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DAFNE

A **D**ecision-**A**nalytic **F**ramework to explore the water-energy-food **NE**xus in complex and transboundary water resources systems of fast growing developing countries

AGRICULTURAL PRODUCTIVITY IN THE ZAMBEZI AND OMO-TURKANA BASINS

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Abbreviations

CC	Canopy Cover
CS	Case Study
DEM	Digital Elevation Model
DoA	Description of Action (Annex I of the Grant Agreement)
EC	European Commission
GIS	Geographic Information System
LAI	Leaf Area Index
LU	Land unit
LUT	Land use type
OTB	Omo-Turkana basin
SMU	Soil Map Unit
WEF	Water-Energy-Food
WP	Work Package
ZRB	Zambezi River Basin

Country Abbreviations[1]

AGO	Angola
BWA	Botswana
ETH	Ethiopia
KEN	Kenya
MWI	Malawi
MOZ	Mozambique
NAM	Namibia
SSD	South Sudan
TZA	Tanzania
UGA	Uganda
ZMB	Zambia
ZWE	Zimbabwe

[1] Country codes follow the UN standard

1 INTRODUCTION

1.1 RATIONALE

This deliverable D3.3, is entitled "*Agricultural productivity in the Zambezi and Omo-Turkana basins*" and describes the spatially and temporally referenced database of agricultural activities and productivities in the two basins. The two components of this deliverable, the database and this report, are related to Subtask 3.1.3 'Agricultural Productivity' of Task 3.1 ("Analysis and modelling of natural and anthropogenically-controlled systems"), in turn part of WP3 ("W-E-F-nexus analysis and modelling"). KU Leuven is the leading partner for ST 3.1.3. Contributing partners are UNZA (Zambezi), UEM (Zambezi), WLRC (Omo Turkana) and HWRM-ETHZ.

This deliverable will be complemented by three milestones: MS26 (WP3) "AquaCrop validated against reference data gathered in WP2" due at the end of May, MS17 (WP2) "Characterisation of agricultural developments in the Omo and Zambezi river basins" by the end of July; and MS11 (WP2) "All inputs and reference data for AquaCrop available" by the end of August 2018.

In line with this sequence of deliverable and milestones, in this report we present the methodology and a selection of results of a GIS-based modelling of the spatial distribution of agricultural activities and their productivity based on official statistical data and geographical datasets. The results of this spatial modelling provide:

a) An analysis of food production to be compared in other project tasks with food requirements under different climate and socio-economic scenarios and;
b) Input and reference data for the process-based crop growth modelling, which will be done using the FAO's AquaCrop-model (see section 4).

For the latter, the results of this deliverable allow to identify the relevant combinations of sub-basin, agricultural activity, climate and soil type and spatially explicit reference productivity data to compare AquaCrop's output with. Subsequently, the output of the AquaCrop modelling is meant to inform about current and future water abstraction by agriculture and about water productivity in agriculture under different pathways and scenarios. The ultimate goal is to interface AquaCrop with the spatially explicit WEF model based on the hydrological model Topkapi-ETH, in order to extend to the catchment scale the local (plot) scale simulation carried out with the standard AquaCrop model.

1.2 OBJECTIVES

The main objective of this deliverable is to come up with a spatial assessment of where crop production, livestock husbandry, fish catch and fish farming is currently practiced in the Zambezi River Basin (ZRB) and the Omo Turkana Basin (OTB), what their productivity is, and simultaneously assign the production activities to sub-basins of the overall ZRB and OTB. The latter step is important in a W-E-F-nexus context with agriculture being the major consumptive user of water resources. Additional objectives are (*i*) to identify the relevant crop–soil–climate–topography combinations for assessment of crop water productivities by means of the AquaCrop model and (*ii*) to generate reference historical data about crop production and productivity to be used as benchmarks for the AquaCrop simulations.

Because most of the available (statistical) data are aggregated by administrative districts, they are poorly informative for the actual location where the activities take place and are not consistent with hydrological, pedological and morphological sub-basin boundaries. The actual agricultural productivity as well as the actual locations where crop production, animal husbandry and fish catch or fish farming take place following the combination of biophysical land characteristics can be estimated only by disaggregating the statistical data according to biophysical land units. These are defined as the combination of slope, landcover, soil and climate classes and therefore account for the key factors that influence agricultural productivity.

