Food and Agriculture Organization of the United Nations

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Using the FAO Agricultural Stress Index System (ASIS) to enhance the understanding of, and boost resilience to, water stress conditions in drought-prone areas

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**Using the FAO Agricultural Stress Index System (ASIS)
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water stress conditions in drought-prone areas**

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Acknowledgements

Abbreviations

ASIS	Agricultural Stress Index System
AVHRR	Advanced Very High Resolution Radiometer
DIX	Agricultural Drought Index
DROUGHT DESCRIBE	DROUGHT Data on Environmental Stress and Characterization Information Base Engine
DROUGHT SMART	DROUGHT System for Monitoring and Assessment in near Real Time
DRR	Disaster Risk Reduction
EO	Earth Observation
FAO	Food and Agriculture Organization of the United Nations
FEWS-NET	Famine Early Warning Systems Network
GAUL	Global Administrative Unit Layers
GIS	Geographic Information System
GMIA	Global Map of Irrigated Areas
GWSI	Global Water Satisfaction Index
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IPCC	International Panel on Climate Change
LDCs	Least Developed Countries
LLDCs	Landlocked Developing Countries
LTA	Long-term average
METOP	Meteorological Operational satellite programme
NAP	National Action Plan
NDIX	Normalized Drought Index
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
SAGE	Center for Sustainability and the Global Environment
SDGs	Sustainable Development Goals
SIDs	Small Island Developing States
SOLAW	State of the World's Land and Water Resources for Food and Agriculture

Abstract

An important share of the population in developing countries is dependent on agriculture for its livelihoods, making these people particularly vulnerable to extreme weather events resulting from changing climatic conditions (IPCC, 2012).

In order to boost the resilience of livelihoods to threats arising from climate change, and especially drought events, it is primordial to identify drought-prone areas and their biophysical, socio-economic and agricultural characteristics.

The DROUGHT DESCRIBE database (Data on Environmental Stress and Characterization Information Base Engine) allows for the analysis of the spatial and temporal extent of drought events and their impact upon agriculture and water management in drought-prone areas. In addition, the study of the database's historical remote sensing data, combined with several other relevant indicators, may provide insights into the occurrence of future drought events. This analysis was carried out by means of a prototype tool, DROUGHT SMART (System for Monitoring and Assessment in near Real Time).

The study generated records for subnational administrative units worldwide, whereby past drought events were defined by severity and rate of recurrence, combined with environmental, agricultural and socio-economic indicators.

The use of earth observations and global statistics may result in the under- or overestimation of values. The results of the study should analysed carefully, and verified against field data at the level of subnational administrative units by national experts.

Keywords:

1. Background

As a result of climate change, extreme adverse natural events are becoming increasingly frequent, severe and costly. Through such events, climate change affects all four dimensions of food security: food *availability*, food *accessibility*, food *utilization* (which is affected by food *safety*), and the *stability* of these three dimensions over time (FAO, 2008).

The increasing frequency and severity of drought events have a significant impact upon crop and livestock production systems, food markets and local economies around the world. Contrary to one-off natural disasters such as earthquakes, droughts are slow-onset shocks, with prolonged and potentially devastating consequences. Drought events affect the very basics of food production, including soil characteristics, water availability and biodiversity. Sparse or absent rains result in a loss of soil productivity and greater land degradation, factors that contribute to desertification (FAO, 2016). In Africa, less – and more erratic – rainfall will make harvests more unpredictable and result in lower aggregate production (Boko *et al.,* 2007).

While developing countries are in particular need of reliable information and evidence-based decision making to better adapt to the recurrence of droughts, drought events constitute a challenge for authorities worldwide, from the national to the local level. Indeed, the adverse effect of droughts on food security is a potential cause for armed conflicts, famine and the creation of refugee flows.

Although the occurrence and severity of future drought events remain unpredictable, overall climate change is expected to result in an increase in the frequency of drought events and worsen their impact on livelihoods (Van Huijgevoort *et al.,* 2013). According to IPCC (2007), a rise in temperatures of two to three degrees Celsius may lead to: a significant decrease in crop and livestock productivity in (sub) tropical regions, and especially in seasonally dry areas; a significant fall in crop yields in certain rain-fed African agricultural systems; an increase in desertification and soil salinization in Asia, sub-Saharan Africa and Latin America; and increased water stress, particularly in irrigated production systems.

A report released in April 2014 by the Intergovernmental Panel on Climate Change (IPCC, 2014) forecasts serious disruptions to agricultural systems due to shifting weather patterns.

A particular cause for concern is the impact of drought events on food security in least-developed countries (LDCs). LDCs' most vulnerable communities often live in drought-prone areas, and are greatly dependent on agriculture for their livelihoods. Those relying on livestock for their livelihoods are particularly vulnerable, as it takes a long time to rebuild herds decimated by drought episodes.

Disaster risk reduction (DRR) and management is one of FAO's corporate priorities, as expressed in its Reviewed Strategic Framework 2010-19. This priority is further elaborated in Strategic Objective 5: to "increase the resilience of livelihoods to threats and crises" (FAO, 2013). Broadening our knowledge of the characteristics of drought-prone areas and the impact of drought events on vulnerable communities is crucial to realizing this objective. Indeed, the identification of hotspot areas, where drought episodes are likely to reoccur, and their characteristics helps authorities and communities to timely detect drought events and take appropriate action to boost the resilience of food production systems in the most vulnerable areas.

2. Study overview and objectives

2.1. Methodological approach

The present study examines the occurrence, frequency and intensity of drought events, as well as the environmental, agricultural and socio-economic characteristics of drought-prone areas across the globe. The identification of hotspots of drought stress is essential to pinpoint administrative areas in need of immediate intervention.

Thirty years' worth of earth observation data from the Agricultural Stress Index System (ASIS) were examined. These seasonal indicators are designed to allow cropland areas with a high likelihood of water stress (drought) to be easily identified. Ancillary biophysical, socio-economic and agricultural datasets were added to the application for further in-depth vulnerability analysis of drought-prone areas.

The resulting database is essential to identify drought hotspots, as well as analyze the interaction between drought events and variables such as water regimes, field size and crop intensity and type. This analysis is key to assessing the impact of droughts on agricultural production and livelihoods, and ensuring that efforts to counter the impact of climate change are directed to the most vulnerable areas. The database allows users to identify, for example, administrative areas with a high proportion of the population living in rural areas, rain-fed small-sized fields (smallholder farms[1]) and a high occurrence of drought events. Such information is essential to target climate-proof investments and formulate science-based development policies.

The earth observation datasets used in the study were obtained through the use of satellites and remote sensing tools, which allow for the systematic collection of a comprehensive and detailed array of parameters.

The generation of drought-related data for the various (subnational) administrative zones and their classification according to ASIS helps to reveal patterns in the occurrence, frequency and severity of drought events for each administrative area based on seasonal, annual and long term (30 years) averages. As such, ASIS allows researchers to analyse the spatial and temporal dynamics of drought events over seasons and years, and examine the potential relationship between agricultural drought events and the El Niño phenomenon[2].

The study focused on agricultural areas affected by drought events at the subnational level, where all drought events affecting agricultural output, even those restricted to a limited area, are relevant. Adopting the same subnational approach, Oscar, Vrieling and Rembold (2011) identified several hotspots, or administrative areas with empirical probabilities of 35 percent (3.5 times every ten years) or more to see at least 30 percent of their agricultural area affected by drought events, in Africa: Tensift and Central in Morocco; Brakna in Mauritania; North Darfur in Sudan; Semenawi Keih Bahri in Eritrea; Coast and Eastern in

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1 It was assumed that small fields represent smallholder and subsistence farming; large fields'commercial, large-scale farming; and medium-sized fields mixed (subsistence/commercial) farming.

2 Originally the term *El Niño* applied to an annual weak warm ocean current that ran southwards along the coast of Peru and Ecuador about Christmas time. However, over time the term has evolved and now refers to the warm and negative phase of the El Niño Southern Oscillation and is the warming of the ocean surface or above-average sea surface temperatures in either the central and eastern tropical Pacific Ocean.

Kenya; Manyara, Tanga, Arusha and Kilimanjaro in Tanzania; Juba Hoose, Juba Dhexe and Shabelle Hoose in Somalia; Kaabong and Kiruhura in Uganda; Southern in Sierra Leone; Gbarpolu in Liberia; and Otjozondjupa in Namibia (Rojas, Vrieling and Rembold, 2011).

As the ASIS dataset is aggregated at the subnational administrative level (GAUL2), all outputs were generated, and the entire analysis conducted, at this level. Outputs are presented for each administrative unit.

2.2. Added value of the study

The study provides timely, reliable and disaggregated subnational data, which are especially useful to drought-prone African countries. Indeed, the timely assessment of drought-affected areas by size and crop type and of the related impact on agricultural revenue helps farming communities and policy makers to concentrate resilience boosting efforts on the most vulnerable areas, and protect agricultural investments against the effects of drought events.

The study's prototype tool for the analysis of drought-related data, DROUGHT SMART, will help strengthen national statistical and information systems in developing countries, including LDCs, small island developing states (SIDS) and landlocked developing countries (LLDCs). DROUGHT SMART is a user friendly tool, and requires only very basic computer equipment. It allows for data to be uploaded, exported, printed and updated as additional information becomes available.

The outputs of the study may be used by experts in the fields of food security early warning systems, economists, investment experts, land managers and land use planners, climate change adaptation and mitigation experts, researchers and NGOs; they can be used as preliminary inputs to build more detailed early warning systems, conduct trend analysis and improve crop growth forecasting.

Moreover, the study promotes transparent best practices sharing and cooperation between authorities by making a wide range of data (including earth observation and geospatial data) available to the public. At the same time, it ensures national ownership in line with the United Nations' Sustainable Development Goals (SDGs) (UN, 2015).

2.3. Contribution to the UN Sustainable Development Goals

In light of the potential contribution of the outputs of this study to boosting livelihood resilience to drought events in vulnerable areas, the study may contribute to a number of SDGs, including Goal 1, 2, 13 and 15:

Goal 1. End poverty in all its forms everywhere.
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
Goal 13. Take urgent action to combat climate change and its impacts.
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

The study directly contributes to several of the targets of the SDGs:

Goal 1: Target 1.5: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability.

Goal 2: Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

Goal 13: Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

> *Target 13.2 Integrate climate change measures into national policies, strategies and planning.*
>
> *Target 13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and smallisland developing States, including focusing on women, youth and local and marginalized communities.*

Goal 15: Target 15.9: By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

3. Study outputs

The study produced the following outputs:

(i) a new, unique database, DROUGHT DESCRIBE, by combining several existing global datasets at medium to high resolution for the subnational level (field size, irrigated areas, cropland intensity, distribution of crop types, number of growing seasons, and Global Administrative Unit Layers (GAUL2), in order to extract drought-related indicators for the past 30 years;

(ii) a characterization of every zone by ASI and associated characteristics, and long-term statistics for every crop growing season, by combining the DROUGHT DESCRIBE and ASIS databases;

(iii) an analysis and assessment of the results of (ii);

(iv) an analysis of spatial and temporal relationships and trends in drought-related data at the subnational (GAUL2) level and, after aggregation of the results, at the level of the country, region and continent;

v) a prototype tool -DROUGHT SMART- for the analysis of drought events and drought response planning, to be used mainly by policy makers, food security and early warning experts, emergency preparedness officers and field managers, without requiring knowledge of Geographic Information Systems (GIS) or remote sensing systems.

