307	6	0.6654	0.2200
BW 29	0.1604	0.5841	0.4025	0.7554	0.2446	6	0.6321	0.1546
BW 30	0.1616	0.7896	0.5226	0.6332	0.3668	9	0.6410	0.2351
BW 31	0.1611	0.8000	0.8663	0.5686	0.4314	9	0.6468	0.2790
BW 35	0.1564	0.3246	0.6174	0.5138	0.4862	6	0.5102	0.2481
BW 36	0.1592	0.5405	0.6448	0.5357	0.4643	6	0.5483	0.2546
BV 21	0.1352	0.2000	0.5125	0.6501	0.3499	6	0.6400	0.2239
BV 22	0.1085	0.2000	0.5037	0.6970	0.3030	6	0.6450	0.1954
BV 23	0.1192	0.2277	0.3775	0.7654	0.2346	6	0.6458	0.1515
BV 24	0.1238	0.2893	0.4105	0.7777	0.2223	6	0.6599	0.1467
BV 28	0.1486	0.2166	0.5896	0.6177	0.3823	6	0.6291	0.2405
BV 29	0.1469	0.2166	0.4835	0.6853	0.3147	6	0.5923	0.1864
BV 30	0.1435	0.5135	0.4710	0.6716	0.3284	6	0.5927	0.1946
CE 15	0.2837	0.2000	0.3530	0.7488	0.2512	11	0.6718	0.1688
CE 17	0.2625	0.2166	0.3291	0.7320	0.2680	11	0.6665	0.1786

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CE 19	0.2822	0.6955	0.6240	0.7201	0.2799	15	0.7568	0.2119
CE 20	0.2684	0.2332	0.5159	0.6762	0.3238	11	0.6976	0.2259
CE 21	0.2602	0.2000	0.0279	0.9997	0.0003	11	0.6489	0.0002
CE 22	0.2990	0.2000	0.0991	0.9285	0.0715	16	0.6629	0.0474
CE 23	0.2928	0.4325	0.3424	0.7714	0.2286	11	0.7091	0.1621
CE 24	0.2600	0.8339	0.4201	0.7690	0.2310	15	0.7485	0.1729
CE 25	0.2651	0.6301	0.4606	0.7107	0.2893	13	0.7194	0.2081
CE 26	0.2879	0.6000	0.3411	0.7721	0.2279	13	0.7102	0.1619
CE 27	0.2778	0.6000	0.3548	0.7559	0.2441	13	0.7166	0.1749
CE 28	0.2507	0.6000	0.6329	0.6765	0.3235	13	0.7308	0.2364
CE 29	0.2457	0.6000	0.6988	0.6182	0.3818	13	0.7389	0.2821
CE 30	0.2616	0.6540	0.4586	0.6276	0.3724	13	0.7146	0.2661
CE 31	0.2565	0.8000	0.4032	0.6333	0.3667	14	0.7037	0.2580
CE 32	0.2485	0.8000	0.5153	0.6264	0.3736	14	0.6970	0.2604
CE 33	0.2477	0.8000	0.3202	0.7116	0.2884	14	0.6767	0.1952
CE 34	0.2604	0.8000	0.4448	0.6737	0.3263	14	0.6937	0.2264
CE 35	0.2461	0.8000	0.4684	0.6601	0.3399	14	0.6857	0.2331
CD 15	0.2916	0.2000	0.3190	0.8163	0.1837	11	0.6720	0.1234
CD 16	0.2788	0.2000	0.5045	0.7205	0.2795	11	0.6926	0.1936
CD 17	0.2747	0.4131	0.5753	0.6483	0.3517	11	0.7264	0.2555
CD 18	0.2750	0.7673	0.5130	0.7097	0.2903	15	0.7612	0.2210
CD 19	0.2715	0.2554	0.5743	0.7074	0.2926	11	0.7131	0.2086
CD 20	0.2090	0.2111	0.5482	0.6919	0.3081	11	0.7053	0.2173
CD 22	0.2286	0.2000	0.1412	0.8675	0.1325	11	0.6590	0.0873
CD 23	0.2721	0.2000	0.3354	0.7335	0.2665	11	0.6722	0.1791
CD 24	0.2746	0.7093	0.5258	0.7106	0.2894	15	0.7434	0.2152
CD 25	0.2605	0.8431	0.4203	0.7428	0.2572	15	0.7429	0.1911
CD 26	0.2644	0.5709	0.3936	0.7311	0.2689	13	0.7101	0.1909
CD 27	0.2574	0.6000	0.3873	0.7116	0.2884	13	0.7113	0.2051
CD 28	0.2531	0.6000	0.7826	0.6499	0.3501	13	0.7397	0.2589

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CD 29	0.2574	0.6429	0.6709	0.6214	0.3786	13	0.7243	0.2742
CD 30	0.2514	0.7792	0.6053	0.5288	0.4712	14	0.7240	0.3411
CD 31	0.2456	0.7843	0.6823	0.5855	0.4145	14	0.7195	0.2982
CD 32	0.2454	0.7460	0.6919	0.5569	0.4431	14	0.7079	0.3137
CD 33	0.2468	0.8000	0.7826	0.5051	0.4949	14	0.7102	0.3515
CD 34	0.2471	0.8000	0.5781	0.6517	0.3483	14	0.6856	0.2388
CD 35	0.2390	0.8000	0.3753	0.6986	0.3014	14	0.6556	0.1976
CC 15	0.3520	0.2000	0.3614	0.7661	0.2339	16	0.6806	0.1592
CC 16	0.2820	0.2000	0.5291	0.6850	0.3150	11	0.6952	0.2190
CC 17	0.2876	0.5599	0.3243	0.7367	0.2633	11	0.7213	0.1899
CC 18	0.2232	0.4013	0.5125	0.6755	0.3245	11	0.7248	0.2352
CC 19	0.2280	0.3356	0.4303	0.7025	0.2975	11	0.7161	0.2131
CC 23	0.2596	0.3246	0.3596	0.7461	0.2539	11	0.6871	0.1744
CC 24	0.2823	0.5599	0.4892	0.6800	0.3200	15	0.7234	0.2315
CC 25	0.2612	0.7516	0.5136	0.6830	0.3170	15	0.7427	0.2354
CC 26	0.2364	0.4630	0.3546	0.7516	0.2484	13	0.6884	0.1710
CC 27	0.2459	0.6000	0.3540	0.7763	0.2237	13	0.7122	0.1593
CC 28	0.2638	0.5031	0.5346	0.6393	0.3607	11	0.7012	0.2530
CC 29	0.2497	0.7806	0.6988	0.5156	0.4844	14	0.7244	0.3509
CC 30	0.2348	0.8062	0.6988	0.4903	0.5097	14	0.7141	0.3640
CC 31	0.2309	0.7451	0.5119	0.6042	0.3958	14	0.6815	0.2697
CC 32	0.2376	0.6360	0.3821	0.6964	0.3036	11	0.6487	0.1970
CC 33	0.2376	0.7896	0.5004	0.6543	0.3457	14	0.6654	0.2300
CC 34	0.2425	0.8000	0.3579	0.7020	0.2980	14	0.6485	0.1932
CC 35	0.2367	0.8000	0.5419	0.6791	0.3209	14	0.6610	0.2121
CB 15	0.4056	0.2000	0.7683	0.6727	0.3273	16	0.7242	0.2370
CB 16	0.3254	0.2000	0.6634	0.6849	0.3151	16	0.7172	0.2260
CB 17	0.2740	0.2194	0.4897	0.7103	0.2897	11	0.7017	0.2033
CB 18	0.2223	0.2052	0.4194	0.7185	0.2815	11	0.6977	0.1964
CB 21	0.2065	0.2000	0.4277	0.6792	0.3208	11	0.6665	0.2138