2 AGRICULTURAL PRODUCTIVITY IN THE ZAMBEZI RIVER BASIN

2.1 MATERIALS AND METHODS

2.1.1 Source data

(Sub-)nationally aggregated statistical data coming from national sources and produced independently from the other countries in the ZRB have been used. This situation inevitably leads to spatial and semantic heterogeneity across the data sources Table 2 to Table 4 and Figure 1 to Figure 4). As a guiding principle, for each country and for each variable, the smallest administrative unit was selected for the analysis (Table 2). In the case of Namibia national averages were disaggregated to a sub-national level. In the case Malawi average production data per household and per district were available and have been aggregated into production values per district (Table 2).

Crop production

The number of crops reported in the available census products varies from country to country with a minimum of three major crops in the case of Botswana and a maximum of 29 for Zambia. A total of 19 crops has been retained for their relative importance in subparts of the basin although data was not available for all administrative units everywhere (Table 2). The 19 selected crops are major crops in the core countries of the basin, i.e. Zambia; Mozambique, Malawi and Zimbabwe, and have the largest current and planned share of agricultural land. For comparison, different types of maize, beans, potatoes and groundnuts have been grouped as detailed in Table 1. Angola published a census in 2016, reporting however only on a subset of provinces of which none is within the Zambezi river basin (King 2016).

Table 1 shows that data were not found for every combination of crop and country. A crop may not or negligibly be practiced in a specific country (e.g., wheat in Namibia) but the empty cells may also point to missing data (e.g., cassava in Malawi). However, for the major staple crops throughout the ZRB, i.e. maize and sorghum, data were found for all riparian countries.

Table 1 – Overview of retained crops and related data availability per country

Crops	AGO	BWA	MWI	MOZ	NAM	TZA	ZMB	ZWE
Bambara nut							x	x
Barley							x	
Bean	x	x	x	x		x	x	x
Cassava	x			x				x
Cowpea							x	
Groundnut	x	x	x	x	x	x	x	x
Maize	x	x	x	x	x	x	x	x
Millet		x		x	x	x	x	x
Pigeon pea			x	x				
Potato				x		x	x	x
Rice	x		x	x		x	x	x
Seed cotton							x	
Sorghum	x	x	x	x	x	x	x	x
Soy			x				x	x
Sugarcane							x	
Sunflower		x					x	x
Sweet potato	x			x		x	x	x
Tobacco			x				x	x
Wheat						x	x	x

Fisheries and aquaculture

For *Zimbabwe*, small scale fish catch is to date negligible and fish production other than in Lake Kariba very limited . An assumption of 90% of the fish production originating in lakes and 10% in rivers has been confirmed[2] . More than half of the fish farming is carried out by the company “Lake Harvest Aquaculture” as reported by Fletscher (2018). National production values are originating from three main reservoirs, of which Lake Kariba represents 99% of the volume, and have thus been associated to the two bordering provinces Matebeleland North and Mashonlaland with an estimated weighting of 1/3÷2/3, repectively in order to account for the concentration of activities around the city of Kariba in Mashonaland, as well as the higher presence of other reservoirs in this province. Literature on fishing and fish farming activities in Lake Kariba as a whole (Kolding et al., 2016), confirms the orders of magnitude of the retained values with a figure of 30,000 tonnes annual outtake of the predominating fish species (kapenta, also known as Tanganyika sardine). The proportion of fish catches is higher on the Zambian side than on the Zimbabwian side of the lake. The differences are explained by differences in legislation, as well as in traditional diets. The values for *Zambia* have been confirmed in a recent report on Aquaculture in Zambia (Genschick et al., 2017). The total output of fish farming and aquaculture of 19,287 tons splits up in four categories: small scale farming, cages in Kariba, small water bodies and big land based commercial farms.