Drought-prone areas were described by agricultural practices, water regime, the share of the population living in rural areas, stunting rates (as a proxy for poverty) and the value of agricultural production. DROUGHT SMART was developed to monitor the frequency and severity of drought events in various parts of the world, identify past trends and help forecast future probabilities. The results of this analysis are presented as maps, tables and charts. Areas which are largely dependent on rainfall (as opposed to irrigation) and characterized by high cropland intensity, a large rural population and high poverty rates are singled out as priority areas for drought monitoring, resilience building, disaster risk reduction and emergency preparedness programs. Priority areas require the development of special contingency plans to alleviate the impact of drought events on food security; however, all areas should be monitored regularly given the unpredictability of drought episodes.

4. Methodology

4.1. Overview

The study was carried out according to the following steps:
- definition of the required outputs and functionality of the products:
    - selection of candidate indicators for the characterization of drought-prone areas;
    - identification of the variables for each indicator, considering biophysical, agricultural and socioeconomic dimensions (and especially variables related to food security and the occurrence of extreme events in space and time);

    screening and evaluation of candidate datasets based on coverage, consistency, and reliability;
- selection of the datasets;
- harmonization and calibration of the datasets using the ASIS reference grid;
- creation of the database;
- establishment of the classification system, class elements, number and classifier ranges:
    - classification rules based on the feature requirements for all data layers;
- classification of the input datasets according to intermediate outputs;
- validation of the preliminary outputs and calibration of the rule sets and datasets;
- quality control and quality assurance of the outputs.

4.2. Identification of drought-prone areas using ASI datasets

Initially, a unique identifier code was assigned to each geographical zone in the subnational administrative layer GAUL2. This code was used as the mapping unit and the main descriptor of the drought-prone areas. Administrative units (GAUL level 2) are commonly referred to as district level; each district area is thus identified by a unique identifier in the dataset, which serves as a joining point to many other variables. As a consequence, every unit /record contains all the information derived from all participating datasets.

ASIS values were then applied to every GAUL2 administrative unit. ASIS classifies administrative areas according to the percentage of their area affected by droughts, allowing cropland areas with a high likelihood of water stress (drought) to be easily identified. ASIS classifies as drought-affected areas those pixels for which a Vegetation Health Index (VHI) value is below 35. The indices are based on remote sensing data of vegetation and land surface temperature, combined with information on agricultural cropping cycles derived from historical data, and a global crop mask. ASIS evaluates the severity (intensity, duration and spatial extent) of drought events and presents the final results by administrative unit, thereby allowing for comparison between areas.

Global ASI time series datasets were used to identify cropland that was affected by drought conditions over the course of the past 30 years. The datasets used include:

- Annual ASI dataset: contains historical earth observation images for the period 1984-2013, and shows the percentage of arable land within an administrative area which has been affected by drought conditions over the entire cropping season. ASI values were extracted for every administrative area over the last 30 years.

- Seasonal ASI (S1 and S2) datasets: contain data for the first and second crop growing season. The seasonal indicators are designed to allow for the easy identification of areas of cropland with a high likelihood of water stress (drought). The values may reveal anomalous vegetation growth and potential drought conditions in crop zones during a growing season.

On the basis of ASI datasets, drought metrics such as Mean, Standard Deviation (SD), Min, Max, Median, SUM and Long-term Average (LTA) were extracted. These metrics are all available at subnational level (GAUL2-polygon) by year for the period 1984-2013.

Agricultural Drought Index (DIX)

ASIS demonstrates that some administrative areas experience few, but intense and protracted drought episodes, while other areas are prone to frequent, less intense and shorter episodes. An index was therefore constructed to identify drought hotspots on the basis of both the intensity (magnitude) and the frequency of drought events for each area over the 30-year time period. This index, the Agricultural Drought Index (DIX), thus reflects both the severity, the spatial and temporal extent of drought episodes and historical risk.

The magnitude of a drought event is defined as the sum of all ASI mean values extracted for an administrative unit, while its frequency is calculated based on the number of events which have occurred over the respective years:

DIX = Magnitude (Sum) * Frequency (Count)

Normalized Drought Index

The Normalized Drought Index (NDIX) was rescaled based on the range of the DIX for each area (values ranging from 0 to 100). It is calculated as follows:

$$NDIX = \left(\frac{DIX - DIX(min)}{DIX(max) - DIX(min)} \right) \times 100$$

where *DIX* is the actual value of the Agricultural Drought Index for each pixel, *DIX(min)* is the minimum value of the Agricultural Drought Index for each pixel, and *DIX(max)* is the maximum value of the Agricultural Drought Index for each pixel.

Normalized Drought Indexes are constructed for the smallest administrative units, and may be aggregated for larger areas.

NDIX and other results were used to identify drought hotspots using the hotspot mapping technique.

4.3. Classification of administrative areas according to ancillary characteristics

Ancillary datasets were selected based on the needs of potential users and the availability, quality and reliability of available data, and added to the application for further and more in-depth vulnerability analysis. This supplementary information allows users to identify, for example, administrative areas with a high proportion of their population living in rural areas, a concentration of rainfed, small-sized fields (smallholder farms) and ASI values as drought hotspots. Similar queries may provide answers to questions related to food security, drought monitoring and climate change adaptation.
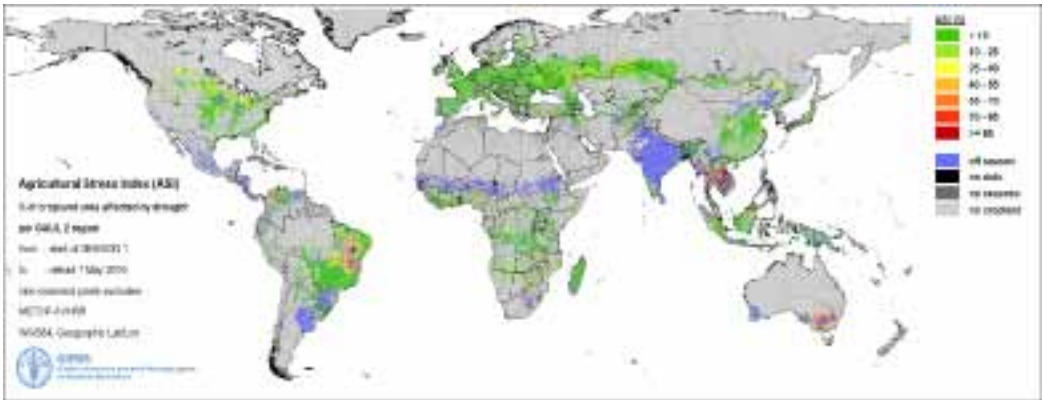
Several ancillary characteristics were added to the description of each administrative unit, including:

- crop phenology (start of season, end of season);
- cropland intensity (low, medium, high and very high);
- rainfed agricultural areas (areas which are mainly dependent on rainfall) as a share of total agricultural area;
- irrigated agricultural areas as a share of total agricultural area;
- field size (small, medium-sized and large fields, representing smallholders to large, commercial producers);
- cropping types and patterns (the study considers 11 major crops, including wheat, rice, maize, sorghum, barley, beans, potatoes, millet, groundnuts, soybeans and pulses);
- stunting data and population density in or around the year 2000 (persons/km²);
- the monetary value of agricultural outputs: the potential output of nine "umbrella" crops (including wheat, maize, sorghum, soybeans, groundnuts, oil palm, sugarcane, cassava and cotton) under rainfed conditions, assuming good management and a high level of inputs, in GK$/ha (a spatial-explicit global database at 5 arc-minute resolution, with the year 2000 as baseline, created using the IIASA/FAO Global Agro-Ecological Zones database 3.0), assessing the agro-ecological suitability for these major crops (Deininger and Byerlee, 2011).
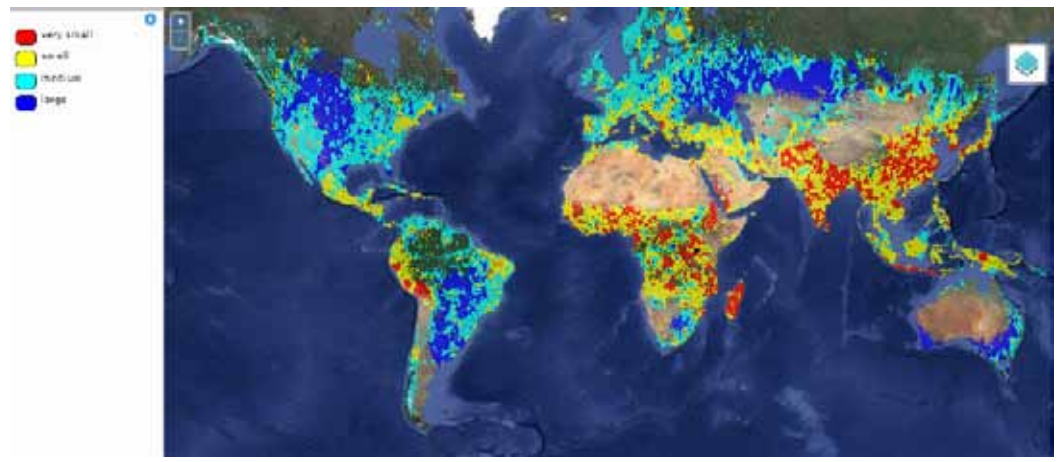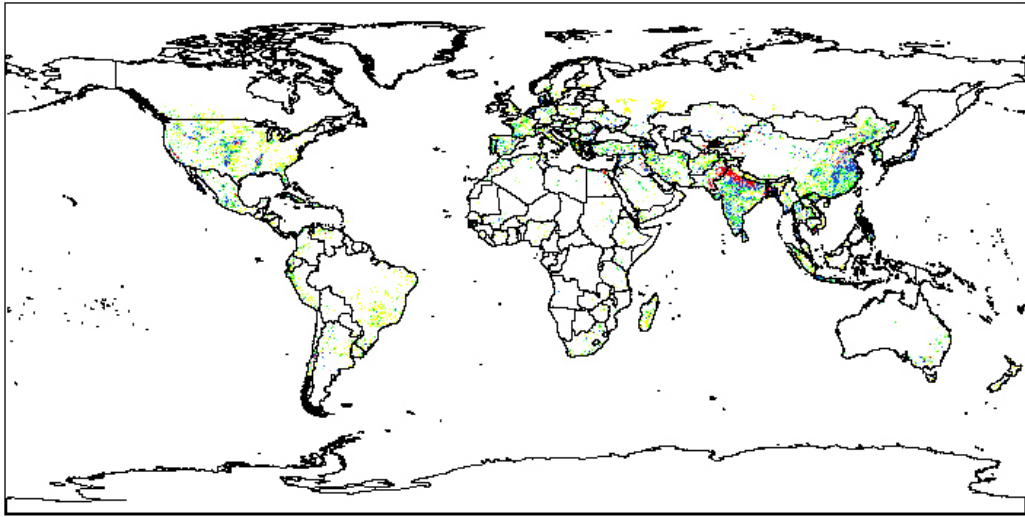
The resulting database, DROUGHT DESCRIBE, is open to the addition of other reliable datasets as they become available.
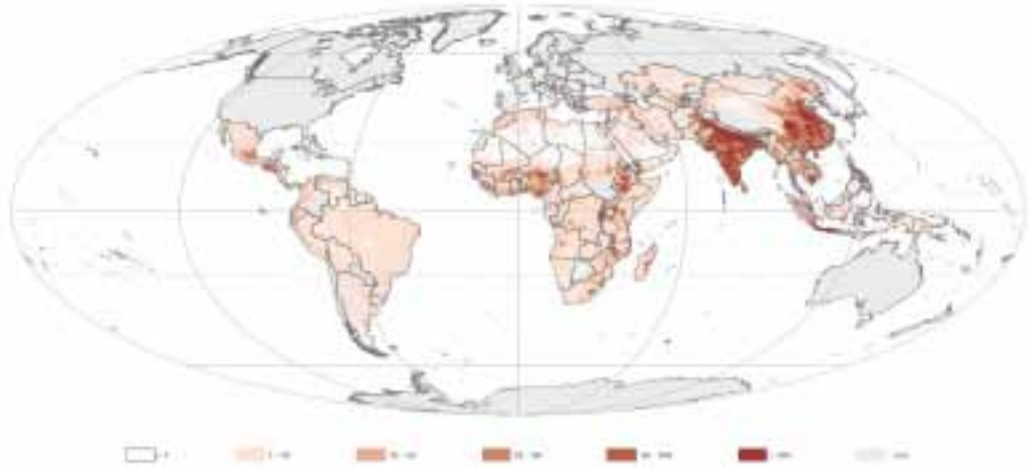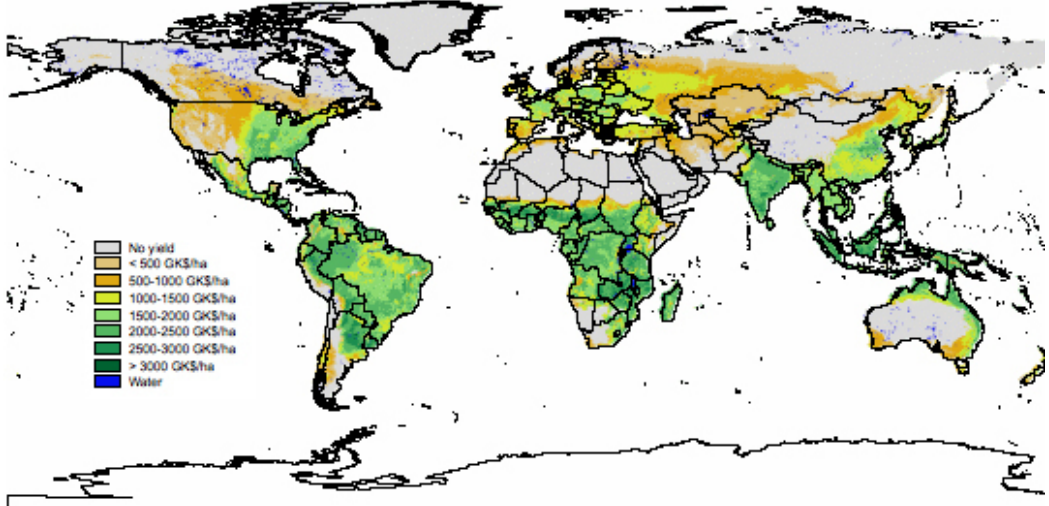
Table 1 details the datasets incorporated in the DROUGHT DESCRIBE database. These datasets include information on cropland intensity, crop type, the number of growing cycles, crop phenology, farm field size, water supply regime, poverty, rural population, the value of agriculture production, and subnational administrative units (GAUL2) worldwide.

