# IDENTIFYING AND EVALUATING HOTSPOTS OF CLIMATE-RELATED INDICATORS IN THE SAHEL MAKING USE OF OBJECT-BASED REGIONALIZATION TECHNIQUES

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**ABSTRACT:**

The countries of the Sahel are among the countries most affected by global climate and/or environmental change. These changes in climate are likely to worsen the prevailing water scarcity in this region and will significantly affect livelihoods, biodiversity, food security and human health. Within a study carried out under the direction of the United Nations Environment Programme (UNEP), historical climate trends and their implications on food security and regional stability in the Sahel and western Africa were investigated. The implementation of an integrated object-based regionalization technique for multi-dimensional indicator spaces and the development of a spatial meta-indicator enabled us to highlight and assess hotpots, which are mainly affected by climatic changes. The observed trends and changes for the past 24 to 36 years were explored for a set of four climate change induced drivers: (1) temperature, (2) precipitation, (3) drought, and (4) major flood events. The identification and evaluation of the hotspots of climate-related indicators, as well as of migration and conflict patterns in the nine Sahelian countries, which form the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS), relied on time-series of freely available global datasets. The resulting conceptual spatial entities, instances of geons, are homogenous in terms of their response to the climate-related spatial phenomena concerned. The presented approach enables the integration of indicators from different domains/sources and reveals a high potential for hotspot assessments of higher systemic properties across various scales, such as socio-economic/ecological vulnerability, while likewise delivering conditioned (policy-oriented) information.

## 1. INTRODUCTION

### 1.1 Climate change in the Sahel and western Africa

The countries of the Sahel rank among the countries currently most affected by global climate and/or environmental change. The combination of multiple stresses such as endemic poverty, population pressure due to high population growth rates, prevailing dominance of the primary sector, complex governance, political instability, population displacement due to natural or man-made disasters, highly degraded environments, etc. and the resulting weak adaptive capacity make the Sahel one of the most vulnerable regions to the projected effects of climate change (Parry et al., 2007). According to the IPCC’s (Intergovernmental Panel on Climate Change) Fourth Assessment Report (AR4), it is very likely that climate change will further exacerbate prevailing water scarcity and have a marked impact on livelihoods, biodiversity, food security and human health in the region. Moreover, increasing frequency and intensity of extreme weather events (e.g. drought, floods) in combination with lacking or inefficient early warning systems (EWS) are expected to further hamper development and the attainment of the Millennium Development Goals (MDGs) (Boko et al., 2007).

### 1.2 Conditioned information for focused adaptation planning

Against this background, a joint study was conducted by the United Nations Environment Programme (UNEP) in cooperation with the International Organization for Migration (IOM), the Office for the Coordination of Humanitarian Affairs (OCHA), the United Nations University (UNU), the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) and the University of Salzburg's Centre for Geoinformatics (Z_GIS), focusing on historical climate trends and their implications for food security and regional stability in the Sahel and western Africa (UNEP, 2011). In order to provide conditioned (i.e. policy-oriented) information (Lang et al., 2010) to support focused climate change adaptation (CCA) planning in the region, a comprehensive mapping task was carried out (Hagenlocher et al., 2011) using integrated object-based regionalization techniques in order to highlight hotpots where climatic changes have been most severe. The observed trends and changes for the past 24 to 36 years (depending on data availability) concerned a set of four climate change induced drivers based on time-series of freely available global datasets. The integrated climate-related drivers were: erratic (1) temperature and (2) precipitation patterns, (3) drought occurrences, and (4) major flood events.

## 2. METHODOLOGY

### 2.1 Study area, datasets and preparatory analysis

The nine countries which form the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS), i.e. Burkina Faso, Cape Verde, Chad, the Gambia, Guinea-Bissau, Mali, Mauritania, Niger and Senegal, constituted the core geographical focus of the study. Given the trans-boundary nature of climate change in these countries, eight neighboring members of the Economic Commission of West African States (ECOWAS), i.e. Benin, Côte d'Ivoire, Ghana, Guinea, Liberia, Nigeria, Sierra Leone and Togo, were also included into the analysis (cf. Fig. 1).