In *Namibia*, in contrast to marine fishing, fisheries in freshwater is neglectable given the absence of noteworthy natural waterbodies or of man-made lakes, while aquaculture is in its infancy (FAO, 2007). The potential for the latter is set at 2,800 t/year. *Botswana* does not run any aquaculture projects and relies on importation of fish products, mainly from South Africa (SOGES, 2011). The Zambezi Integrated Agro-Commercial Development Project Consolidated Feasibility Report (Ministry of Agriculture, 2010) states that the plan to diverse part of the Zambezi river would allow for 39,000 tonnes per year of tilapia fish. For *Malawi* no recent numbers of total outtake have been found other than on national level.

Livestock

Similar as for the crop data, data on livestock species was compiled from various sources as indicated in Table 3. For comparison only major categories have been retained: cattle, sheep, pigs, goats and poultry. Headcounts for subspecies, especially in the case of cattle and poultry, have been summed up if a total was not provided.

Boundaries of the administrative units

Administrative boundaries for GIS applications[3] have been downloaded from the Global Administrative Areas Database (GADM), version 2.8, November 2015 (available at https://gadm.org/data.html). Vertical integration of boundaries is entirely assured. Boundary geometries are not projected and after assembling the partial source datasets, have been projected to the transverse Mercator projection WGS 1984 UTM Zone 35S.

For crops, livestock and fisheries separate base maps have been created taking the different levels of detail available for each of the key variables. The various national sets have been assembled using the function *merge*. Masks of the basins have been used in the tool *clip* in order to exclude areas outside the ZRB. As administrative boundaries do not always coincide with the ZRB boundaries, the figures concerning agriculture, livestock and fisheries were proportionally adjusted depending on their relative area within the basin.

Classification rules for all maps in this chapter follow the Jenks Natural Breaks Algorithm with zero values being excluded as ‘No Data’ (Jenks, 1967).

[2] Personal communication with Tim Kilner, RADCO / Mashonaland Fisheries PVT Ltd, 29/03/2018

[3] All spatial analyses have been conducted using the software ArcGIS 10.4.

Table 2 – Data sources and pre-processing operations for standardizing the data on crop production, area and yields

Country	Admin. unit	Year	Variable	Source	Source Institution	Pre-processing
Angola	Province	2007-2008	Production in tonnes, cultivated area in ha, yields in t/ha	(Ministério da Agricultura 2009)	Ministry of Agriculture	None
Botswana	Province	2015	Production in tonnes, cultivated area in ha, yields in t/ha	(STATISTICS BOTSWANA 2016)	Statistics Botswana, Dept. of Agricultural Research, Statistics & Policy Development (DARSPD), Ministry of Agriculture	Conversion of yields from kg/ha to t/ha
Malawi	District	2015-2016	Average production by household, share of cultivated area per crop, average household size, percentage of households involved in agriculture	(NSO Malawi 2017)	National Statistical Office Malawi, World bank	Average production values from households have been converted to production values per districts based on the number of households per district. Production values given in units of kg or 50kg bags have been harmonised and added up. Other units were neglected
Mozambique	Province	2014	Production in tonnes, cultivated area in ha, yields in t/ha	(Ministério da Agricultura e Segurança Alimentar 2014)	Ministry of Agriculture and Food Security	Yields were computed as production/ cultivated area; Values for varieties of beans, potatoes, groundnuts have been summed up
Namibia	Country	2013	Number of households, area, production, yields	(Namibia Statistic Agency 2015)	Namibia Statistic Agency, Ministry of Agriculture, Water and Forestry	None
Namibia	Province	2013	Number of households involved in crop, livestock or forestry production	(Namibia Statistic Agency 2015)	Namibia Statistic Agency, Ministry of Agriculture, Water and Forestry	Provincial proportions of national area, production and yields were computed based on provincial count of households involved in crop production as share of all households of the country