Table 1: Datasets incorporated in the DROUGHT DESCRIBE database

	ASIS database
Data used	The remote sensing data used in this study are decadal and monthly normalized difference vegetation index (NDVI) time series at 1 km geometric resolution for the period 1984-2014. These data are derived from METOP-AVHRR (2007-2014, 1 km resolution) and NOAA-AVHRR (1984-2007, 16 km resolution) images. Original NDVI values are resampled in 8 bit images (0-255).
Link	http://www.fao.org/giews/earthobservation/
Notes	ASI represents the percentage of cropped areas within each administrative region affected by drought conditions according to Earth Observation (EO) data and defined over the course of the growing season.
Percentage of cropland area affected by drought	

	Cropland intensity
Data used	The data on cropland intensity used in this study were derived from the FAO Global Land Cover-SHARE (GLC-SHARE) database (Beta-Release 1.0 for the year 2010, with a resolution of 30 arc-second in geographic projection); the main layer used is cropland. The value of the pixels (ranging from 0 to 100) indicates the share of the area of the pixel that is used for agricultural purposes.
Link	www.fao.org/geonetwork
Notes	The dataset is used to classify areas according to cropland intensity in DROUGHT DESCRIBE (own calculations).
Cropland Intensity	
	GAUL
Data used	The administrative regions used in the study were obtained from the Global Administrative Unit Layers (GAUL) database, an initiative carried out by FAO and funded by the European Commission. The size of the administrative units varies considerably, according to the administrative organization of each country.
Link	http://www.foodsec.org/tools_gaul.htm
Notes	GAUL provides, for all the world's countries, the most consistent spatial information on administrative units existing. This study considered subnational administrative units (level 2), which form a homogeneous reference layer at the global scale. GAUL data were aggregated to various levels to enable their analysis and visualization.
	Global field size
Data used	A global field size map was produced at the same resolution as the global cropland map (30 arc-second resolution in geographic projection), through the interpolation of field size data collected from Geo-Wiki, which compiles geographical information through crowdsourcing. The results corresponded satisfactorily with control data, especially considering the relatively modest size of the field size dataset used to create the map. This study used the 1 km global IIASA-IFPRI cropland percentage map for the baseline year 2005, which was developed by integrating a number of individual cropland maps at global to regional to national scales. The individual map products include existing global land cover maps such as GlobCover 2005 and MODIS v.5, regional maps such as AFRICOVER and national maps from mapping agencies and other organizations. The new IIASA-IFPRI cropland product has been validated using very high-resolution satellite imagery via Geo-Wiki and has an overall accuracy of 82.4 percent. It has also been compared with the EarthStat cropland product, and shows a lower root mean square error on an independent dataset collected from Geo-Wiki.
Link	http://www.geo-wiki.org/downloads/
Notes	The dataset is used to classify areas according to field size in DROUGHT DESCRIBE (own calculations).

Global field size	
Global field size Map	

Global Map of Irrigated Areas	
Data used	The C version 5.0 (GMIA-5) shows the area equipped for irrigation (in or around the year 2005) as a percentage of the total land area on a raster, with a resolution of five arc-minutes. Additional map layers show the percentage of the area equipped for irrigation that is actually used for irrigation, and the percentage of the area equipped for irrigation that is irrigated with groundwater, surface water or non-conventional sources of water. The information for these additional layers was derived from statistical survey data (e.g. census reports). All grid cells belonging to the same statistical unit therefore have the same value, and the accuracy at pixel level is limited, depending on the size of the statistical unit. The value of the pixels ranges from 0 to 100, indicating the area equipped for irrigation as a percentage of total land area for each cell.
Link	www.fao.org/geonetwork
Notes	The dataset is used to classify areas according to water regime in DROUGHT DESCRIBE (own calculations).
Global Map of Irrigated Areas	Map layers are generated as grids and distributed as follows:

Poverty distribution in developing countries, based on child stunting	
Data used	Chronic child malnutrition as evidenced by stunting among children under 5 years of age constitutes a good proxy for rural poverty and food insecurity (FAO, 2008b). The map shows poverty distribution (poor persons/square kilometer) by overlaying stunting rates and population density rates.
Link	http://www.fao.org/geonetwork/srv/en/main.home?uuid=eaadb457-734a-4f4f-aaf2-de2af4f489a3

	Poverty distribution in developing countries, based on child stunting
Notes	The map published in FAO's State of the World's Land and Water Resources for Food and Agriculture (SOLAW) is reproduced below. The input data used to produce the map include: - Global Administrative Unit Layers (GAUL 2008); - stunting data and population density rates in or around the year 2000 (with a resolution of 5 arc-minutes) from the Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007).
Poverty distribution in developing countries, based on child stunting	

|	**Value of agricultural production**
Data used	Potential productivity of the umbrella crop under rainfed conditions (GK$/ha).
Link	www.iiasa.ac.at http://siteresources.worldbank.org/INTARD/Resources/ESW_Sept7_final_final.pdf
Notes	The "umbrella" crop is obtained from a spatial-explicit global database at 5 arc-minute resolution with the year 2000 as baseline. It is created using the IIASA/FAO Global Agro-Ecological Zones database (version 3.0), assessing the agro-ecological suitability for nine major crops (wheat, maize, sorghum, soybeans, groundnuts, oil palm, sugar cane, cassava and cotton). It estimates the attainable agro-ecological yield and production and constructs an "umbrella" crop by selecting, for each grid cell, the crop that has the highest net output value, considering the yield and value of agriculture production. The "fair" land value is calculated on the basis of estimated attainable output values, minus location-specific reference production and transportation costs using data from FAOSTAT 1999-2001 database and other sources. The pixel value indicates the value of agriculture production using the "umbrella" crop under rain-fed conditions, assuming good management and high input level (in 000 GK$/ha). It is used as a proxy for the value of agriculture production and indicates the potential impacts of drought events on agricultural areas.
Map	

	Cropping patterns
Data used	Crop masks were created by combining FAO's major crop masks with SAGE (Center for Sustainability and the Global Environment) crop masks for which the harvested area is greater than 10 percent (see Monfreda *et al.,* 2008). These combined sources were generalized to eliminate scattered cropland masking patterns. The final mask is a selection of Global Water Satisfaction Index (GWSI) grid cells intersecting with the generalized mask or with one of the original crop masks (FAO or SAGE). As such, no areas are omitted, while the final mask is generally contiguous. For some crops, no FAO major crop mask was available, and only SAGE data were used.
Link	http://www.isprs.org/proceedings/XXXVI/part7/PDF/066.pdf
Notes	The crops include barley, maize, wheat, rice, sorghum, soybean, millet, potatoes*, beans*, groundnuts* and chickpeas/pulses. * no FAO major crop mask available.
Maize cropping patterns	

5. Findings

5.1. Identification of drought hotspots

Hotspots were identified by means of hotspot analysis, a statistical technique usually undertaken to identify incidents that are concentrated within certain geographical areas over time. The identification of drought hotspots and the analysis of their characteristics is essential to tackle the consequences of drought events. In this study, hotspots were identified based on z-scores and p-values of NDIX. The study identified 1928 highly significant records (administrative units with a z-score ≥ 2.58 at the global scale and a p-value for each feature[3]) (Figure 1). The administrative units were intersected with the cropland data layer to avoid non-crop areas from being identified as hotspots.