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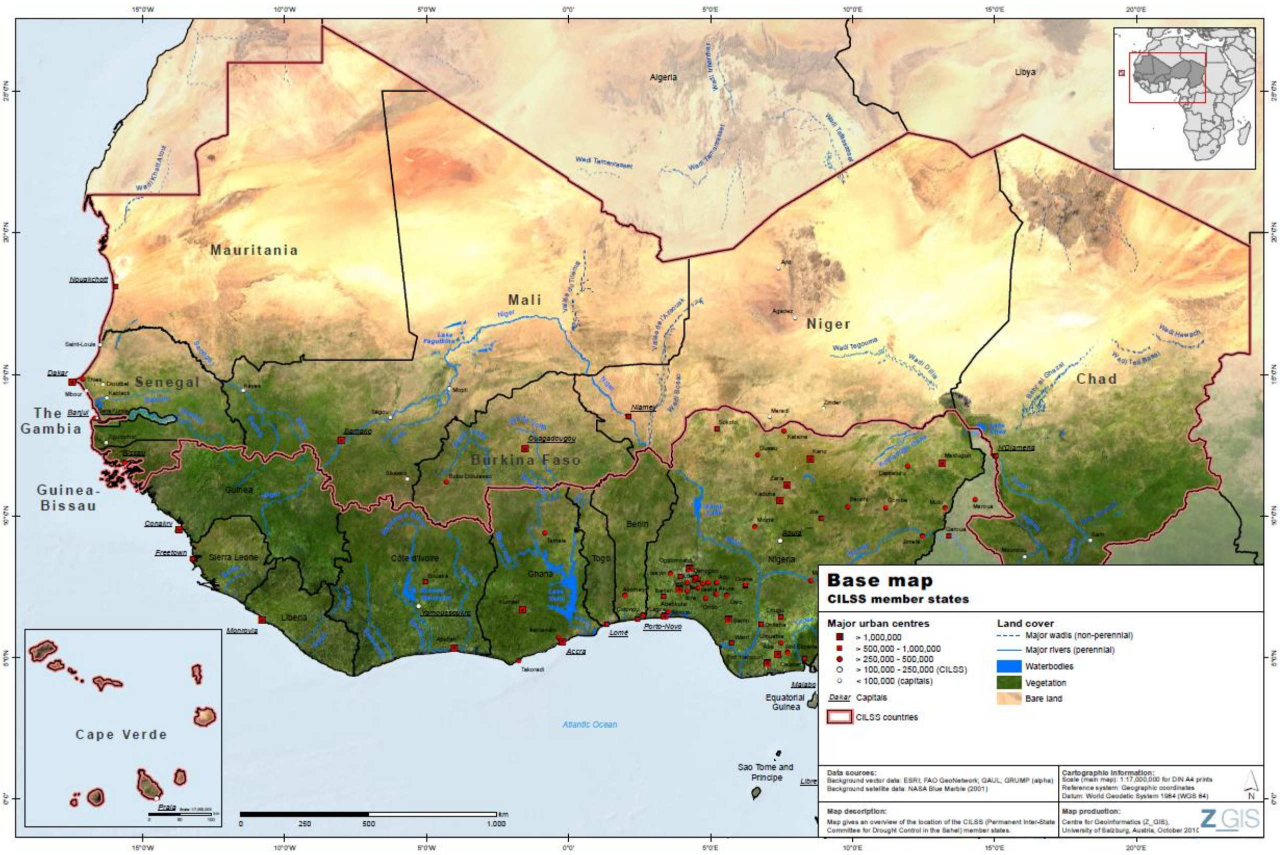


Figure 1. Base map showing the location of the study area

Table 1 provides an overview of the datasets utilized in the study. Besides specifying available time series of the datasets additional information on their sources is provided.

| Datasets | Start/end date | Source |
|---|---|---|
| Climate-related indicators | | |
| Temperature | 1901-2006 | CRU TS 3.0 |
| Precipitation | 1901-2006 | CRU TS 3.0 |
| Vegetation Health* | 1982-to date | NESDIS-STAR |
| Flood Events | 1985-to date | DFO |
| ** as a proxy for vegetative drought* | | |
| Additional information layers | | |
| Population | 1960-2010 | UNEP; GPWv3 |
| Conflict | 1946-2005 | PRIO-CSCW |
| Background vector data | | |
| Major rivers | 2006 | FAO GeoNetwork |
| Major wadis | 2006 | FAO GeoNetwork |
| Waterbodies | 2000 | FAO GeoNetwork |
| Administrative units | 2008 | FAO GeoNetwork |
| Settlements | 2004 (2008) | GRUMP (alpha) |

Table 1. Datasets and sources

As a first step, subsets covering the target region (cf. Fig. 1) were created for all relevant datasets. Moreover, datasets were geo-referenced and converted into appropriate formats.

Based on the requirements formulated by the UNEP and given constraints inherent in the datasets, an individual observation period focusing on the past 24 to 36 years was defined for each of the four climate-related indicators and the two additional information layers (i.e. population and conflict). The latter were integrated into the mapping task in order to show population trends and large-scale conflict occurrences (> 25 battle-related deaths) during the same time period.