Country	Admin. unit	Year	Variable	Source	Source Institution	Pre-processing
Tanzania	Province	2015	Planted area; production; yield	(National Bureau of Statistics Tanzania 2016)	National Bureau of Statistics (NBS), Ministry of Agriculture, Livestock and Fisheries; Ministry of Industry, Trade and Investment; the President's Office, Regional Administration and Local Government (PO/RALG); Office of the Chief Government Statistician, (OCGS);	Addition of area and production of long and short rainy seasons, averaging yields of short and long rainy season.
Zambia	District	2016-2017	Planted area; expected, production; expected yield	(CSO 2017)	Central Statistical Office Zambia	Regrouping of different varieties of tobacco, beans and maize
Zimbabwe	Province	2015	Planted area; production; yield	(ZIMSTAT 2015)	Zimbabwe National Statistic Agency	Convert yields from kg/ha to ton/ha

Table 3 – Data sources and pre-processing operations for standardizing the data on livestock production

Country	Admin. unit	Year	Variable	Source	Source Institution	Pre-processing
Angola	Province	2007-2008	Headcount of cattle, sheep & goats, pigs, poultry	(Ministério da Agricultura 2009)	Ministry of Agriculture	Dividing the category "Goats and Sheep" equally
Botswana	Province	2015	Headcount of cattle, sheep, goats, pigs, poultry	(STATISTICS BOTSWANA 2016)	Statistics Botswana, Department of Agricultural Research, Statistics & Policy Development (DARSPD), Ministry of Agriculture	None
Malawi	District	2006/2007	Headcount of cattle, sheep, goats, poultry	(NSO Malawi 2010)	National Statistical Office Malawi	none
Mozambique	Province	2012-2014	Headcount of cattle, sheep, goats, pigs, poultry	(Ministério da Agricultura e Segurança Alimentar 2014)	Ministry of Agriculture and Food Security	None
Namibia	Country	2013	Detailed headcount of cattle, sheep, goats, poultry; number of households	(Namibia Statistic Agency 2015)	Namibia Statistic Agency, Ministry of Agriculture, Water and Forestry	None

Country	Admin. unit	Year	Variable	Source	Source Institution	Pre-processing
Namibia	Province	2013	Number of households involved in animal husbandry	(Namibia Statistic Agency 2015)	Namibia Statistic Agency, Ministry of Agriculture, Water and Forestry	Multiplication of provincial share of livestock holders with countrywide headcount
Tanzania	Province	2015	Detailed headcount of cattle, sheep, goats, pigs, poultry	(National Bureau of Statistics Tanzania 2016)	National Bureau of Statistics (NBS), Ministry of Agriculture, Livestock and Fisheries; Ministry of Industry, Trade and Investment; the President's Office, Regional Administration and Local Government (PO/RALG); Office of the Chief Government Statistician, (OCGS);	None
Zambia	Province	2014	Detailed headcount of cattle, headcount of sheep, goats and pigs	(CSO 2015)	Central Statistical Office	None
Zambia	Province	2013	Headcount of poultry	(CSO 2015)	Central Statistical Office	None
Zimbabwe	Province	2014	Detailed headcount of cattle and poultry, headcount of sheep, goats and pigs	(ZIMSTAT 2015)	Zimbabwe National Statistic Agency	None

Table 4 – Data sets used and pre-processing operations for standardizing the data on the fisheries sector

Country	***Admin. unit***	***Year***	***Variable***	***Source***	***Source Institution***	***Pre-processing***
Malawi	Country	2015	Total output	(NSO Malawi 2016)	National statistical Office Malawi	None
Mozambique	District	2012	Fish Catch	(Ministério das Pescas 2012)	Ministry of Fisheries, Mozambique	Addition of species-specific output (in tons) of fresh water fish
Zambia	Province	2014	Catches, fish farming, aquaculture	(DOF 2015),	Department of Fisheries	Assigning water body specific values to administrative units based on equal proportions; Assigning outtakes of individual exploitations to administrative units based on location
Zimbabwe	Lake Kariba	2014	Fish Farming outtake Lake Kariba; Small scale fishing	(Fletscher 2018; Kolding et al. 2016)		Weighted attribution to the two adjacent provinces

Example maps of pre-processed source data

Figure 1 to Figure 3 illustrate the availability and spatial distribution of published regional statistical data of five sample crops for the Zambezi basin. While this data gives some insight into the relative importance of specific crops per administrative areas, this information is too coarse for modelling crop production and identifying where crop water uses are potentially more efficient. Similarly, Figure 4 illustrates the spatial distribution of major livestock species and Figure 5 that of fisheries.