**Figure 1: Z-scores and p-values of normal distribution**
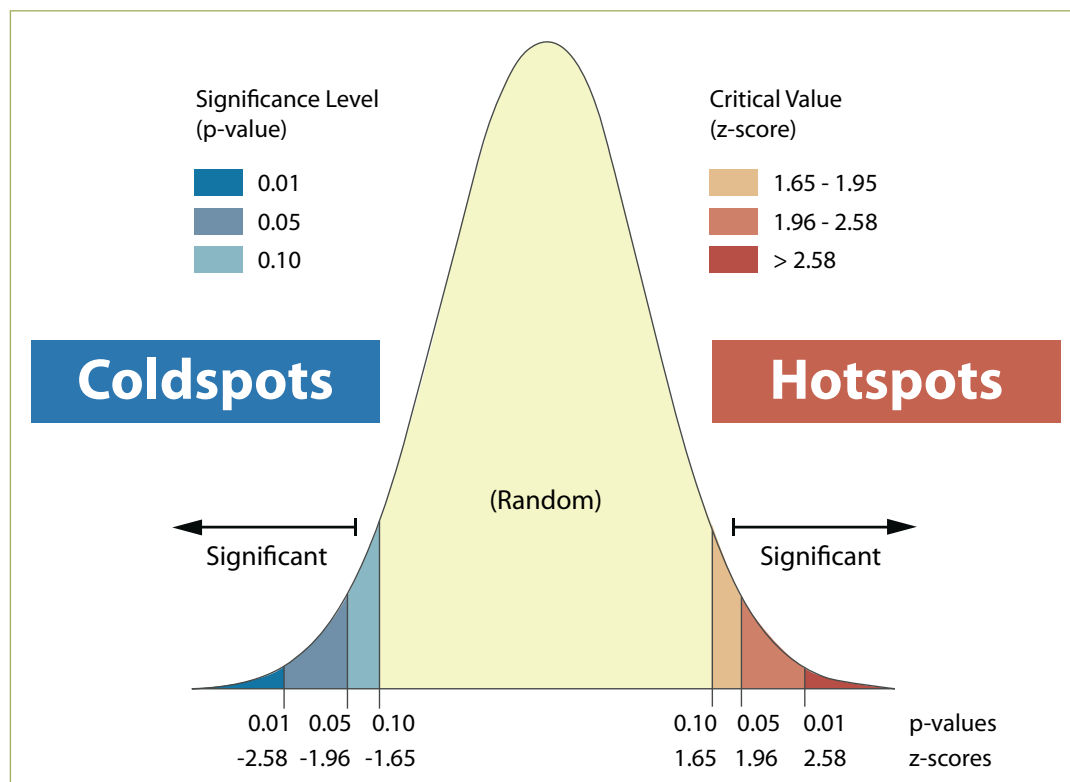
Source: ESRI

The study's resulting product indicates where drought-prone areas are concentrated, showing locations (administrative units) which require immediate attention from their respective authorities. The most statistically significant drought hotspots for the period 1984-2013 are indicated in red on Figure 2. They seem to be principally located in semi-arid and arid areas, for example in eastern and southern Africa, the Mediterranean region, the western United States, India, China, Sri Lanka, Chile, Brazil, Peru and around the equator. Some areas in these countries are permanently dry, while others have gone through long spells of drought over the past three decades (1984-2013).

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3 The standard score or z-score indicates the probability of a score occurring within the normal distribution of the data, while the p-value helps determine the significance of the results.

Figure 2: **Global distribution of drought hotspots**
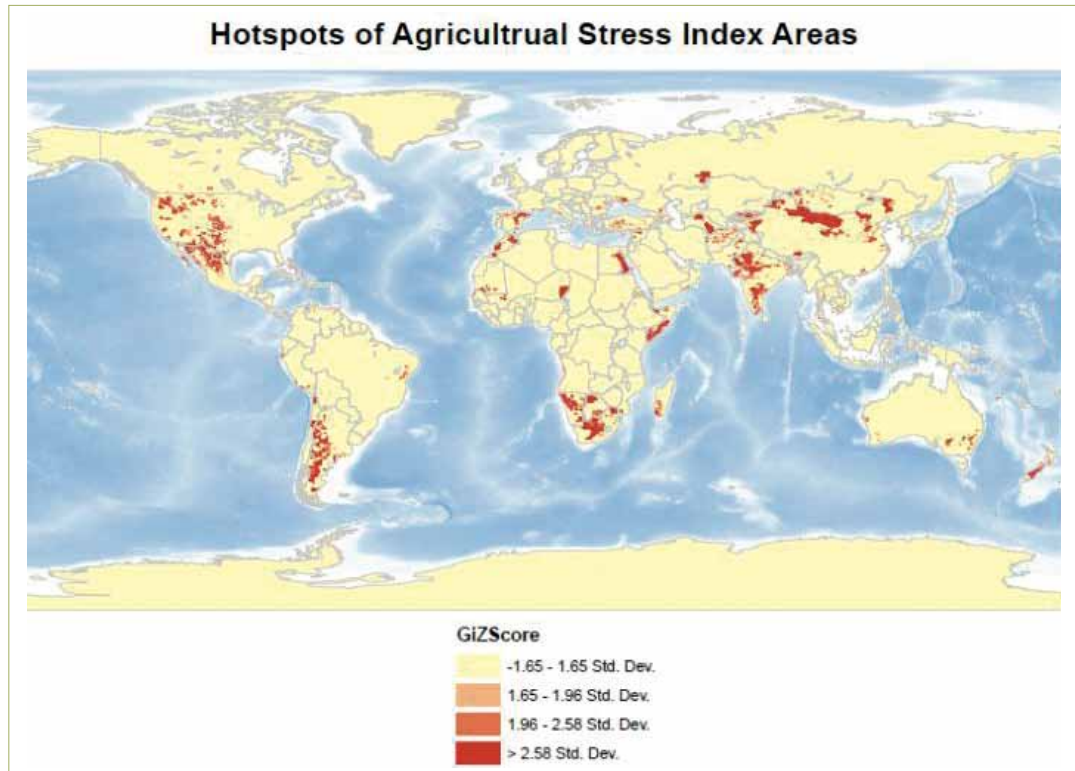
Further information on cropland density in these areas allows researchers to estimate the cropland area affected by protracted and recurrent drought events. Hotspots should be further analyzed by experts on the situation on the ground, using field data (for example on crop masks or the use of irrigation) to interpret the observations made in this study.

The identification of drought hotspots is crucial to drought-prone countries in the elaboration of policies (early warning systems, DRR, national action programs (NAPs), emergency preparedness plans) to strengthen their resilience to drought events; attention should be directed specifically towards these areas.

In many developing countries, the population in drought hotspots is heavily dependent on agriculture for its livelihood. The adverse effects of drought episodes on food security may therefore lead to political unrest, highlighting the imperativeness of immediate remedial actions.

Figures 3 to 9 illustrate the information generated over the course of the study.

Figure 3: Distribution of rain-fed fields as percentage of total cropland area at the second subnational level (baseline year 2010)
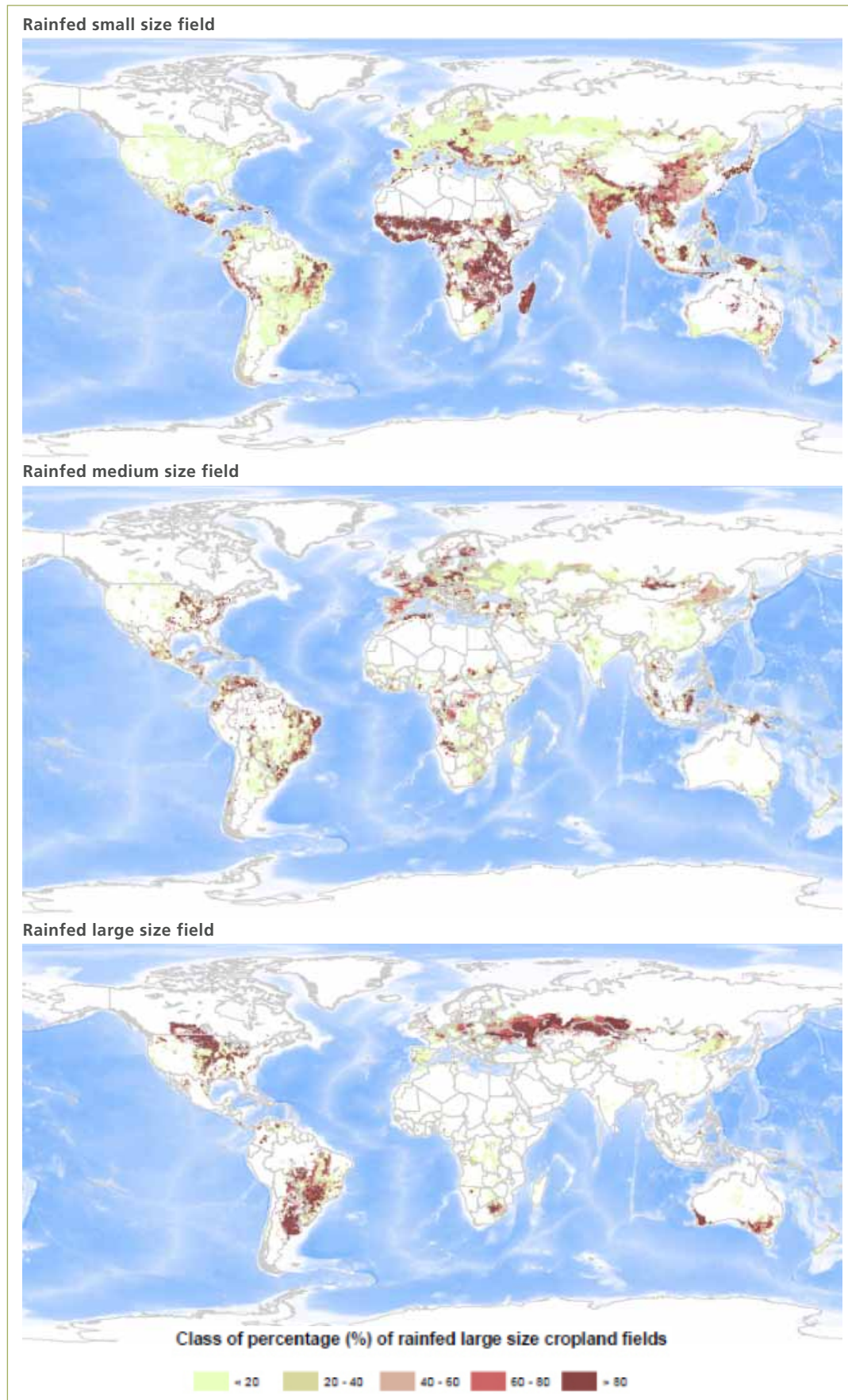
Rainfed small size field