Moreover, as a majority of livelihoods in the Sahel and western Africa are highly dependent on natural resource availability, which in turn is (among other factors) also a function of rainfall and temperature, the rainy season was chosen as a critical season to be observed. Consequently, the seasonal focus for the observation of indicator 1 (temperature), 2 (precipitation) and indicator 3 (drought) was set to the months May to October.

### 2.2 Integrated spatial meta-indicators

In addition to exclusively analyzing singular trends in the four climate indicators in order to provide information on individual components of climate change in the study area, an integrated spatial meta-indicator was developed for highlighting and assessing hotspots of the four climate change indicators listed above.

This meta-indicator (Lang et al., 2008) is composed by integrating and weighting the singular indicators in a multi-dimensional indicator space, making use of object-based regionalization techniques (Kienberger et al., 2009). Thereby, regionalization refers to the technique of creating contiguous regions both in dimensional space and in real space based on homogeneity criteria (Strobl, 2008).

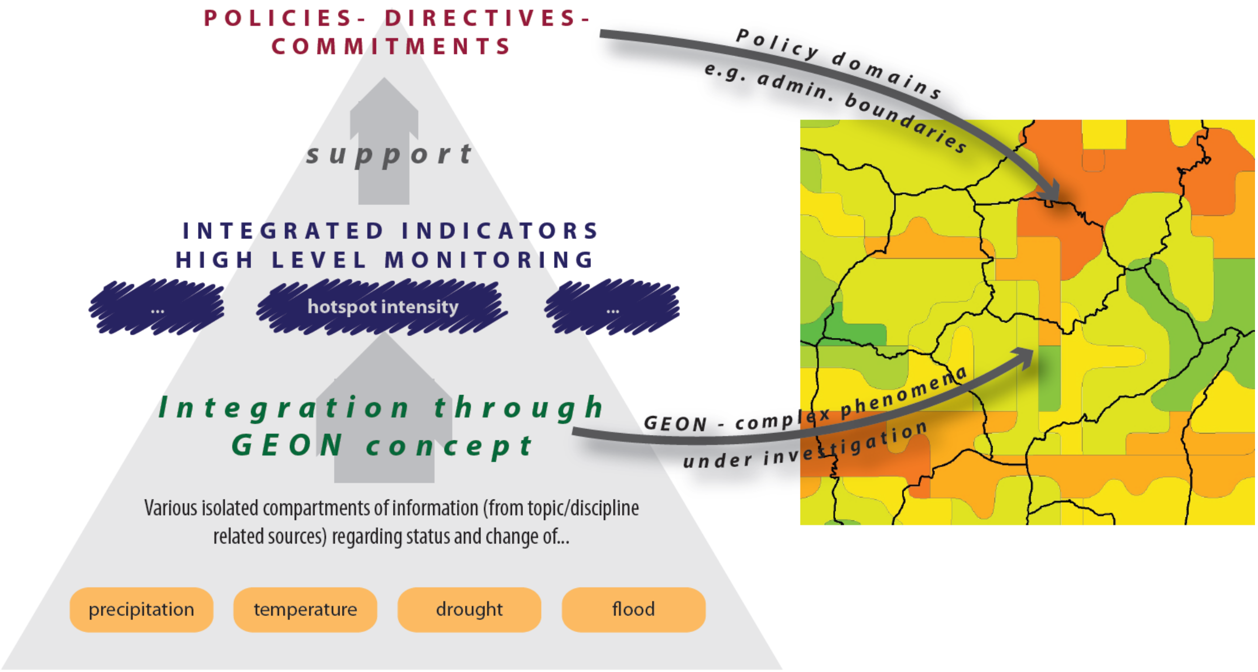


Figure 2. The geon concept - integration of various indicators to model complex spatial phenomena and provide conditioned information (Kienberger et al., 2009 following Lang et al. 2008; modified and completed)

Spatial meta-indicators are constructed based on regionalization techniques using a feature space that is built by a set of singular (spatial) indicators. The resulting conceptual spatial entities, instances of *geons* (Lang et al., 2008), are homogenous in terms of their response to the spatially varying phenomenon under concern (ibid.). Finally, they reflect conceptual spatial entities, referred to as concept-related fiat objects (Lang et al., 2010).

Thus, the approached concept is an automated zoning method for delineating units where similar spatial conditions apply with respect to a set of defined integrated spatial indicators (here: four climate-related indicators).