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CB 22	0.2387	0.3329	0.3750	0.7062	0.2938	11	0.6957	0.2044
CB 23	0.2455	0.4657	0.4016	0.7361	0.2639	11	0.7100	0.1874
CB 24	0.2540	0.3107	0.5119	0.6909	0.3091	11	0.6961	0.2152
CB 25	0.2411	0.2837	0.5318	0.7017	0.2983	11	0.6845	0.2042
CB 26	0.2252	0.3176	0.3405	0.8235	0.1765	11	0.6735	0.1189
CB 27	0.2304	0.6000	0.3491	0.8143	0.1857	13	0.7110	0.1320
CB 28	0.2248	0.4727	0.3522	0.7604	0.2396	13	0.6708	0.1607
CB 29	0.2246	0.6609	0.5959	0.5660	0.4340	14	0.6988	0.3033
CB 30	0.2163	0.8997	0.5770	0.6177	0.3823	14	0.7147	0.2732
CB 31	0.2261	0.6497	0.5091	0.6256	0.3744	14	0.6632	0.2483
CB 32	0.2138	0.4990	0.6709	0.4968	0.5032	14	0.6384	0.3212
CB 33	0.2214	0.4554	0.6682	0.5436	0.4564	11	0.6227	0.2842
CB 34	0.2204	0.8000	0.6682	0.6318	0.3682	14	0.6539	0.2408
CB 35	0.2322	0.8000	0.5002	0.6642	0.3358	14	0.6258	0.2102
CA 15	0.4491	0.2000	0.6348	0.6640	0.3360	16	0.7104	0.2387
CA 16	0.3115	0.2000	1.0000	0.6497	0.3503	16	0.7574	0.2653
CA 17	0.2611	0.7647	0.2291	0.8187	0.1813	15	0.7473	0.1355
CA 18	0.2107	0.2889	0.4323	0.7359	0.2641	11	0.6943	0.1833
CA 19	0.1969	0.2000	0.4157	0.7185	0.2815	11	0.6679	0.1880
CA 21	0.2012	0.2000	0.5203	0.6830	0.3170	11	0.6800	0.2156
CA 23	0.1989	0.2000	0.3774	0.7329	0.2671	11	0.6654	0.1777
CA 24	0.2223	0.2000	0.3290	0.7408	0.2592	11	0.6553	0.1699
CA 25	0.2376	0.3111	0.3540	0.7603	0.2397	11	0.6627	0.1589
CA 26	0.2072	0.3229	0.3646	0.7749	0.2251	11	0.6616	0.1489
CA 27	0.1999	0.5477	0.2561	0.8225	0.1775	13	0.6831	0.1213
CA 28	0.2083	0.5529	0.3823	0.8001	0.1999	13	0.6830	0.1366
CA 29	0.2204	0.3412	0.3545	0.7127	0.2873	13	0.6325	0.1817
CA 30	0.2164	0.3412	0.3547	0.7138	0.2862	11	0.6151	0.1760
CA 31	0.2235	0.2000	0.6097	0.5074	0.4926	11	0.5924	0.2918
CA 32	0.2040	0.2000	0.7101	0.4728	0.5272	11	0.5659	0.2984

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
CA 33	0.2169	0.3000	0.7911	0.5263	0.4737	11	0.5869	0.2780
CA 34	0.2122	0.7882	0.3167	0.7342	0.2658	14	0.6006	0.1597
CA 35	0.2155	0.8000	0.6794	0.6401	0.3599	14	0.6303	0.2268
CA 36	0.2234	0.7529	0.4176	0.7196	0.2804	14	0.5824	0.1633
BZ 15	0.3947	0.3993	0.3444	0.7790	0.2210	16	0.7147	0.1580
BZ 16	0.2938	0.2685	0.5781	0.7128	0.2872	11	0.7240	0.2079
BZ 17	0.2592	0.8284	0.3730	0.7718	0.2282	15	0.7655	0.1747
BZ 18	0.2250	0.3477	0.5258	0.6750	0.3250	12	0.6984	0.2270
BZ 19	0.1824	0.2062	0.4250	0.6754	0.3246	11	0.6565	0.2131
BZ 20	0.1988	0.5737	0.4245	0.7015	0.2985	15	0.6993	0.2087
BZ 21	0.2060	0.2498	0.5165	0.6968	0.3032	11	0.6864	0.2081
BZ 24	0.2027	0.2000	0.3578	0.7057	0.2943	11	0.6424	0.1890
BZ 25	0.2224	0.2000	0.4054	0.7325	0.2675	11	0.6360	0.1701
BZ 27	0.1788	0.5059	0.2163	0.8748	0.1252	13	0.6633	0.0831
BZ 28	0.1952	0.3938	0.2750	0.7832	0.2168	11	0.6466	0.1402
BZ 29	0.2088	0.2000	0.2601	0.7267	0.2733	11	0.5948	0.1626
BZ 30	0.2101	0.2000	0.4691	0.6801	0.3199	11	0.5826	0.1864
BZ 31	0.2124	0.2000	0.4695	0.6185	0.3815	11	0.5506	0.2100
BZ 32	0.2048	0.2000	0.9471	0.4278	0.5722	11	0.5769	0.3301
BZ 33	0.2061	0.2000	0.9126	0.4583	0.5417	11	0.5689	0.3082
BZ 34	0.2009	0.5882	0.6223	0.6292	0.3708	11	0.5981	0.2217
BZ 35	0.1972	0.8000	0.4957	0.6643	0.3357	14	0.5846	0.1962
BZ 36	0.2013	0.7059	0.7748	0.6170	0.3830	14	0.5883	0.2253
BY 18	0.3596	0.4000	0.8219	0.6695	0.3305	17	0.7579	0.2505
BY 19	0.2736	0.3176	0.6117	0.5982	0.4018	12	0.6957	0.2796
BY 20	0.2211	0.2000	0.6953	0.6214	0.3786	11	0.6825	0.2584
BY 23	0.1682	0.7343	0.5284	0.6997	0.3003	10	0.7391	0.2219
BY 24	0.1731	1.0000	0.5053	0.7071	0.2929	10	0.7591	0.2224
BY 25	0.1845	1.0000	0.4613	0.7361	0.2639	10	0.7449	0.1966
BY 26	0.1752	0.8754	0.4289	0.7330	0.2670	10	0.7249	0.1936

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BY 30	0.2160	0.2000	0.4695	0.7114	0.2886	11	0.5873	0.1695
BY 31	0.1997	0.2000	0.4317	0.6897	0.3103	11	0.5556	0.1724
BY 32	0.1961	0.2000	0.5896	0.5507	0.4493	11	0.5434	0.2442
BY 33	0.1993	0.2000	0.9471	0.4366	0.5634	11	0.5755	0.3242
BY 34	0.2020	0.2498	0.7543	0.5498	0.4502	11	0.5549	0.2498
BY 35	0.1945	0.6879	0.4279	0.6703	0.3297	14	0.5565	0.1835
BX 19	0.3429	0.4000	0.5256	0.6789	0.3211	17	0.7077	0.2272
BX 20	0.2070	0.6028	0.5701	0.6177	0.3823	10	0.7133	0.2727
BX 21	0.1464	0.8671	0.5584	0.6608	0.3392	10	0.7476	0.2536
BX 23	0.1781	0.6318	0.4627	0.7386	0.2614	10	0.7186	0.1878
BX 25	0.1646	0.7908	0.4733	0.7165	0.2835	10	0.7220	0.2047
BX 30	0.1908	0.3993	0.5325	0.6333	0.3667	11	0.6066	0.2224
BX 32	0.1831	0.4824	0.7373	0.5615	0.4385	9	0.5873	0.2575
BX 33	0.1816	0.4325	0.9471	0.4442	0.5558	9	0.6076	0.3377
BX 36	0.1819	0.7003	0.6427	0.5280	0.4720	9	0.5685	0.2684
BW 20	0.2213	0.2429	0.5963	0.5384	0.4616	11	0.6574	0.3035
BW 26	0.1611	0.5792	0.4370	0.7588	0.2412	10	0.6884	0.1660
BW 27	0.1559	0.8249	0.4279	0.7478	0.2522	10	0.7075	0.1784
BW 32	0.1551	0.8000	0.7427	0.5106	0.4894	9	0.6146	0.3008
BW 33	0.1690	0.7938	0.5959	0.4692	0.5308	9	0.6137	0.3258
BW 34	0.1654	0.7087	0.7748	0.5154	0.4846	9	0.6089	0.2951
BW 37	0.1598	0.6955	0.6142	0.6510	0.3490	9	0.5842	0.2039
BV 25	0.1383	0.7948	0.3619	0.7710	0.2290	9	0.7128	0.1632
BV 26	0.1383	0.9813	0.5708	0.7178	0.2822	10	0.7416	0.2092
BV 27	0.1415	0.7024	0.4634	0.7426	0.2574	9	0.6944	0.1788
BV 31	0.1348	0.8000	0.7748	0.5660	0.4340	9	0.6382	0.2770
BV 32	0.1221	0.8000	0.7826	0.5030	0.4970	9	0.6249	0.3105
BV 33	0.1240	0.8000	0.3686	0.6943	0.3057	9	0.5856	0.1790
BV 34	0.1306	0.8000	0.5718	0.6472	0.3528	9	0.6033	0.2128
BV 35	0.1433	0.7543	0.4115	0.6340	0.3660	9	0.5684	0.2080