Rainfed medium size field

Rainfed large size field

Class of percentage (%) of rainfed large size cropland fields

< 20   20 - 40   40 - 60   60 - 80   > 80

Figure 4: Distribution of irrigated fields as percentage of total cropland area at the second subnational level (baseline year 2010)
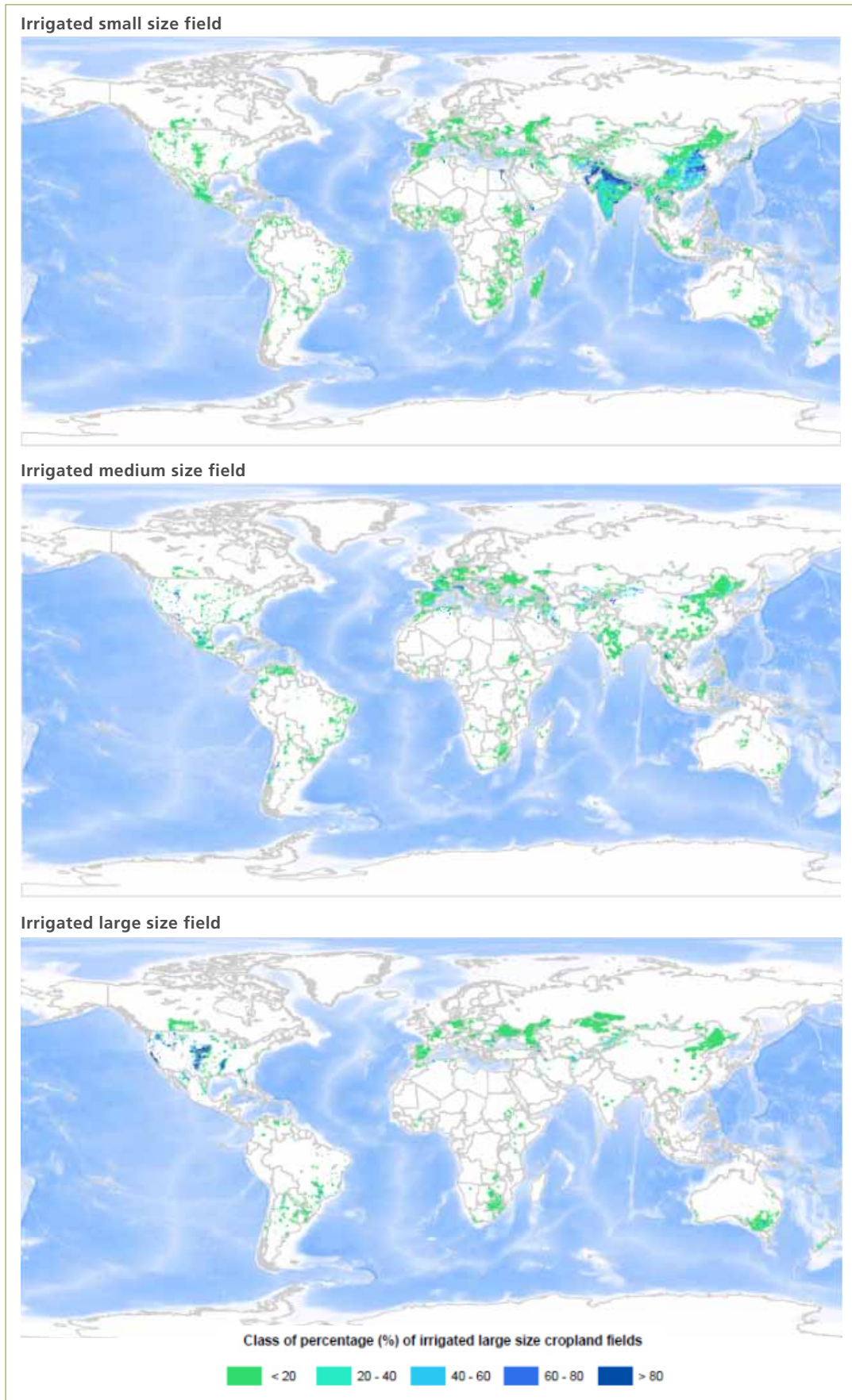
Irrigated small size field

Irrigated medium size field

Irrigated large size field

Class of percentage (%) of irrigated large size cropland fields

< 20   20 - 40   40 - 60   60 - 80   > 80

Figure 5: Distribution of irrigated and rainfed cropland share as percentage of total cropland area (baseline year 2010)
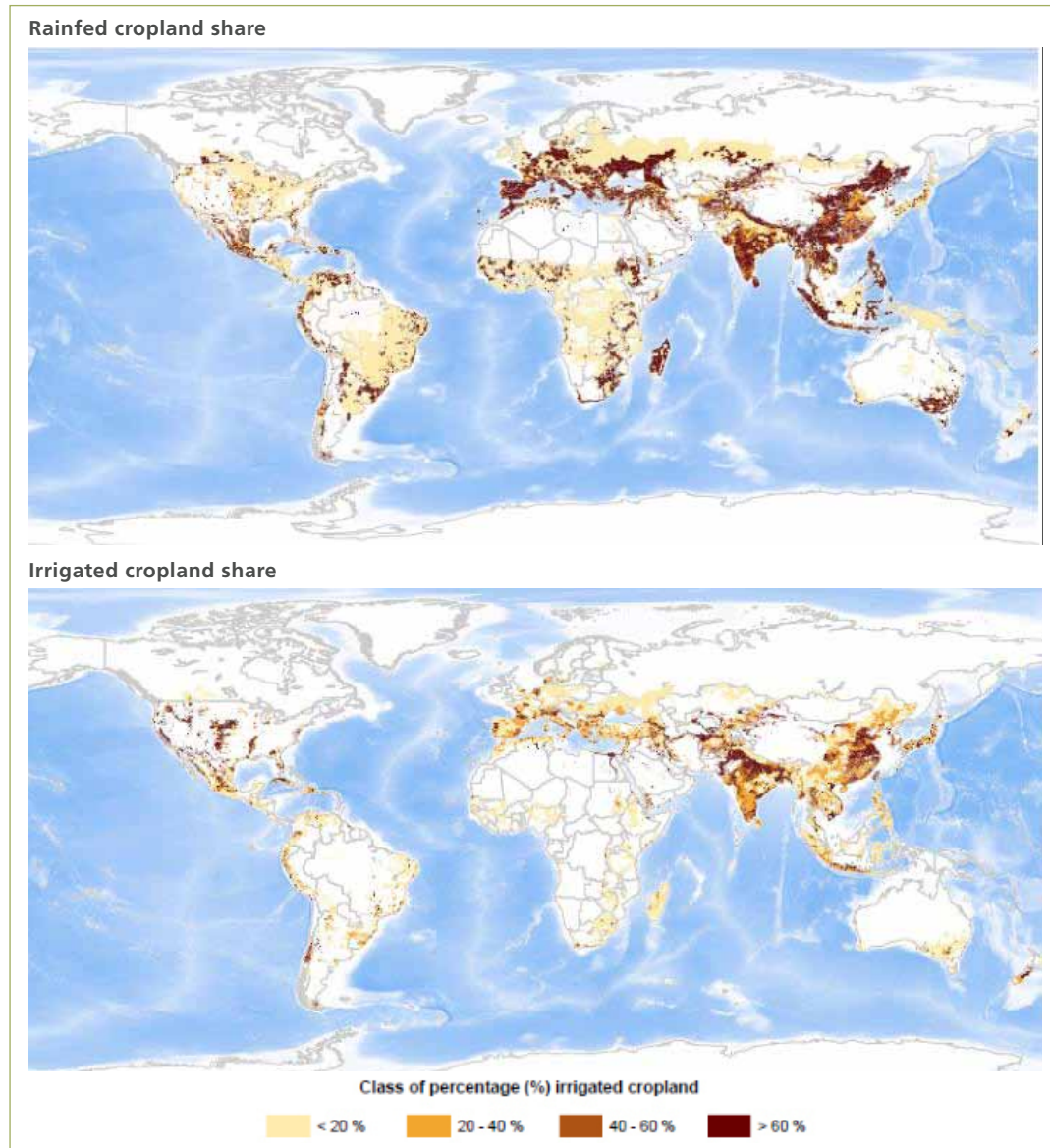
Rainfed cropland share

Irrigated cropland share

Class of percentage (%) irrigated cropland

< 20 %   20 - 40 %   40 - 60 %   > 60 %

Figure 6: Distribution of cropland intensity share (baseline year 2010)

Classes of cropland intensity share
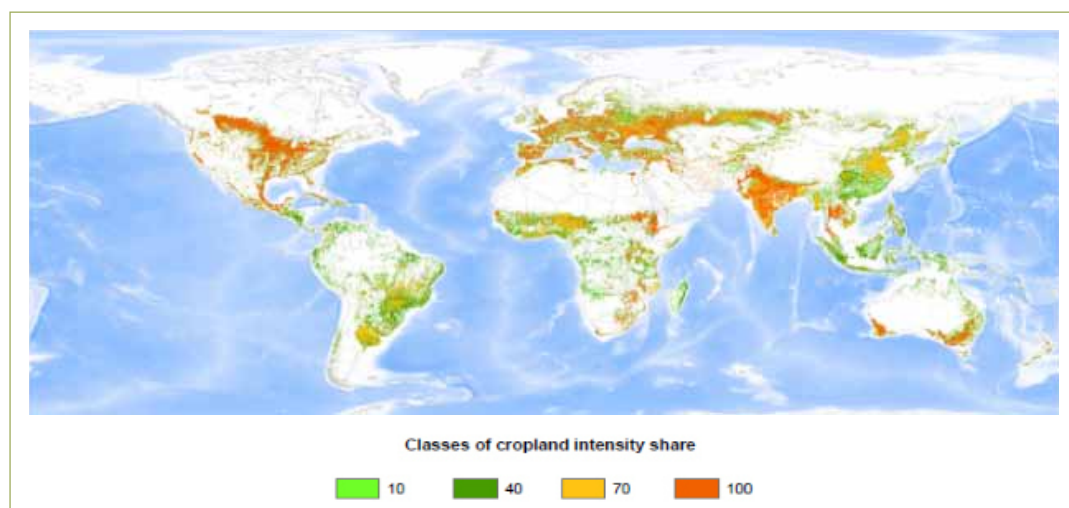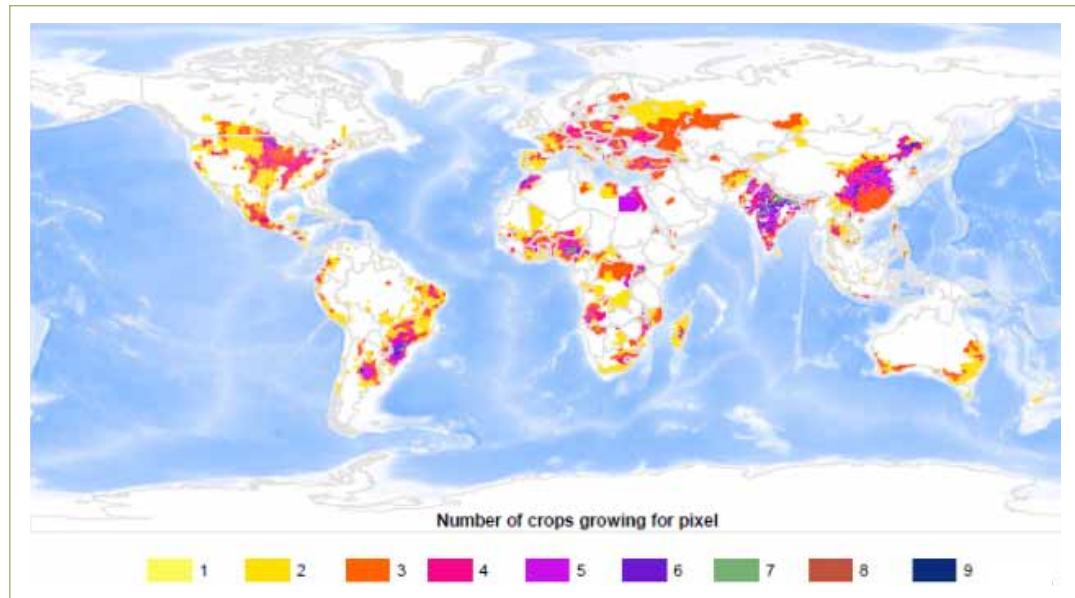
10   40   70   100

Figure 7: Global distribution of major cropping patterns

5.2. DROUGHT SMART

The study generated thousands of records, spanning a period of 30 years and containing biophysical, socio-economic and demographic data. To facilitate their interpretation, DROUGHT SMART was developed using StatPlanet (Statplanet, 2016), a free software application. DROUGHT SMART is based on big data principles; it adds intelligence to data and explores sustainability, social, environmental and economic impact analysis scenarios. The tool presents geo-statistical datasets (including both time series and static data) in easy-to-read and -interpret graphs, bar charts and color-coded thematic maps that can be easily navigated, viewed and exported in various alternative formats (see Figures 8 and 9). It allows for an interactive visualization of indicators individually (including the share of irrigated or rain-fed cropland, NDIX, rural population and ASIS indicators) or in relation to a second or third indicator. The current version of the tool maps and displays data at the second administrative unit level, for a country or for larger regions or area of interest.