To allow the integration and comparison of these different datasets, normalization was applied based on the following linear function:

$$v' = \frac{v - \min}{\max - \min}(\max_{norm} - \min_{norm}) + \min_{norm}$$

In a subsequent step the normalized datasets were integrated into the eCognition Developer software environment in order to perform the regionalization by making use of a multiresolution segmentation (Baatz and Schäpe, 2000) algorithm. Thereby the four climate indicators were given equal weight to analyze their cumulative impact. For each of the resulting objects a hotspot intensity (HI) value was calculated considering the integrated layers ($v_1$, $v_2$ …, $v_4$) in a four-dimensional feature space trough the vector product:

$$|HI| = \sqrt{v_1^2 + v_2^2 + v_3^2 + v_4^2}$$

Next, the share of each of the four integrated indicators per object was calculated making use of arithmetic features. Then, the results were exported as vector data (polygons) for subsequent processing and visualization in ArcGIS 10 software (see Fig. 3).

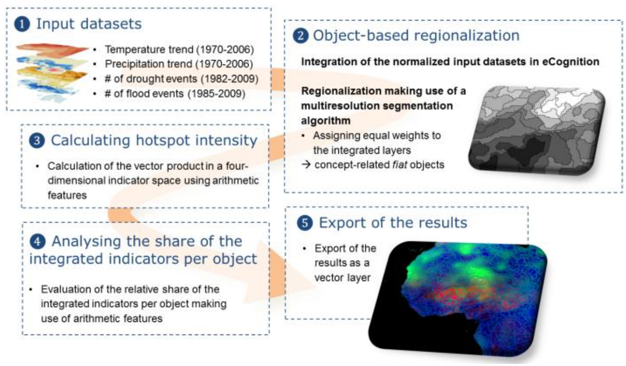


Figure 3. Workflow for the identification and evaluation of climate change hotspots in eCognition Developer software

In order to ease the subsequent interpretation of the results, values were standardized within a new range from zero to one [0 …, 1], where zero reflects a very low and one a very high hotspot intensity (HI). Following an expert evaluation, all units with significant hotspot intensity (> 0.65) were defined as climate hotspots.

## 3. RESULTS AND DISCUSSION

### 3.1 Regionalization

Using object-based regionalization techniques homogenous objects were delineated within the feature space, whose dimensions are built by the standardized singular indicators. As mentioned above the weighting of the composite dimensions was equal. Thus, a *geon* set comprising conceptual *fiat* objects characterized by a uniform cumulative behavior in terms of climate change impact in the region was derived.

### 3.2 Hotspot identification

Figure 4 shows the identified climate hotspots based on the calculated hotspot intensity (HI) surface which is visualized using a 'white to yellow to red' color scheme. Thereby, areas that have experienced the greatest cumulative changes in climate are displayed in dark red (hotspots). As indicated in chapter 2.1, data on population dynamics and large-scale conflict is overlaid on the map (i) to highlight areas with higher insecurity and (ii) to provide information where the population is most at risk due to climate-related factors.