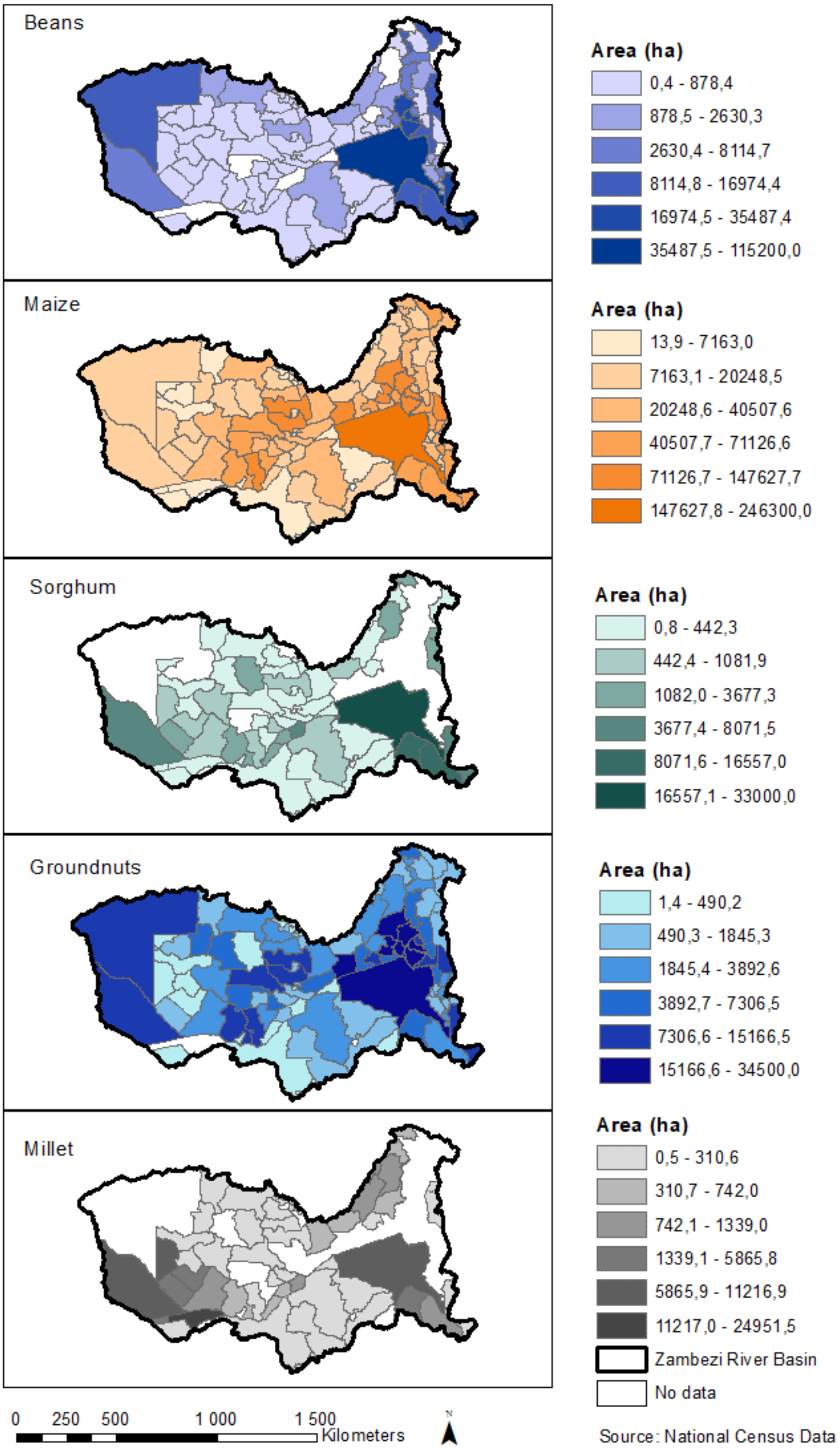

Figure 1 – Example maps of reported crop areas per administrative unit in the Zambezi River Basin