Figure 8: Distribution of rainfed small fields in Ethiopia, Kenya and Somalia (reference year 2010)
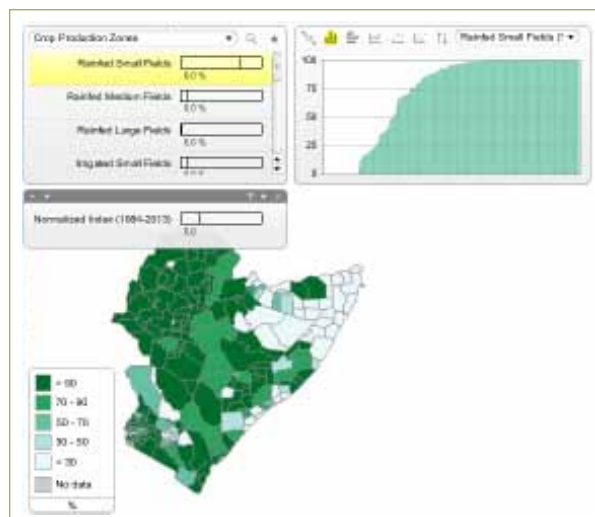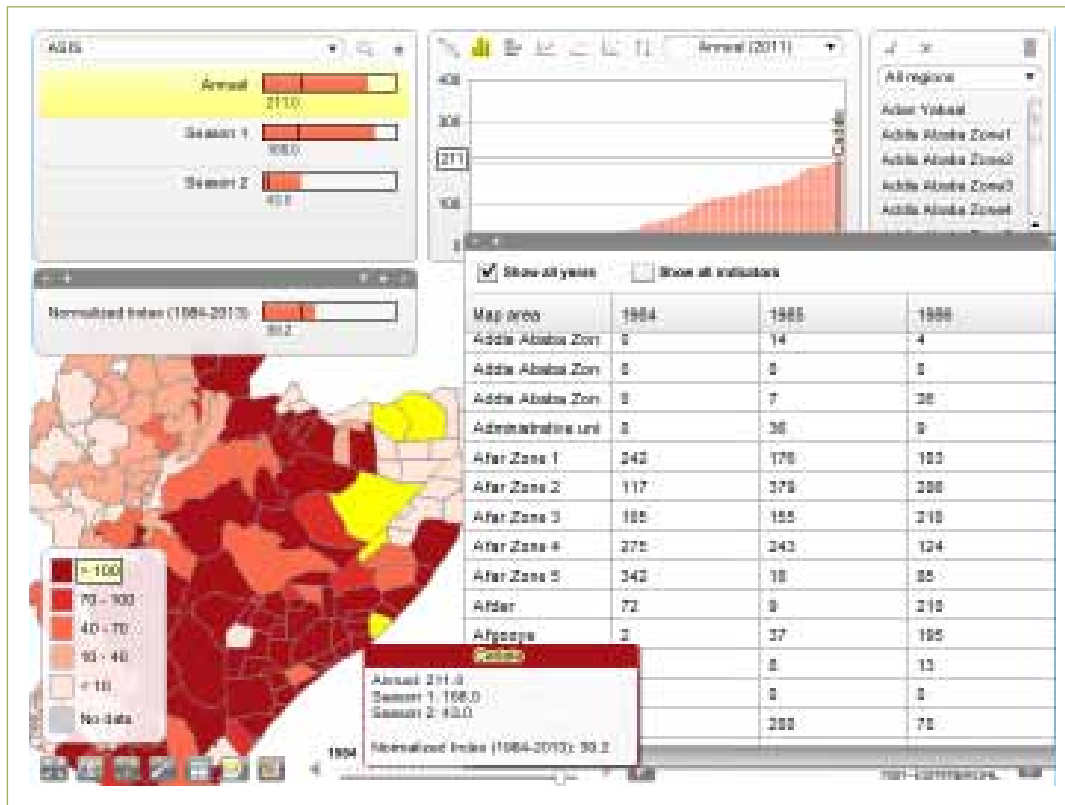
Figure 9: Distribution of annual ASIS values in Ethiopia, Kenya and Somalia (reference year 2011)[4]

DROUGHT SMART allows users to generate vertical bubble charts, where bubbles can be resized according to a third indicator (see Figure 10 for an example); multiple indicator and time series charts can be generated. Users may generate multidimensional tables to visualize historical ASI values for all time units for a selected area.

4 The table on the right contains ASIS values for the period 1984-1986 for the listed administrative areas. The annual, season 1 and season 2 ASIS values characterize the highlighted areas in yellow.

Figure 10: Distribution of rural population (x-axis) in relation to the share of rainfed small fields (smallholders) of total agricultural area (y-axis) and the value of agricultural output (size of the bubble)
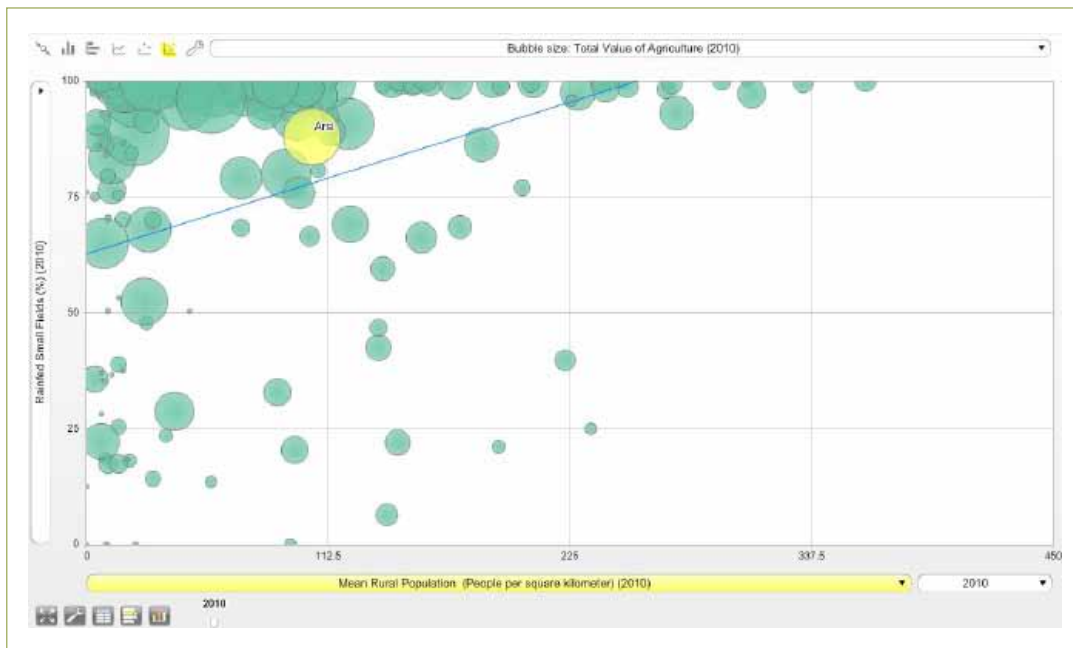
6. Case study: drought hotspots in eastern Africa

Drought events cause significant human and economic losses across the whole of eastern Africa. According to Funk (2011), a combination of poor rainfall and rising food prices at the end of the past decade has increased the vulnerability of the region's population to the effects of droughts. In 2011, the Horn of Africa experienced its worst drought spell in 60 years, with a total of more than 15 million people requiring assistance (Headey and Kennedy, 2012). Drought events commonly affect food supply, and may aggravate situations of famine. For example, the UN declared a famine crisis in southeastern Somalia in July 2011, as a severe drought affected the entire eastern African region. Drought conditions have now become an important concern for populations in vulnerable areas in the eastern African countries of Ethiopia, Somalia and Kenya, where drought episodes have become more frequent over the past years, and the likelihood of drought episodes reoccurring increases.

DROUGHT SMART, the conceptual and logical prototype developed in this study, was created to help drought-prone countries strengthen their resilience to drought events by timely identifying critical hotspots and concentrating relief efforts on these areas. The prototype takes particular account of seasonal changes in ASI values. Such changes result in a steep spike in drought cases, signaling the need for authorities to dedicate additional resources to drought-prone areas. For example, the effects of drought episodes may be mitigated through investments in irrigation infrastructure.

Our case study examined the effect of the El Niño phenomenon on agriculture in Ethiopia, Somalia and Kenya over the period 1984-2013, especially in terms of anomalous vegetation growth and water stress. The DROUGHT SMART tool provides a quick and comprehensive picture of the situation in the study area.

The graphs in Figures 11 to 28 illustrate annual ASI values over the 30-year period for the selected administrative area. The thematic color-coded map designates, in dark red, the critical areas (extreme drought stress), and, in light red, areas with minimal stress. Users can select an administrative area on the map and examine its drought stress situation on the graph above; the drought stress situation for two or more administrative areas can be compared by selecting multiple areas on the map or in the list.

Figures 11 to 19 illustrate the distribution of ASI values for the various "El Niño years" in the study area. The DROUGHT SMART tool allows users to select a year on the time series bar (1984-2013), examine the drought stress situation across the country or region during that year, and distinguish the most vulnerable areas.
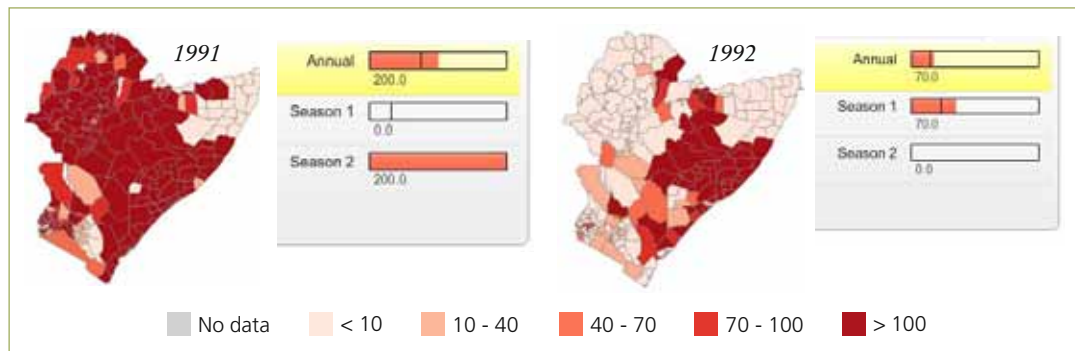
Drought during El Niño episode years: 1986-1988 years