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BV 36	0.1350	0.7294	0.5920	0.6669	0.3331	9	0.5897	0.1964
BV 37	0.1383	0.7709	0.4072	0.7003	0.2997	9	0.5866	0.1758
CE 16	0.2847	0.5156	0.5946	0.7449	0.2551	20	0.7411	0.1891
CE 18	0.2955	0.6601	0.6275	0.7015	0.2985	20	0.7513	0.2243
BU 21	0.1417	0.3370	0.5201	0.6495	0.3505	6	0.6608	0.2316
BU 22	0.1156	0.2000	0.4445	0.7253	0.2747	6	0.6467	0.1777
BU 23	0.0993	0.3121	0.3940	0.7455	0.2545	6	0.6502	0.1654
BU 24	0.1159	0.3038	0.5148	0.7415	0.2585	6	0.6748	0.1745
BU 26	0.1149	0.6824	0.5718	0.7041	0.2959	6	0.7103	0.2102
BU 27	0.1250	0.4796	0.4183	0.6976	0.3024	6	0.6612	0.2000
BU 28	0.1273	0.2000	0.5760	0.5820	0.4180	6	0.6259	0.2616
BU 29	0.1298	0.2000	0.5760	0.6310	0.3690	6	0.5995	0.2212
BU 30	0.1209	0.5862	0.5896	0.6355	0.3645	6	0.6067	0.2211
BU 25	0.1270	0.8039	0.5375	0.7228	0.2772	10	0.7277	0.2017
BU 31	0.1248	0.8000	0.8492	0.5633	0.4367	9	0.6444	0.2814
BP 22	0.0768	0.2000	0.5291	0.6523	0.3477	1	0.6211	0.2159
BP 23	0.0742	0.4097	0.5291	0.6223	0.3777	1	0.6422	0.2425
BP 28	0.0749	0.5682	0.6736	0.6214	0.3786	1	0.6812	0.2579
BO 26	0.0598	0.2747	0.7373	0.4853	0.5147	1	0.6330	0.3258
BO 27	0.0620	0.2830	0.5397	0.6745	0.3255	1	0.6276	0.2043
BN 20	0.0530	0.2000	0.4394	0.6747	0.3253	1	0.5908	0.1922
BN 21	0.0668	0.4588	0.5298	0.6303	0.3697	1	0.6301	0.2329
BN 26	0.0514	0.4157	0.7141	0.4960	0.5040	1	0.6136	0.3093
BM 20	0.0560	0.2166	0.4609	0.6921	0.3079	1	0.5927	0.1825
BL 14	0.0787	0.4824	0.6794	0.6459	0.3541	1	0.5887	0.2085
BL 16	0.0735	0.3827	0.6682	0.6305	0.3695	1	0.6241	0.2306
BL 17	0.0726	0.2166	0.4969	0.6697	0.3303	1	0.6099	0.2015
BL 18	0.0749	0.2471	0.5485	0.6429	0.3571	1	0.6154	0.2198
BL 20	0.0679	0.6076	0.5728	0.6369	0.3631	1	0.6525	0.2369
BK 9	0.0713	0.2000	0.7675	0.6296	0.3704	1	0.5993	0.2220

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BK 10	0.0729	0.2000	0.7748	0.6202	0.3798	1	0.5856	0.2225
BK 11	0.0679	0.2000	0.5419	0.6151	0.3849	1	0.5378	0.2070
BK 12	0.0574	0.2000	0.7748	0.6221	0.3779	1	0.5575	0.2107
BK 13	0.0453	0.2000	0.5245	0.6470	0.3530	1	0.5328	0.1881
BK 14	0.0547	0.3993	0.4109	0.6707	0.3293	1	0.5606	0.1846
BK 15	0.0651	0.2000	0.5427	0.6217	0.3783	1	0.5728	0.2167
BK 16	0.0632	0.3744	0.6736	0.6617	0.3383	1	0.6215	0.2103
BK 17	0.0542	0.2374	0.5526	0.6607	0.3393	1	0.5941	0.2016
BK 19	0.0618	0.2291	0.5291	0.6158	0.3842	1	0.5918	0.2274
BT 25	0.1224	0.5852	0.1031	0.9926	0.0074	6	0.6568	0.0048
BT 26	0.1298	0.2000	0.5064	0.6668	0.3332	6	0.6592	0.2196
BT 27	0.1285	0.2000	0.4777	0.7023	0.2977	6	0.6396	0.1904
BT 28	0.1209	0.2000	0.5848	0.6857	0.3143	6	0.6341	0.1993
BT 29	0.1154	0.2471	0.7184	0.6066	0.3934	6	0.6310	0.2482
BS 12	0.2089	0.2000	0.6535	0.6836	0.3164	6	0.6728	0.2129
BS 13	0.2029	0.2000	0.7427	0.6832	0.3168	6	0.6716	0.2128
BS 23	0.1074	0.5820	0.4217	0.7398	0.2602	6	0.6822	0.1775
BS 24	0.1288	0.2623	0.5382	0.7206	0.2794	6	0.6771	0.1892
BS 25	0.1237	0.3176	0.5165	0.7153	0.2847	6	0.6815	0.1940
BS 26	0.1211	0.2747	0.5311	0.6290	0.3710	6	0.6494	0.2410
BS 36	0.0810	0.8000	0.5933	0.6837	0.3163	4	0.5585	0.1766
BR 13	0.2008	0.2000	0.6387	0.6943	0.3057	6	0.6566	0.2007
BR 14	0.1913	0.2000	0.6082	0.6955	0.3045	6	0.6445	0.1962
BR 18	0.2117	0.3137	0.4849	0.7239	0.2761	7	0.6235	0.1722
BR 19	0.1351	0.4000	0.6017	0.6395	0.3605	7	0.6296	0.2270
BR 20	0.1189	0.4706	0.5091	0.7444	0.2556	6	0.6504	0.1663
BR 21	0.1185	0.5322	0.4699	0.7677	0.2323	6	0.6791	0.1577
BR 22	0.1020	0.2685	0.5037	0.6384	0.3616	6	0.6353	0.2297
BR 23	0.1043	0.2000	0.5482	0.6617	0.3383	6	0.6449	0.2182
BR 24	0.1173	0.2000	0.5258	0.6444	0.3556	6	0.6473	0.2302

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BR 25	0.0971	0.2000	0.5884	0.6801	0.3199	6	0.6545	0.2094
BR 26	0.1056	0.2519	0.5884	0.6493	0.3507	6	0.6560	0.2300
BR 34	0.0704	0.8000	0.7427	0.5266	0.4734	4	0.5848	0.2768
BR 35	0.0784	0.8000	0.8868	0.5081	0.4919	4	0.5818	0.2862
BR 37	0.0684	0.8000	0.5920	0.6584	0.3416	4	0.5296	0.1809
BR 38	0.0798	0.8000	0.5933	0.6557	0.3443	4	0.5171	0.1780
BQ 12	0.1778	0.2000	0.6535	0.6659	0.3341	6	0.6619	0.2211
BQ 13	0.1583	0.2886	0.6068	0.6681	0.3319	6	0.6409	0.2127
BQ 14	0.1674	0.2000	0.6582	0.6821	0.3179	6	0.6300	0.2003
BQ 18	0.1693	0.5549	0.5518	0.6663	0.3337	7	0.6511	0.2173
BQ 19	0.1338	0.2803	0.5678	0.6009	0.3991	6	0.6243	0.2492
BQ 20	0.1113	0.2637	0.5291	0.6558	0.3442	6	0.6325	0.2177
BQ 21	0.1040	0.2166	0.5291	0.6558	0.3442	6	0.6386	0.2198
BQ 22	0.1012	0.3993	0.4901	0.6638	0.3362	6	0.6594	0.2217
BQ 23	0.1181	0.2000	0.4699	0.6333	0.3667	6	0.6275	0.2301
BQ 24	0.1025	0.2000	0.5760	0.6270	0.3730	6	0.6388	0.2383
BQ 25	0.1016	0.2000	0.4892	0.6501	0.3499	6	0.6295	0.2203
BQ 26	0.1083	0.3903	0.6275	0.6888	0.3112	6	0.6823	0.2123
BQ 33	0.0849	0.8000	0.6988	0.5567	0.4433	4	0.5725	0.2538
BQ 34	0.0667	0.8083	0.8868	0.5252	0.4748	4	0.5653	0.2684
BQ 37	0.0740	0.8028	0.7141	0.5109	0.4891	4	0.5247	0.2566
BP 15	0.1627	0.2249	0.5342	0.6601	0.3399	6	0.6002	0.2040
BP 17	0.1771	0.2630	0.4033	0.6805	0.3195	6	0.5897	0.1884
BP 19	0.1631	0.2298	0.3201	0.7564	0.2436	6	0.6259	0.1525
BP 20	0.1294	0.2000	0.2510	0.8044	0.1956	6	0.6297	0.1232
BP 21	0.0976	0.2000	0.4785	0.7008	0.2992	6	0.6462	0.1934
BP 24	0.0875	0.3557	0.5985	0.5343	0.4657	6	0.6586	0.3067
BP 25	0.0901	0.2000	0.5920	0.5850	0.4150	6	0.6370	0.2644
BP 26	0.0901	0.3488	0.2656	0.8663	0.1337	6	0.6235	0.0834
BP 27	0.0796	0.4685	0.4835	0.6502	0.3498	6	0.6560	0.2295