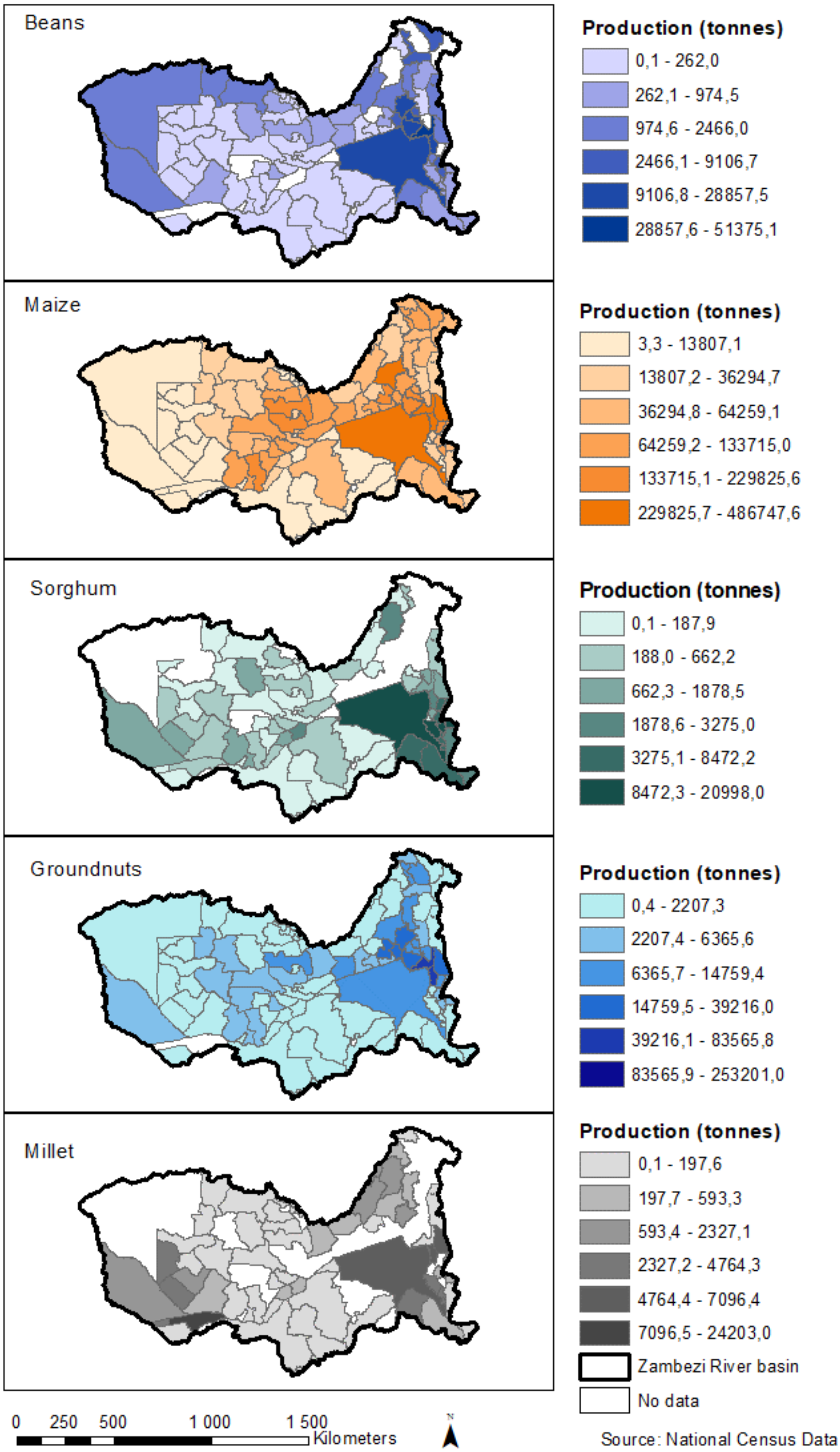

Figure 2 – Example maps of reported crop production per administrative unit in the Zambezi River Basin