Figure 11: Anomalous vegetation growing conditions in the study area (map) during the years of 1986-87-88
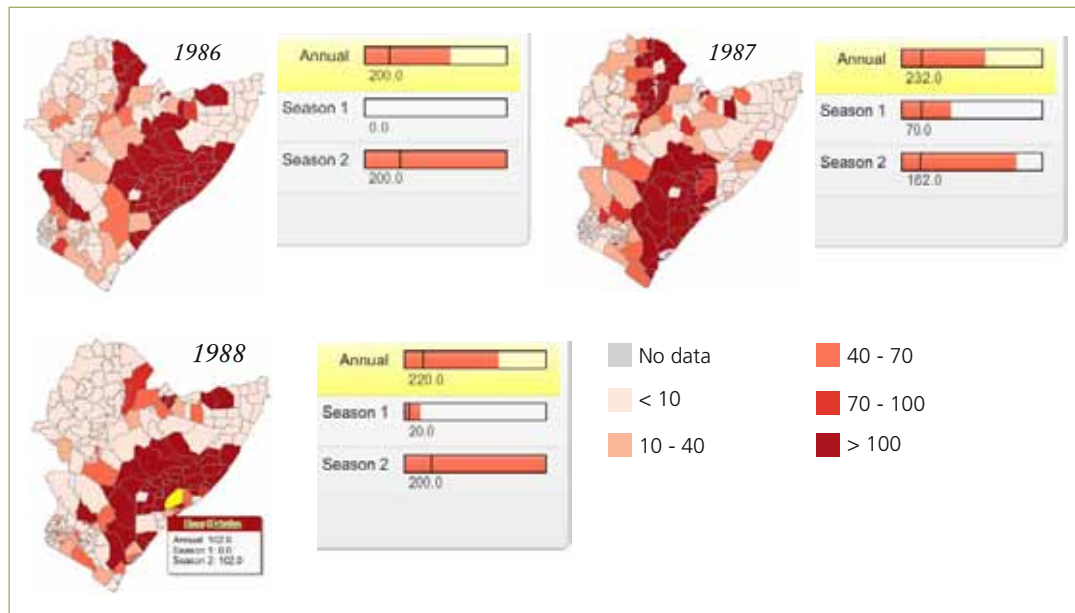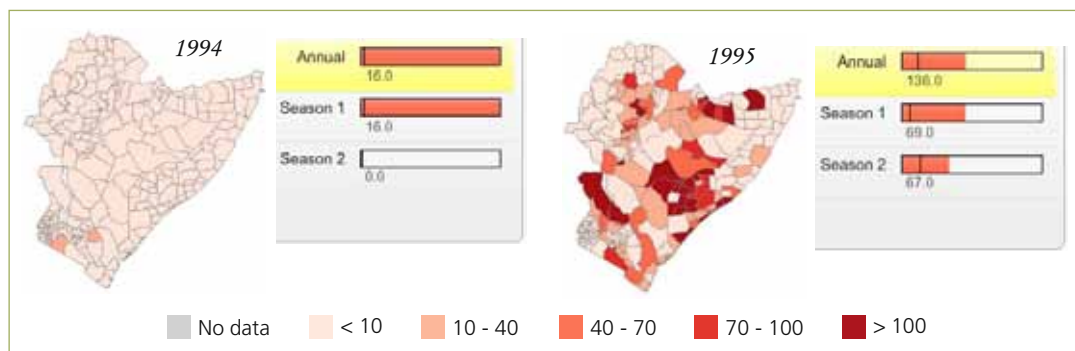

Drought during El Niño episode years: 1991-1992

Figure 12: Anomalous vegetation growing conditions in the study area (map) during the years of 1991-92
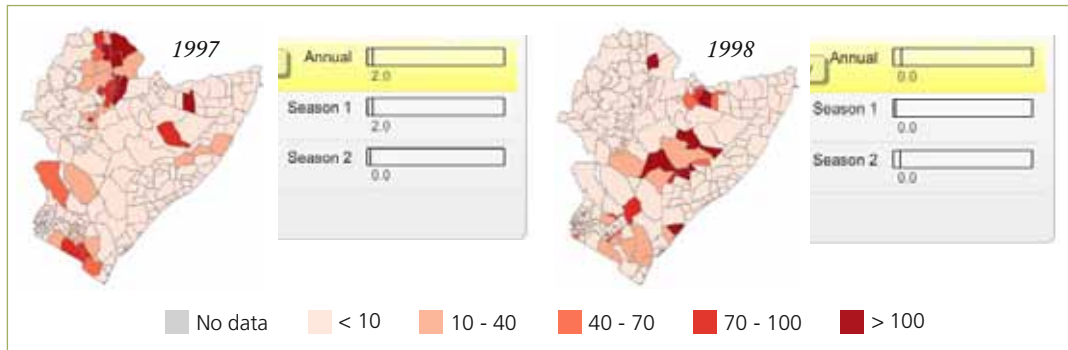

Drought during El Niño episode years: 1994-1995

Figure 13: Anomalous vegetation growing conditions in the study area (map) during the years of 1994-95
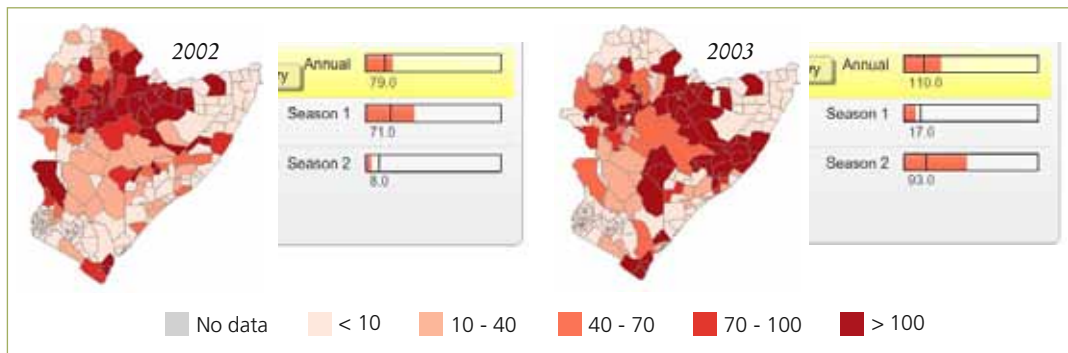
Drought during El Niño episode years: 1997-1998

Figure 14: **Anomalous vegetation growing conditions for the study area (map) during the years of 1997-98**

Drought during El Niño episode years: 2002-2003

Figure 15: **Anomalous vegetation growing conditions for the study area (map) during the years of 2002-03**

Drought during El Niño episode years: 2004-2005

Figure 16: **Anomalous vegetation growing conditions for the study area (map) during the years of 2004-05**
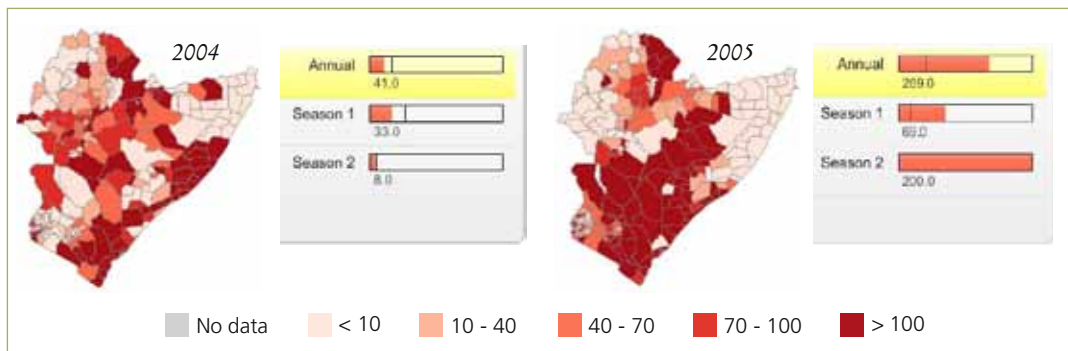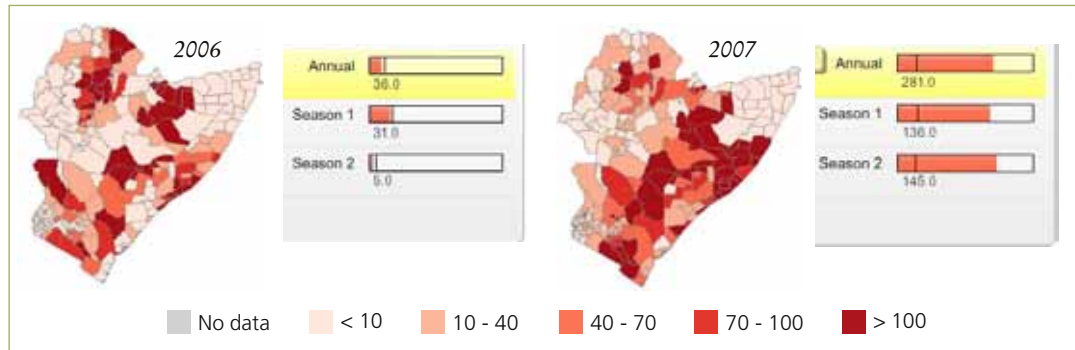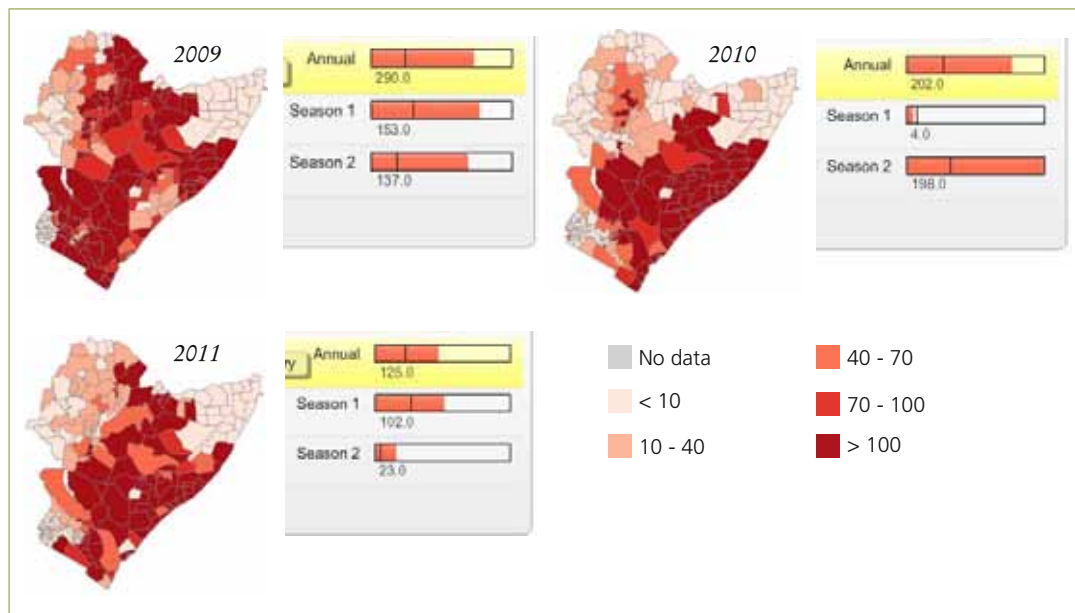
Drought during El Niño episode years: 2006-2007

Figure 17: Anomalous vegetation growing conditions for the study area (map)
during the years of 2006-07

El Niño episode years: 2009-2011

Figure 18: Anomalous vegetation growing conditions for the study area (map)
during the years of 2009-10

The ASIS values of the first crop season for 2009/10 for eastern Africa are in line with the drought warnings of several early warning reports for the area by the Famine Early Warning Systems Network (FEWS-NET), and thus corroborate ASIS' reliability (Figure 19).