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BP 30	0.0736	0.8311	0.8868	0.5095	0.4905	5	0.6854	0.3362
BP 31	0.0732	0.8765	0.5639	0.6046	0.3954	4	0.6259	0.2475
BP 32	0.0694	0.8311	0.8346	0.5287	0.4713	5	0.6144	0.2896
BP 33	0.0720	0.8000	0.6246	0.5715	0.4285	4	0.5567	0.2386
BP 34	0.0570	0.8083	0.7427	0.5164	0.4836	4	0.5330	0.2578
BP 36	0.0766	0.8000	0.8868	0.4785	0.5215	4	0.5413	0.2823
BP 37	0.0721	0.8028	0.7141	0.4645	0.5355	4	0.5323	0.2851
BO 11	0.1521	0.3176	0.5130	0.6706	0.3294	6	0.6000	0.1976
BO 12	0.1659	0.3246	0.7543	0.6551	0.3449	6	0.6174	0.2129
BO 13	0.1547	0.3107	0.7826	0.6552	0.3448	6	0.6058	0.2089
BO 14	0.1403	0.2000	0.5130	0.6816	0.3184	6	0.5483	0.1746
BO 15	0.1539	0.2000	0.5130	0.6706	0.3294	6	0.5622	0.1852
BO 16	0.1580	0.2000	0.5214	0.6675	0.3325	6	0.5761	0.1915
BO 17	0.1494	0.3550	0.4818	0.6504	0.3496	6	0.6175	0.2158
BO 19	0.1288	0.2284	0.5291	0.6859	0.3141	6	0.6608	0.2076
BO 20	0.1071	0.2000	0.5304	0.6660	0.3340	6	0.6545	0.2186
BO 21	0.0928	0.2000	0.4425	0.6587	0.3413	6	0.6155	0.2101
BO 22	0.0549	0.5488	0.5102	0.6683	0.3317	0	0.6298	0.2089
BO 23	0.0500	0.7689	0.4606	0.6098	0.3902	4	0.6576	0.2566
BO 24	0.0573	0.7792	0.7543	0.5200	0.4800	4	0.6972	0.3347
BO 25	0.0640	0.6471	0.5872	0.6032	0.3968	4	0.6692	0.2656
BO 28	0.0673	0.5709	0.5749	0.6748	0.3252	6	0.6672	0.2170
BO 29	0.0675	0.8138	0.6736	0.6231	0.3769	4	0.6851	0.2582
BO 30	0.0603	0.8561	0.6886	0.5469	0.4531	4	0.6402	0.2901
BO 31	0.0676	0.8529	0.6117	0.5642	0.4358	4	0.6062	0.2642
BO 32	0.0686	0.8000	0.8868	0.5154	0.4846	4	0.5982	0.2899
BO 33	0.0638	0.8000	0.6582	0.5164	0.4836	4	0.5311	0.2569
BO 34	0.0574	0.8000	0.8868	0.4362	0.5638	4	0.5420	0.3056
BO 35	0.0398	0.8000	0.8492	0.4370	0.5630	4	0.5167	0.2909
BO 36	0.0553	0.8000	0.8868	0.4305	0.5695	9	0.5451	0.3104

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BO 37	0.0646	0.8000	0.8868	0.3755	0.6245	4	0.5567	0.3477
BN 11	0.1342	0.2000	0.7607	0.6680	0.3320	6	0.5748	0.1909
BN 12	0.1386	0.2000	0.4962	0.6969	0.3031	6	0.5295	0.1605
BN 13	0.1468	0.2000	0.5130	0.6875	0.3125	6	0.5356	0.1674
BN 14	0.1479	0.2941	0.7826	0.6567	0.3433	6	0.5888	0.2021
BN 15	0.1359	0.2000	0.4948	0.7232	0.2768	6	0.5552	0.1537
BN 16	0.1338	0.2000	0.3743	0.7226	0.2774	6	0.5628	0.1562
BN 17	0.1544	0.2000	0.5271	0.7135	0.2865	6	0.6171	0.1768
BN 18	0.1088	0.5074	0.4691	0.7141	0.2859	7	0.6597	0.1886
BN 19	0.0971	0.2902	0.4957	0.7139	0.2861	6	0.6500	0.1860
BN 22	0.0587	0.4980	0.6337	0.6633	0.3367	1	0.6340	0.2135
BN 23	0.0561	0.6824	0.5130	0.6651	0.3349	4	0.6415	0.2149
BN 24	0.0607	0.8000	0.7427	0.5783	0.4217	4	0.6813	0.2873
BN 25	0.0703	0.8222	0.5540	0.5763	0.4237	4	0.6522	0.2763
BN 30	0.0615	0.8000	0.6275	0.5932	0.4068	4	0.6234	0.2536
BN 31	0.0440	0.8444	0.9126	0.4986	0.5014	4	0.6229	0.3123
BN 32	0.0555	0.8000	0.8868	0.4858	0.5142	4	0.5808	0.2986
BN 33	0.0505	0.8000	0.8492	0.5173	0.4827	4	0.5519	0.2664
BN 34	0.0445	0.8575	0.9126	0.5073	0.4927	4	0.5607	0.2763
BN 35	0.0402	0.8314	0.8663	0.4841	0.5159	0	0.5558	0.2867
BN 36	0.0473	0.8000	0.8868	0.4060	0.5940	4	0.5516	0.3276
BN 37	0.0472	0.8052	0.9471	0.2341	0.7659	4	0.5425	0.4155
BM 10	0.0997	0.2000	0.6736	0.6579	0.3421	6	0.5544	0.1897
BM 11	0.1070	0.2314	0.5291	0.6668	0.3332	6	0.5182	0.1727
BM 12	0.1078	0.5405	0.5311	0.6550	0.3450	6	0.5570	0.1921
BM 13	0.1135	0.3412	0.7543	0.6472	0.3528	6	0.5851	0.2064
BM 15	0.1055	0.2997	0.6606	0.6650	0.3350	6	0.5835	0.1955
BM 16	0.1129	0.4408	0.5214	0.6607	0.3393	6	0.6036	0.2048
BM 17	0.1126	0.2332	0.5239	0.6637	0.3363	6	0.6199	0.2085
BM 18	0.1006	0.2229	0.3518	0.7439	0.2561	6	0.6105	0.1563

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BM 19	0.0886	0.3550	0.3910	0.7416	0.2584	6	0.6330	0.1636
BM 21	0.0593	0.6360	0.5298	0.6221	0.3779	4	0.6389	0.2414
BM 22	0.0687	0.7813	0.5392	0.6176	0.3824	4	0.6448	0.2466
BM 23	0.0649	0.7066	0.5540	0.6248	0.3752	4	0.6356	0.2384
BM 25	0.0721	0.8471	0.6823	0.5658	0.4342	4	0.6685	0.2903
BM 26	0.0632	0.8000	0.6318	0.5397	0.4603	4	0.6370	0.2932
BM 27	0.0369	0.7446	0.5515	0.5516	0.4484	0	0.6051	0.2713
BM 28	0.0340	0.8000	0.8663	0.4465	0.5535	0	0.6483	0.3588
BM 29	0.0741	0.8000	0.5490	0.5988	0.4012	4	0.6368	0.2555
BM 31	0.0462	0.8000	0.9126	0.4205	0.5795	4	0.6230	0.3611
BM 32	0.0534	0.8000	0.8868	0.5118	0.4882	4	0.5836	0.2850
BM 33	0.0429	0.8000	0.8663	0.5151	0.4849	4	0.5603	0.2717
BM 34	0.0415	0.8000	0.8663	0.5047	0.4953	0	0.5676	0.2811
BM 35	0.0408	0.8000	0.8868	0.4714	0.5286	4	0.5583	0.2951
BM 36	0.0363	0.8000	0.9126	0.3297	0.6703	0	0.5398	0.3619
BM 37	0.0462	0.7917	0.9471	0.3397	0.6603	0	0.5402	0.3567
BL 9	0.0955	0.3993	0.7607	0.6393	0.3607	6	0.6174	0.2227
BL 10	0.1008	0.2000	0.7748	0.6266	0.3734	6	0.5665	0.2115
BL 11	0.0848	0.4275	0.7675	0.6328	0.3672	6	0.5639	0.2071
BL 13	0.0823	0.4824	0.7748	0.6401	0.3599	6	0.5954	0.2143
BL 15	0.0821	0.5488	0.6794	0.6555	0.3445	6	0.6265	0.2159
BL 19	0.0834	0.3163	0.5291	0.6422	0.3578	6	0.6215	0.2223
BL 21	0.0628	0.5799	0.5325	0.6663	0.3337	4	0.6183	0.2063
BL 22	0.0455	0.7626	0.5770	0.5963	0.4037	4	0.6210	0.2507
BL 23	0.0494	0.8000	0.7228	0.5294	0.4706	4	0.6380	0.3003
BL 24	0.0540	0.8000	0.8346	0.4754	0.5246	4	0.6488	0.3403
BL 25	0.0586	0.8418	0.6794	0.5308	0.4692	4	0.6500	0.3049
BL 26	0.0686	0.8166	0.8868	0.5009	0.4991	4	0.6740	0.3364
BL 27	0.0424	0.8000	0.8868	0.4950	0.5050	0	0.6330	0.3197
BL 28	0.0251	0.8000	0.6469	0.5334	0.4666	0	0.5779	0.2697