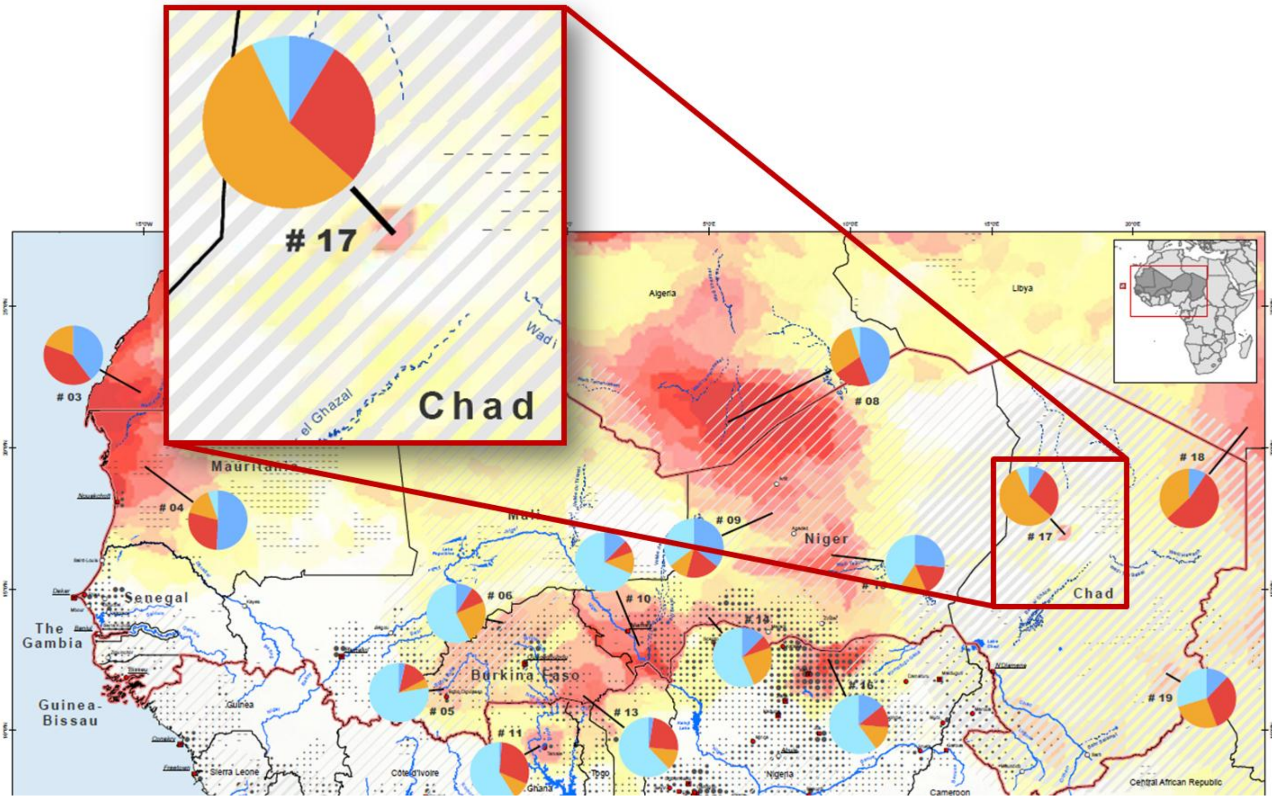


Figure 4. Areas most affected by changes in climate: analysis of cumulative changes regarding climate-related indicators (temperature, precipitation, drought and flood)

Next to the location and approximated size of the delineated hotspots, the specific composition of the hotpots was visualized by means of a pie chart for each of them, showing the proportional influence of each of the four climate-related indicators for the specific area in order to support targeted adaptation policies or programs in the identified hotspot areas.

Based on the presented approach hotspots of climate change were identified in three main areas: (i) the northern and north-western part of the study area, including Mauritania and Algeria; (ii) the center of the study area, including Niger, Burkina Faso and the northern parts of the coastal states of Ghana, Togo, Benin and Nigeria; and (iii) Chad, Libya and Sudan.

### 3.3 Visualization

In addition to presenting the results in a static map (see Fig. 4), the final results were converted to Google Earth *.kml (keyhole markup language) or to zipped Google Earth *.kmz files as a means of effective and comprehensible information delivery (cf. Tiede and Lang, 2010). This was achieved by making use of prevalent conversion tools in ArcGIS 10. Within this context a legend was created as a portable network graphic (*.png) using graphic design tools. The legend was then integrated into a Google Earth *.kml file and, by defining its X and Y coordinates, placed in the upper left corner of the Google Earth screen (see Fig. 5).

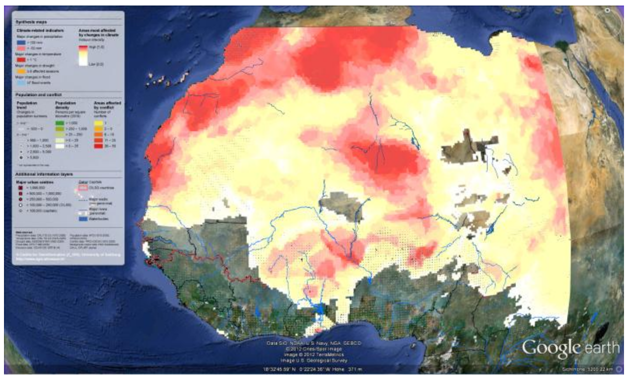


Figure 5. Visualization of the climate change hotspot intensity surface in Google Earth

## 4. CONCLUSIONS

As the approach enables the integration and expert-based weighting of different indicators from various domains (climate change, vulnerability, etc.) and sources (e.g. in-situ versus Earth observation based), the developed object-based regionalization approach for conditioned information delivery reveals high potential for future hotspot assessments concerning other complex spatial phenomena, such as vulnerability or sensitivity.

Moreover, the presented approach provides valuable information to policy makers, experts or stakeholders, as not only the estimated size and location, but also the composition of the hotspots was determined and mapped, indicating where fine-scaled follow-up studies could be conducted and at the same time highlighting which domains should be addressed in particular within the context of targeted climate change adaptation (CCA) programs and policies.

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