Figure 19: Anomalous vegetation growing conditions for the study area (map) during the year 2010 and the situation of stress in Hobyo (Somalia) throughout the years 1984-2013 (graph)
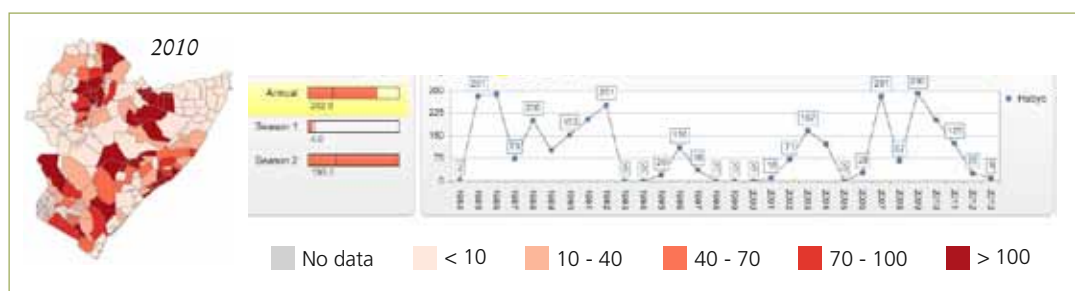
Vertical bubble charts allow users to analyse the relationship between three indicators: two variables are indicated on the x- and y-axes, while the size of the bubble indicates a third variable. This three-dimensional analysis can be performed at the subnational level.

As an example, the DROUGHT SMART tool is used to identify drought-prone areas for the study area (1984-2013) (in the case study area characterized by a large proportion of rural population and a high dependency on rainfed agriculture (Figure 20). The following indicators are selected:

- *x-axis*: rainfed smallholder cropland as a share of total cropland (from 0 to 100 percent);
- *y-axis*: NDIX (from 0 to100 percent);
- z: population distribution living in rural areas (indicated by the size of the bubble).

The red square on Figure 20 encompasses those administrative areas for which the values on both the x- and the y-axes are higher than 75 percent; these areas are likely to be drought-prone and therefore require immediate remedial action (although areas with values of more than 50 percent require monitoring as well) (Figure 21).Large-sized bubbles indicate that a high proportion of the population may be affected by drought events.

Figure 20: Rainfed smallholder agriculture, NDIX and rural population in Kenya

Figure 21: Communicating the critical information on the three dimensional graph (with a quick glance)
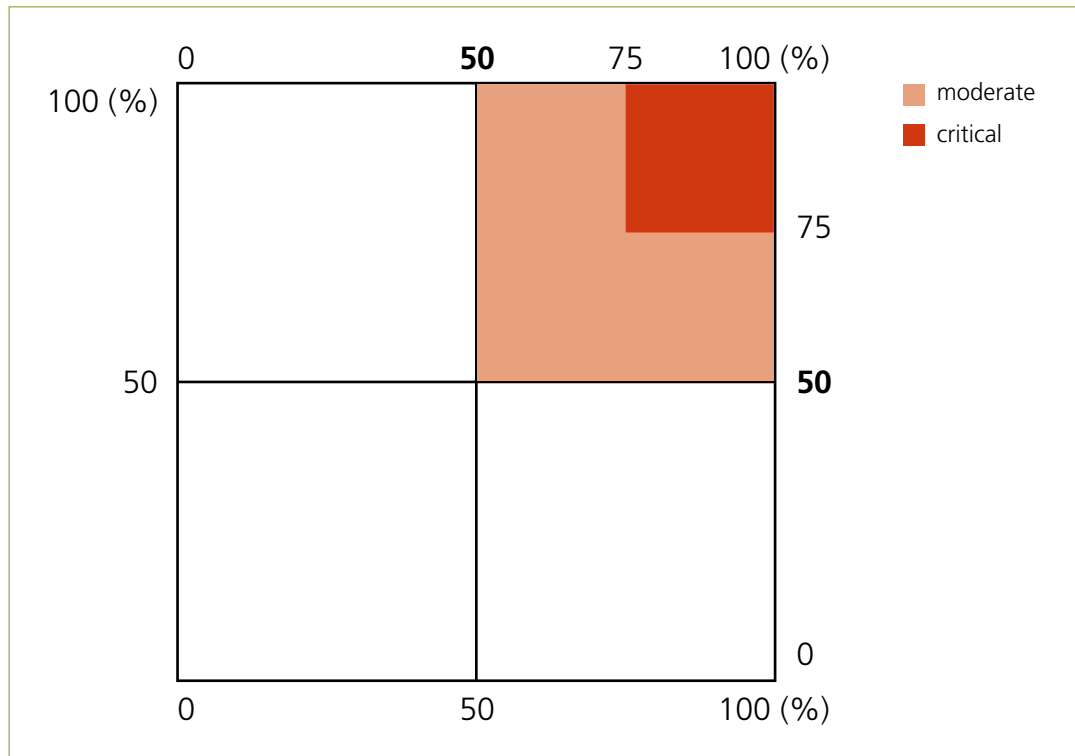
Figure 22 shows the correlation between rainfed smallholder farming, the NDIX and the total value of agricultural production in Kenya. The Turkana District in northwest Kenya, for example (highlighted in yellow), which combines a relatively high value of agricultural output with a high dependency on rainfall and an elevated NDIX, requires attention.

Figure 22: Rainfed smallholder agriculture, NDIX and value of agricultural output in Kenya
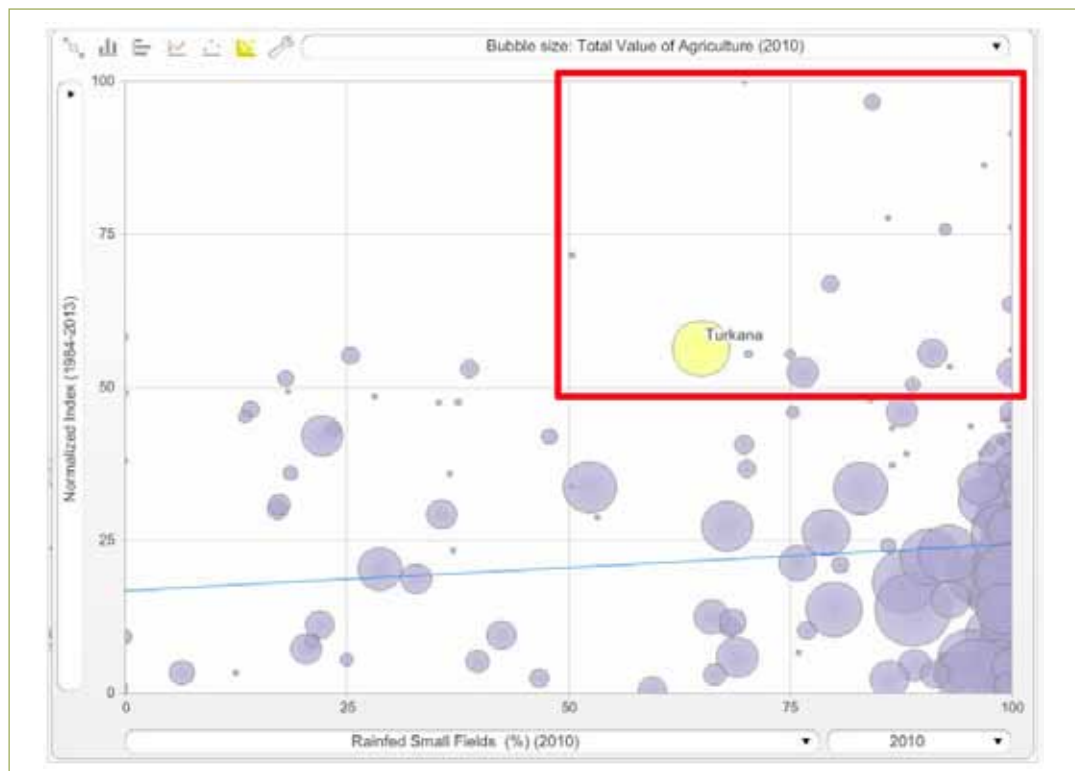
7. Conclusion and recommendations

7.1. Added value of DROUGHT DESCRIBE and DROUGHT SMART

This study analysed the impact drought events on agricultural areas based on calibrated 30-year (1984-2014) remote sensing time series of annual and seasonal Agricultural Stress Indexes and global biophysical, agricultural and socio-economic baseline datasets (in or around the year 2010, at approximately one square kilometer resolution), consolidated in the DROUGHT DESCRIBE database.

In a first step, drought-prone areas were characterized according to cropland distribution, water regime, field size, crop type and number of crops, value of agricultural production, distribution of rural population and poverty at the second administrative unit level. In a second step, these data were combined with ASIS data to analyse potential cause-and-effect chains of drought events. In a final step, the results of this exercise were interpreted by means of the DROUGHT SMART tool to assess vulnerability to drought events, and specifically the impact of drought events in terms of food security.

DROUGHT SMART allows users to identify the location and size of communities affected by chronic drought conditions, and pinpoint areas where the adverse effects of water stress may be remedied through, for example, the cultivation of drought-tolerant crops and crop diversification. DROUGHT SMART thereby contributes towards evidence-based decision making and strategic planning, improved emergency preparedness planning and effective drought monitoring, which all help mitigate the adverse effect of drought events on livelihoods.

Any country would profit from a thorough, comprehensive understanding of the extent of drought events and their impact on livelihoods and the economy against a background of changing climatic conditions. DROUGHT SMART is a first attempt to build a user-friendly information tool that will allow authorities to direct relief efforts towards the most vulnerable populations in drought-prone areas.

7.2. Recommendations to enhance DROUGHT DESCRIBE and DROUGHT SMART

The validity and reliability of ASI data justifies their use in the study; they allow for the rapid and effective analysis of drought trends, and may be used to predict future drought events. However, these data need to be supplemented with information on additional variables for drought-prone areas, to enhance their usefulness in drought-related policy formulation and strategic planning. Local experts and other actors are encouraged to complement the current results of the study with field data, preferably at the subnational level. Indeed, DROUGHT DESCRIBE and DROUGHT SMART would greatly benefit from the addition of reliable country data and the incorporation of information from recent studies in the same field of work. Feedback on this study and follow-on activities in countries affected by chronic drought conditions are crucial to refine the tool.

The combination of EO datasets and cropland masks at various resolutions may result in the under- or overestimation of values. To avoid such inaccuracies, results should be verified against field data by experts in the various subject matters, and complemented with additional information.

It is recommended to use dynamic cropland masks in the study, as opposed to the static cropland masks currently used.

The frequency of severe drought events is increasing, which presents a threat in terms of food security. Governments seeking to adopt measures to increase resilience to drought events may apply the DROUGHT SMART methodology; FAO can offer training and customize the DROUGHT SMART tool to incorporate country-specific data.

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Drought is one of the main causes of food insecurity. In 2011, the horn of Africa faced the worst drought in 60 years. An estimated 12.4 million people suffered from massive food shortages. To mitigate the impact of agricultural drought, it is of high importance that timely and reliable information on the condition of food crops and grassland areas in all regions and countries in the world is shared. The case study looks at the agricultural drought prone areas in the Horn of Africa and shows overlapping socioeconomic variables such as small or large farmers, irrigation, population, production, etc. The final results of such studies can turn statistics into knowledge and assist the decision makers to improve adaptation and mitigation planning.