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BL 29	0.0236	0.8000	0.8868	0.4205	0.5795	0	0.6321	0.3663
BL 30	0.0553	0.8000	0.8663	0.4874	0.5126	4	0.6599	0.3383
BL 31	0.0566	0.8000	0.8868	0.4894	0.5106	4	0.6399	0.3267
BL 32	0.0564	0.8000	0.9126	0.5051	0.4949	4	0.6245	0.3091
BL 33	0.0532	0.8000	0.8346	0.4553	0.5447	4	0.6114	0.3330
BL 34	0.0449	0.8000	0.8663	0.5159	0.4841	4	0.5981	0.2895
BL 35	0.0341	0.8028	0.9126	0.4230	0.5770	0	0.5713	0.3297
BL 36	0.0322	0.8083	0.9126	0.3511	0.6489	0	0.5623	0.3649
BK 18	0.0633	0.5529	0.5349	0.6263	0.3737	5	0.6165	0.2304
BK 20	0.0615	0.7135	0.7024	0.4788	0.5212	5	0.6482	0.3379
BK 22	0.0421	0.8000	0.7911	0.5502	0.4498	0	0.6328	0.2846
BK 23	0.0351	0.8000	0.7911	0.5752	0.4248	4	0.5980	0.2540
BK 24	0.0416	0.8000	0.5148	0.5877	0.4123	4	0.5668	0.2337
BK 25	0.0439	0.8229	0.8492	0.4966	0.5034	4	0.6248	0.3145
BK 26	0.0553	0.8581	0.8868	0.4775	0.5225	4	0.6526	0.3410
BK 28	0.0665	0.7336	0.8868	0.5176	0.4824	4	0.6169	0.2976
BK 30	0.0671	0.8000	0.8868	0.4775	0.5225	4	0.6761	0.3533
BK 31	0.0693	0.8000	0.8868	0.4916	0.5084	4	0.6618	0.3365
BK 32	0.0588	0.8000	0.8868	0.4666	0.5334	4	0.6521	0.3479
BK 33	0.0524	0.8166	0.6775	0.4586	0.5414	4	0.6172	0.3342
BK 34	0.0448	0.8692	0.8663	0.4491	0.5509	4	0.6124	0.3374
BK 35	0.0421	0.8180	0.8492	0.4832	0.5168	4	0.5993	0.3097
BK 36	0.0316	0.8180	0.8663	0.3846	0.6154	0	0.5868	0.3611
BU 32	0.1014	0.8000	0.8105	0.4825	0.5175	9	0.6232	0.3226
BU 33	0.1117	0.8000	0.6512	0.6153	0.3847	9	0.6299	0.2423
BU 34	0.1143	0.8000	0.6387	0.6549	0.3451	9	0.6216	0.2146
BU 35	0.1270	0.8000	0.5239	0.6701	0.3299	9	0.6196	0.2044
BU 36	0.1367	0.8000	0.4103	0.6890	0.3110	9	0.6115	0.1902
BU 37	0.1403	0.8000	0.5920	0.6733	0.3267	9	0.6213	0.2030
BU 38	0.1449	0.7895	0.6427	0.6362	0.3638	9	0.5986	0.2178

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BT 14	0.2306	0.2706	0.4226	0.7201	0.2799	11	0.6563	0.1837
BT 15	0.2311	0.2000	0.3748	0.7340	0.2660	11	0.6517	0.1733
BT 16	0.2695	0.2000	0.4250	0.7569	0.2431	11	0.6737	0.1637
BT 17	0.3055	0.2412	0.5077	0.7081	0.2919	11	0.6898	0.2014
BT 18	0.2569	0.3556	0.5280	0.6727	0.3273	12	0.6827	0.2235
BT 19	0.2106	0.5941	0.6867	0.6748	0.3252	9	0.7124	0.2316
BT 20	0.1425	0.7882	0.5214	0.6388	0.3612	9	0.7006	0.2531
BT 21	0.1226	0.7647	0.4472	0.6970	0.3030	9	0.6953	0.2107
BT 22	0.1073	0.7471	0.4684	0.7043	0.2957	9	0.7071	0.2091
BT 23	0.1019	0.7882	0.5048	0.7423	0.2577	9	0.7228	0.1863
BT 24	0.1452	0.5863	0.4378	0.7580	0.2420	10	0.7005	0.1695
BT 30	0.1071	0.6824	0.6082	0.6045	0.3955	9	0.6354	0.2513
BT 31	0.1070	0.8000	0.8868	0.5042	0.4958	9	0.6603	0.3274
BT 32	0.1020	0.8000	0.7911	0.5040	0.4960	9	0.6447	0.3198
BT 33	0.0972	0.8000	0.6709	0.6566	0.3434	9	0.6495	0.2230
BT 34	0.1018	0.8000	0.3186	0.7419	0.2581	9	0.6032	0.1557
BT 35	0.0964	0.8000	0.3686	0.7169	0.2831	9	0.5923	0.1677
BT 36	0.1158	0.8000	0.5920	0.6506	0.3494	9	0.5994	0.2094
BT 37	0.1218	0.8000	0.5920	0.6548	0.3452	9	0.5698	0.1967
BT 38	0.1400	0.8000	0.5639	0.6204	0.3796	9	0.5465	0.2075
BS 11	0.2166	0.2000	0.4917	0.7440	0.2560	11	0.6525	0.1671
BS 14	0.2136	0.2000	0.7483	0.6732	0.3268	11	0.6843	0.2236
BS 15	0.2231	0.2000	0.6427	0.6934	0.3066	11	0.6834	0.2096
BS 16	0.2058	0.2000	0.2051	0.8260	0.1740	11	0.6368	0.1108
BS 17	0.2186	0.2000	0.3898	0.7037	0.2963	11	0.6490	0.1923
BS 18	0.1963	0.2778	0.4774	0.7119	0.2881	11	0.6345	0.1828
BS 19	0.1637	0.6436	0.4326	0.6983	0.3017	9	0.6605	0.1993
BS 20	0.1069	0.6837	0.5404	0.6564	0.3436	9	0.6570	0.2257
BS 21	0.0789	0.6879	0.5332	0.6712	0.3288	9	0.6690	0.2200
BS 22	0.1075	0.7626	0.4292	0.7106	0.2894	9	0.6885	0.1993

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BS 27	0.1212	0.3619	0.4651	0.7025	0.2975	9	0.6443	0.1917
BS 28	0.1107	0.4118	0.5803	0.6725	0.3275	9	0.6470	0.2119
BS 29	0.0885	0.5031	0.5427	0.6173	0.3827	9	0.6246	0.2390
BS 30	0.1020	0.8000	0.7228	0.5296	0.4704	9	0.6688	0.3146
BS 31	0.0890	0.8000	0.6469	0.5768	0.4232	9	0.6461	0.2734
BS 32	0.0868	0.8000	0.6590	0.6274	0.3726	9	0.6521	0.2430
BS 33	0.0780	0.8000	0.6448	0.5765	0.4235	9	0.6352	0.2690
BS 34	0.0750	0.8000	0.6919	0.5893	0.4107	9	0.6136	0.2520
BS 35	0.0779	0.8000	0.5688	0.6420	0.3580	9	0.5771	0.2066
BS 37	0.0958	0.8000	0.4478	0.6800	0.3200	9	0.5203	0.1665
BS 38	0.1067	0.8000	0.6387	0.5802	0.4198	9	0.5314	0.2231
BR 11	0.2041	0.2000	0.5032	0.7213	0.2787	11	0.6526	0.1819
BR 12	0.2000	0.2000	0.5130	0.6943	0.3057	11	0.6595	0.2016
BR 15	0.2116	0.2000	0.5177	0.6819	0.3181	11	0.6482	0.2062
BR 16	0.2166	0.2554	0.3737	0.7366	0.2634	12	0.6432	0.1694
BR 17	0.2940	0.3149	0.5278	0.6639	0.3361	17	0.6686	0.2247
BR 27	0.1134	0.7003	0.5540	0.7159	0.2841	9	0.6921	0.1966
BR 28	0.1107	0.8000	0.6240	0.6931	0.3069	9	0.7071	0.2170
BR 29	0.1057	0.8000	0.5848	0.6832	0.3168	9	0.6953	0.2203
BR 30	0.0965	0.8000	0.6794	0.6087	0.3913	9	0.6876	0.2690
BR 31	0.0890	0.8000	0.6240	0.5621	0.4379	9	0.6586	0.2884
BR 32	0.0851	0.8000	0.5946	0.6267	0.3733	9	0.6282	0.2345
BR 33	0.0937	0.8000	0.6558	0.6434	0.3566	9	0.6147	0.2192
BR 36	0.0753	0.8000	0.7274	0.6047	0.3953	9	0.5509	0.2178
BQ 11	0.2036	0.2000	0.6682	0.6684	0.3316	11	0.6808	0.2257
BQ 15	0.2183	0.2000	0.4470	0.7184	0.2816	11	0.6322	0.1780
BQ 16	0.2316	0.3003	0.6448	0.6882	0.3118	11	0.6625	0.2066
BQ 17	0.2361	0.3467	0.6206	0.6685	0.3315	12	0.6484	0.2150
BQ 27	0.1097	0.8422	0.5136	0.7223	0.2777	9	0.7143	0.1984
BQ 28	0.1083	0.8249	0.5490	0.7215	0.2785	9	0.7110	0.1980

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BQ 29	0.1053	0.8000	0.5058	0.6850	0.3150	9	0.6858	0.2161
BQ 30	0.0875	0.8000	0.7748	0.5139	0.4861	9	0.6837	0.3323
BQ 31	0.0851	0.8000	0.7274	0.5276	0.4724	9	0.6383	0.3016
BQ 32	0.0802	0.8000	0.7062	0.5910	0.4090	9	0.6010	0.2458
BQ 35	0.0753	0.8166	0.8868	0.5160	0.4840	9	0.5455	0.2640
BQ 36	0.0774	0.8000	0.8868	0.5253	0.4747	9	0.5276	0.2505
BQ 38	0.0923	0.8183	0.7141	0.5256	0.4744	9	0.5307	0.2518
BP 11	0.1781	0.6941	0.7483	0.6636	0.3364	10	0.7223	0.2430
BP 12	0.1785	0.2997	0.7911	0.6543	0.3457	11	0.6623	0.2290
BP 13	0.1498	0.5765	0.7675	0.6562	0.3438	10	0.6682	0.2297
BP 14	0.1407	0.6235	0.5130	0.6581	0.3419	10	0.6264	0.2142
BP 16	0.1720	0.4242	0.6490	0.6633	0.3367	10	0.6436	0.2167
BP 18	0.1661	0.6667	0.4112	0.7235	0.2765	9	0.6639	0.1836
BP 29	0.0764	0.8360	0.5770	0.6192	0.3808	9	0.6839	0.2604
BP 35	0.0656	0.8166	0.8868	0.4113	0.5887	9	0.5391	0.3173
BP 38	0.0840	0.8503	0.6953	0.5851	0.4149	9	0.5461	0.2266
BO 18	0.1232	0.7471	0.5311	0.6598	0.3402	9	0.6965	0.2370
BN 27	0.0804	0.5542	0.6682	0.5681	0.4319	9	0.6636	0.2866
BN 28	0.0833	0.8000	0.6656	0.6498	0.3502	9	0.7018	0.2457
BN 29	0.0809	0.8000	0.6886	0.6090	0.3910	9	0.6738	0.2635
BM 14	0.1140	0.8893	0.5284	0.6540	0.3460	10	0.6372	0.2205
BM 24	0.0748	0.8000	0.5848	0.6148	0.3852	9	0.6628	0.2553
BM 30	0.0765	0.8000	0.6025	0.5593	0.4407	9	0.6266	0.2762
BL 12	0.0727	0.6817	0.7543	0.6357	0.3643	10	0.5880	0.2142
BK 21	0.0705	0.7945	0.8663	0.3652	0.6348	9	0.6598	0.4189
BK 27	0.0747	0.8000	0.8868	0.4834	0.5166	9	0.6363	0.3287
BK 29	0.0578	0.7336	0.8663	0.5133	0.4867	9	0.6235	0.3035
BJ 9	0.0555	0.4242	0.6709	0.6633	0.3367	1	0.6191	0.2084
BJ 10	0.0484	0.2000	0.4703	0.6848	0.3152	1	0.5548	0.1749
BJ 12	0.0542	0.2221	0.3792	0.6955	0.3045	1	0.5468	0.1665

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BJ 13	0.0538	0.2000	0.4201	0.6957	0.3043	1	0.5499	0.1673
BJ 14	0.0426	0.2000	0.4475	0.7124	0.2876	1	0.5524	0.1589
BJ 15	0.0357	0.2000	0.5427	0.6496	0.3504	1	0.5537	0.1940
BJ 16	0.0448	0.3308	0.5382	0.6368	0.3632	1	0.5637	0.2048
BJ 17	0.0708	0.4990	0.5959	0.6114	0.3886	1	0.6244	0.2426
BJ 11	0.0348	0.2026	0.3380	0.6973	0.3027	0	0.5324	0.1611
BJ 18	0.0395	0.2353	0.5427	0.6144	0.3856	0	0.5490	0.2117
BJ 19	0.0384	0.4471	0.7675	0.5701	0.4299	0	0.6080	0.2613
BI 10	0.0796	0.2000	0.6606	0.6564	0.3436	1	0.5788	0.1989
BI 13	0.0398	0.2000	0.5214	0.6782	0.3218	1	0.5350	0.1722
BI 14	0.0432	0.2000	0.7543	0.6317	0.3683	1	0.5707	0.2102
BH 11	0.0793	0.2000	0.7826	0.6423	0.3577	1	0.5644	0.2019
BH 12	0.0645	0.2000	0.6953	0.6235	0.3765	1	0.5440	0.2048
BH 13	0.0390	0.2000	0.5207	0.6753	0.3247	1	0.5112	0.1660
BG 10	0.0472	0.2000	0.7911	0.6200	0.3800	1	0.5443	0.2068
BA 31	0.0018	0.5647	1.0000	0.0000	1.0000	0	0.4903	0.4903
BA 32	0.0018	0.5647	1.0000	0.0000	1.0000	0	0.5109	0.5109
BA 35	0.0037	0.6145	1.0000	0.0000	1.0000	0	0.4174	0.4174
BJ 20	0.0538	0.8000	0.8219	0.5732	0.4268	4	0.6460	0.2757
BJ 21	0.0501	0.8436	0.7911	0.4844	0.5156	4	0.6218	0.3206
BJ 22	0.0281	0.8000	0.7274	0.5146	0.4854	0	0.5775	0.2803
BJ 23	0.0271	0.8000	0.7024	0.5776	0.4224	0	0.5718	0.2415
BJ 24	0.0425	0.8000	0.8219	0.5786	0.4214	4	0.5775	0.2433
BJ 25	0.0359	0.8000	0.8219	0.5456	0.4544	0	0.5856	0.2661
BJ 26	0.0417	0.8000	0.8868	0.4273	0.5727	4	0.6003	0.3438
BJ 27	0.0535	0.8000	0.8868	0.4599	0.5401	4	0.6023	0.3253
BJ 28	0.0495	0.8000	0.8868	0.5156	0.4844	4	0.6066	0.2939
BJ 29	0.0333	0.8028	0.8868	0.4780	0.5220	0	0.6253	0.3264
BJ 30	0.0373	0.7910	0.5032	0.5719	0.4281	0	0.6161	0.2637
BJ 31	0.0513	0.6418	0.7101	0.4722	0.5278	4	0.6017	0.3176

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BJ 32	0.0501	0.7142	0.6794	0.4855	0.5145	4	0.6007	0.3091
BJ 33	0.0263	0.7225	0.8492	0.4296	0.5704	0	0.6187	0.3529
BJ 34	0.0342	0.6685	0.8492	0.4278	0.5722	0	0.5757	0.3294
BJ 35	0.0461	0.6048	0.8868	0.4113	0.5887	0	0.5688	0.3349
BI 11	0.0723	0.4092	0.3981	0.6927	0.3073	6	0.5757	0.1769
BI 12	0.0744	0.3772	0.7483	0.6453	0.3547	6	0.5991	0.2125
BI 15	0.0258	0.3993	0.5389	0.6554	0.3446	0	0.5461	0.1882
BI 16	0.0346	0.4491	0.5389	0.6384	0.3616	0	0.5532	0.2000
BI 17	0.0305	0.3495	0.5397	0.5807	0.4193	0	0.5633	0.2362
BI 18	0.0318	0.3235	0.7826	0.5339	0.4661	0	0.5816	0.2711
BI 19	0.0331	0.4657	0.7911	0.5481	0.4519	0	0.5748	0.2598
BI 20	0.0459	0.8000	0.8219	0.5611	0.4389	4	0.6050	0.2656
BI 21	0.0413	0.8000	0.7911	0.5519	0.4481	4	0.5800	0.2599
BI 22	0.0457	0.8000	0.7911	0.5743	0.4257	4	0.5691	0.2423
BI 23	0.0495	0.8000	0.7141	0.5933	0.4067	4	0.5847	0.2378
BI 24	0.0357	0.8000	0.7373	0.5757	0.4243	0	0.5591	0.2372
BI 25	0.0182	0.8000	0.8219	0.4954	0.5046	0	0.5518	0.2785
BI 26	0.0134	0.8000	0.9126	0.3411	0.6589	0	0.5754	0.3791
BI 27	0.0274	0.8000	0.9126	0.3970	0.6030	0	0.5763	0.3475
BI 28	0.0398	0.8000	0.8868	0.4323	0.5677	0	0.6078	0.3450
BI 29	0.0425	0.8471	0.9126	0.4483	0.5517	4	0.6482	0.3576
BI 30	0.0124	0.7218	0.8868	0.3929	0.6071	0	0.6500	0.3946
BI 31	0.0177	0.5464	0.9126	0.2914	0.7086	0	0.6101	0.4323
BI 32	0.0217	0.4000	0.8346	0.3885	0.6115	0	0.5533	0.3384
BI 33	0.0209	0.4000	1.0000	0.0908	0.9092	0	0.5731	0.5210
BI 34	0.0041	0.4000	0.9471	0.0573	0.9427	0	0.5849	0.5514
BI 35	0.0166	0.5467	0.9471	0.3356	0.6644	0	0.5376	0.3572
BH 10	0.0804	0.3772	0.7826	0.6393	0.3607	6	0.6111	0.2204
BH 14	0.0232	0.5765	0.5469	0.5996	0.4004	0	0.5620	0.2251
BH 15	0.0182	0.2471	0.7826	0.5702	0.4298	0	0.5333	0.2292

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BH 16	0.0111	0.6235	0.7826	0.5791	0.4209	0	0.5650	0.2378
BH 17	0.0265	0.5176	0.8105	0.3822	0.6178	0	0.5828	0.3600
BH 18	0.0098	0.2000	0.9471	0.2291	0.7709	0	0.5391	0.4156
BH 19	0.0127	0.4844	0.9471	0.1719	0.8281	0	0.5514	0.4566
BH 20	0.0228	0.8014	0.7911	0.4759	0.5241	0	0.5602	0.2936
BH 21	0.0324	0.8111	0.8346	0.4060	0.5940	0	0.5754	0.3418
BH 22	0.0385	0.8000	0.8346	0.4096	0.5904	0	0.5586	0.3298
BH 23	0.0446	0.8000	0.8219	0.4822	0.5178	4	0.5562	0.2880
BH 24	0.0252	0.8000	0.7483	0.4487	0.5513	0	0.5438	0.2998
BH 25	0.0260	0.8000	0.8219	0.4375	0.5625	0	0.5500	0.3094
BH 26	0.0103	0.8000	0.9126	0.2660	0.7340	0	0.5969	0.4381
BH 27	0.0165	0.8000	0.9471	0.1903	0.8097	0	0.5766	0.4669
BH 28	0.0270	0.8000	0.9126	0.2120	0.7880	0	0.6129	0.4829
BH 29	0.0483	0.8000	0.9126	0.3691	0.6309	4	0.6368	0.4018
BH 30	0.0249	0.4554	0.9126	0.3929	0.6071	0	0.6025	0.3658
BH 31	0.0144	0.4000	0.9126	0.3534	0.6466	0	0.5925	0.3831
BH 32	0.0804	0.4000	0.9471	0.2238	0.7762	2	0.5799	0.4501
BH 33	0.0620	0.4374	0.9126	0.3127	0.6873	7	0.5405	0.3714
BH 34	0.0189	0.5744	0.8346	0.4458	0.5542	0	0.5445	0.3018
BH 35	0.0173	0.6367	0.8868	0.4119	0.5881	0	0.5453	0.3207
BG 11	0.0399	0.2000	0.7826	0.5929	0.4071	0	0.5191	0.2113
BG 12	0.0435	0.2000	0.7911	0.4964	0.5036	0	0.5197	0.2617
BG 13	0.0295	0.4118	0.7826	0.5102	0.4898	0	0.5290	0.2591
BG 14	0.0165	0.3882	0.7748	0.5307	0.4693	0	0.5231	0.2455
BG 15	0.0117	0.2235	0.7826	0.5958	0.4042	0	0.4900	0.1981
BG 16	0.0074	0.2000	0.7826	0.5781	0.4219	0	0.5055	0.2133
BG 17	0.0122	0.4471	0.8003	0.4446	0.5554	0	0.5614	0.3118
BG 18	0.0094	0.6500	1.0000	0.0000	1.0000	0	0.6050	0.6050
BG 19	0.0115	0.8412	0.8346	0.2476	0.7524	0	0.5529	0.4160
BG 20	0.0138	0.8118	0.8003	0.3990	0.6010	0	0.5317	0.3196

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BG 21	0.0166	0.8000	1.0000	0.0000	1.0000	0	0.5583	0.5583
BG 22	0.0145	0.8000	1.0000	0.0000	1.0000	0	0.5563	0.5563
BG 23	0.0187	0.8000	1.0000	0.0000	1.0000	0	0.5403	0.5403
BG 24	0.0175	0.8000	0.8219	0.3700	0.6300	0	0.5178	0.3262
BG 25	0.0197	0.8000	0.8219	0.4010	0.5990	0	0.5507	0.3299
BG 26	0.0171	0.7412	0.9471	0.1330	0.8670	0	0.5654	0.4902
BG 27	0.0090	0.5647	0.9471	0.2433	0.7567	0	0.5573	0.4217
BG 28	0.0166	0.8000	0.9471	0.1146	0.8854	0	0.5815	0.5149
BG 29	0.0395	0.8000	1.0000	0.0000	1.0000	0	0.6396	0.6396
BG 30	0.0349	0.6765	0.9126	0.3233	0.6767	4	0.5775	0.3908
BG 31	0.0069	0.5278	0.9126	0.3523	0.6477	0	0.5601	0.3628
BG 32	0.0138	0.5059	0.9471	0.2591	0.7409	0	0.5877	0.4354
BG 33	0.0154	0.6000	0.9126	0.3312	0.6688	0	0.5747	0.3844
BG 34	0.0516	0.6529	0.8868	0.3523	0.6477	4	0.5652	0.3661
BG 35	0.0297	0.8353	0.8868	0.3475	0.6525	0	0.5486	0.3580
BF 10	0.0421	0.2000	0.8105	0.4905	0.5095	0	0.4952	0.2523
BF 11	0.0236	0.2000	0.8346	0.3957	0.6043	0	0.4634	0.2800
BF 12	0.0105	0.2000	0.8105	0.3806	0.6194	0	0.4681	0.2900
BF 13	0.0079	0.2000	0.8492	0.2291	0.7709	0	0.4664	0.3595
BF 14	0.0212	0.2000	0.8346	0.2555	0.7445	0	0.4605	0.3429
BF 15	0.0100	0.2000	0.7826	0.5025	0.4975	0	0.4878	0.2427
BF 16	0.0040	0.2000	0.7911	0.3914	0.6086	0	0.5251	0.3196
BF 17	0.0008	0.6464	0.8105	0.3970	0.6030	0	0.6064	0.3656
BF 18	0.0009	0.6902	1.0000	0.0000	1.0000	0	0.6176	0.6176
BF 19	0.0030	0.5419	1.0000	0.0000	1.0000	0	0.5465	0.5465
BF 20	0.0038	0.8678	1.0000	0.0000	1.0000	0	0.5641	0.5641
BF 21	0.0040	0.8000	1.0000	0.0000	1.0000	0	0.5161	0.5161
BF 22	0.0055	0.8000	1.0000	0.0000	1.0000	0	0.5159	0.5159
BF 23	0.0079	0.8000	1.0000	0.0000	1.0000	0	0.5267	0.5267
BF 24	0.0116	0.8000	1.0000	0.0000	1.0000	0	0.5144	0.5144

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BF 25	0.0094	0.8000	0.8663	0.2341	0.7659	0	0.5521	0.4228
BF 27	0.0120	0.8000	1.0000	0.0000	1.0000	0	0.6040	0.6040
BF 28	0.0164	0.8000	0.9471	0.0908	0.9092	0	0.5364	0.4877
BF 29	0.0250	0.8000	1.0000	0.0000	1.0000	0	0.5914	0.5914
BF 30	0.0441	0.8000	1.0000	0.0000	1.0000	0	0.6150	0.6150
BF 31	0.0264	0.8529	0.9126	0.2120	0.7880	0	0.6001	0.4729
BF 32	0.0385	0.8941	0.9471	0.1903	0.8097	0	0.6189	0.5011
BF 33	0.0531	0.8000	0.9471	0.2054	0.7946	4	0.5925	0.4708
BF 34	0.0532	0.8000	1.0000	0.0000	1.0000	4	0.5798	0.5798
BF 35	0.0330	0.8125	1.0000	0.0000	1.0000	4	0.5489	0.5489
BE 17	0.0014	0.4471	1.0000	0.2341	0.7659	0	0.6111	0.4680
BE 20	0.0001	0.8235	1.0000	0.0000	1.0000	0	0.5731	0.5731
BE 21	0.0035	0.8000	1.0000	0.0000	1.0000	0	0.5082	0.5082
BE 22	0.0025	0.8332	1.0000	0.0000	1.0000	0	0.5423	0.5423
BE 23	0.0024	0.8166	1.0000	0.0000	1.0000	0	0.5689	0.5689
BE 24	0.0101	0.8000	1.0000	0.0000	1.0000	0	0.5413	0.5413
BE 25	0.0098	0.8000	1.0000	0.0000	1.0000	0	0.5392	0.5392
BE 26	0.0010	0.8000	1.0000	0.0000	1.0000	0	0.6124	0.6124
BE 27	0.0004	0.8000	1.0000	0.0000	1.0000	0	0.6060	0.6060
BE 28	0.0069	0.8000	1.0000	0.0000	1.0000	0	0.5331	0.5331
BE 29	0.0091	0.8000	1.0000	0.0000	1.0000	0	0.5546	0.5546
BE 30	0.0139	0.8000	1.0000	0.0000	1.0000	0	0.5629	0.5629
BE 31	0.0283	0.8000	1.0000	0.0000	1.0000	0	0.6118	0.6118
BE 32	0.0332	0.8000	0.9126	0.2341	0.7659	0	0.5736	0.4393
BE 33	0.0442	0.8000	1.0000	0.0000	1.0000	4	0.5617	0.5617
BE 34	0.0459	0.8000	1.0000	0.0000	1.0000	4	0.5433	0.5433
BE 35	0.0374	0.8000	1.0000	0.0000	1.0000	4	0.5264	0.5264
BD 17	0.0077	0.7647	0.7826	0.3327	0.6673	0	0.5496	0.3668
BD 20	0.0020	0.8353	1.0000	0.0000	1.0000	0	0.5214	0.5214
BD 21	0.0038	0.8097	1.0000	0.0000	1.0000	0	0.5051	0.5051

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BD 22	0.0006	0.8042	1.0000	0.0000	1.0000	0	0.5728	0.5728
BD 23	0.0037	0.8021	1.0000	0.0000	1.0000	0	0.5509	0.5509
BD 24	0.0114	0.8000	1.0000	0.0000	1.0000	0	0.5356	0.5356
BD 25	0.0108	0.8000	1.0000	0.0000	1.0000	0	0.5391	0.5391
BD 26	0.0160	0.8000	1.0000	0.0000	1.0000	0	0.5230	0.5230
BD 27	0.0034	0.8000	1.0000	0.0000	1.0000	0	0.5541	0.5541
BD 29	0.0040	0.8000	1.0000	0.0000	1.0000	0	0.5129	0.5129
BD 30	0.0079	0.8000	1.0000	0.0000	1.0000	0	0.5190	0.5190
BD 31	0.0186	0.8000	1.0000	0.0000	1.0000	0	0.5658	0.5658
BD 32	0.0241	0.8443	0.9471	0.2555	0.7445	0	0.5472	0.4074
BD 33	0.0289	0.8699	1.0000	0.0000	1.0000	0	0.5450	0.5450
BD 34	0.0384	0.8291	1.0000	0.0000	1.0000	0	0.5218	0.5218
BD 35	0.0202	0.8000	1.0000	0.0000	1.0000	0	0.4887	0.4887
BC 17	0.0018	0.7958	0.7826	0.2238	0.7762	0	0.5060	0.3927
BC 18	0.0017	0.8118	1.0000	0.0000	1.0000	0	0.5381	0.5381
BC 19	0.0009	0.8976	1.0000	0.0000	1.0000	0	0.5656	0.5656
BC 20	0.0034	0.8948	1.0000	0.0000	1.0000	0	0.4920	0.4920
BC 21	0.0074	0.8152	1.0000	0.0000	1.0000	0	0.5018	0.5018
BC 22	0.0008	0.8332	1.0000	0.0000	1.0000	0	0.5560	0.5560
BC 23	0.0043	0.8000	1.0000	0.0000	1.0000	0	0.4828	0.4828
BC 24	0.0101	0.8000	1.0000	0.0000	1.0000	0	0.4861	0.4861
BC 25	0.0057	0.8000	1.0000	0.0000	1.0000	0	0.4896	0.4896
BC 26	0.0103	0.8000	1.0000	0.0000	1.0000	0	0.4891	0.4891
BC 27	0.0060	0.8000	1.0000	0.0000	1.0000	0	0.5372	0.5372
BC 28	0.0020	0.8000	1.0000	0.0000	1.0000	0	0.5395	0.5395
BC 29	0.0027	0.8000	1.0000	0.0000	1.0000	0	0.5160	0.5160
BC 30	0.0071	0.8000	1.0000	0.0000	1.0000	0	0.4991	0.4991
BC 31	0.0061	0.8000	1.0000	0.0000	1.0000	0	0.5332	0.5332
BC 32	0.0131	0.8055	1.0000	0.0000	1.0000	0	0.5230	0.5230
BC 33	0.0157	0.8796	1.0000	0.0000	1.0000	0	0.5123	0.5123

Grid cell number	PRA	PGA	PWS	RPOP	1-RPOP	Water availability ranking	MHVI	ELVI
BC 34	0.0168	0.8664	1.0000	0.0000	1.0000	0	0.5102	0.5102
BB 19	0.0030	0.8097	1.0000	0.0000	1.0000	0	0.5081	0.5081
BB 20	0.0037	0.9073	1.0000	0.0000	1.0000	0	0.5110	0.5110
BB 21	0.0015	0.9308	1.0000	0.0000	1.0000	0	0.4894	0.4894
BB 22	0.0031	0.8754	1.0000	0.0000	1.0000	0	0.4636	0.4636
BB 23	0.0012	0.8000	1.0000	0.0000	1.0000	0	0.5141	0.5141
BB 24	0.0026	0.8000	1.0000	0.0000	1.0000	0	0.5101	0.5101
BB 25	0.0080	0.8000	1.0000	0.0000	1.0000	0	0.4890	0.4890
BB 26	0.0101	0.8000	1.0000	0.0000	1.0000	0	0.4934	0.4934
BB 27	0.0035	0.8000	1.0000	0.0000	1.0000	0	0.5209	0.5209
BB 28	0.0030	0.8000	1.0000	0.0000	1.0000	0	0.4878	0.4878
BB 29	0.0033	0.8000	1.0000	0.0000	1.0000	0	0.4658	0.4658
BB 30	0.0091	0.8000	1.0000	0.0000	1.0000	0	0.4916	0.4916
BB 31	0.0037	0.8000	1.0000	0.0000	1.0000	0	0.5486	0.5486
BB 32	0.0048	0.8000	1.0000	0.0000	1.0000	0	0.5028	0.5028
BB 33	0.0111	0.8042	1.0000	0.0000	1.0000	0	0.4856	0.4856
BB 34	0.0083	0.8817	1.0000	0.0000	1.0000	0	0.4797	0.4797
BA 21	0.0012	0.8125	1.0000	0.0000	1.0000	0	0.4826	0.4826
BA 25	0.0004	0.8000	1.0000	0.0000	1.0000	0	0.4902	0.4902
BA 26	0.0029	0.8000	1.0000	0.0000	1.0000	0	0.4831	0.4831
BA 27	0.0024	0.8000	1.0000	0.0000	1.0000	0	0.4453	0.4453
BA 28	0.0019	0.8000	1.0000	0.0000	1.0000	0	0.4588	0.4588
BA 29	0.0008	0.8000	1.0000	0.0000	1.0000	0	0.5287	0.5287
BA 30	0.0056	0.6339	1.0000	0.0000	1.0000	0	0.4473	0.4473
BA 33	0.0053	0.7308	1.0000	0.0000	1.0000	0	0.4457	0.4457
BA 34	0.0065	0.7834	1.0000	0.0000	1.0000	0	0.4371	0.4371