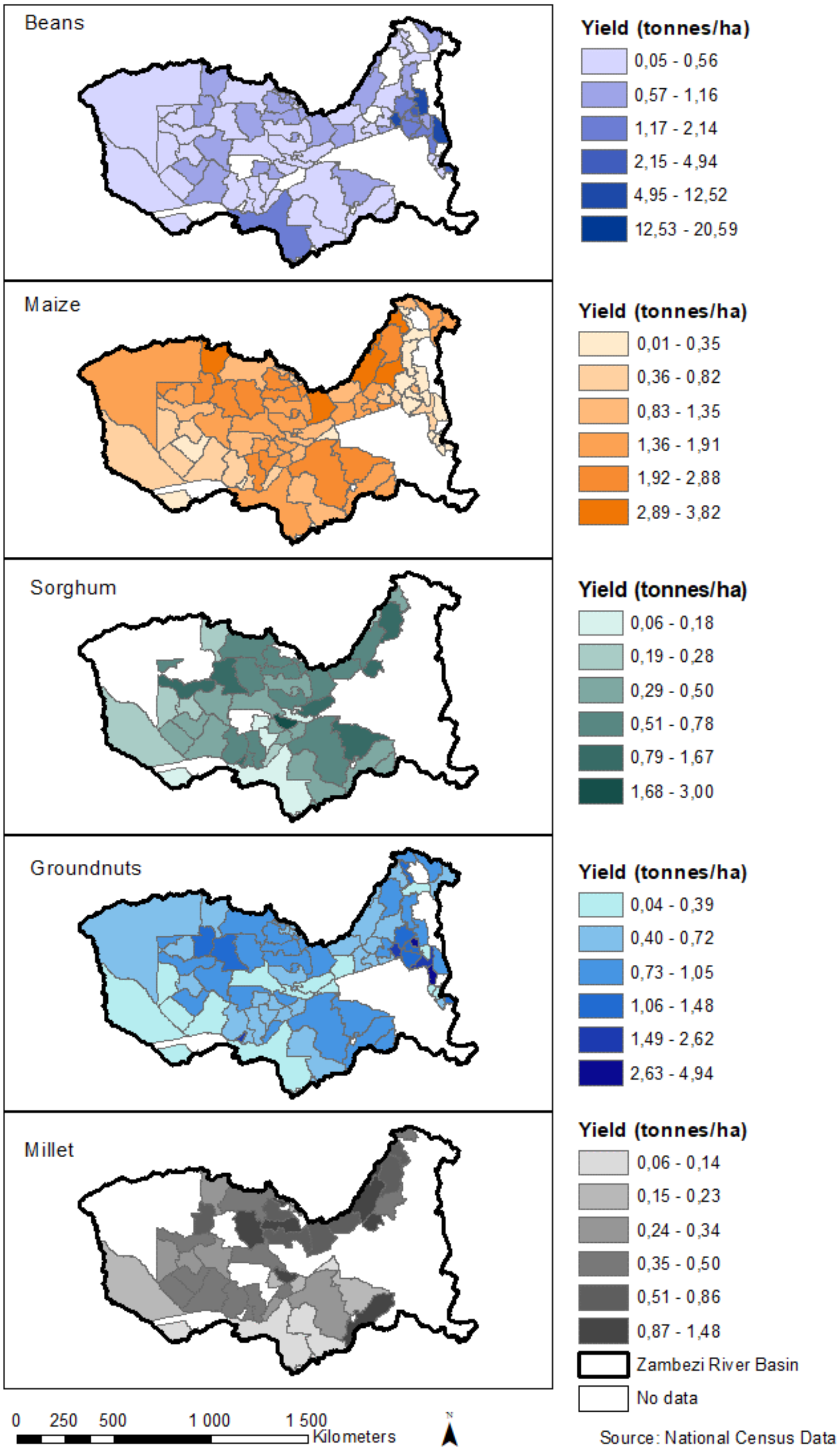

Figure 3 – Example maps of reported crop productivity per administrative unit in the Zambezi River Basin

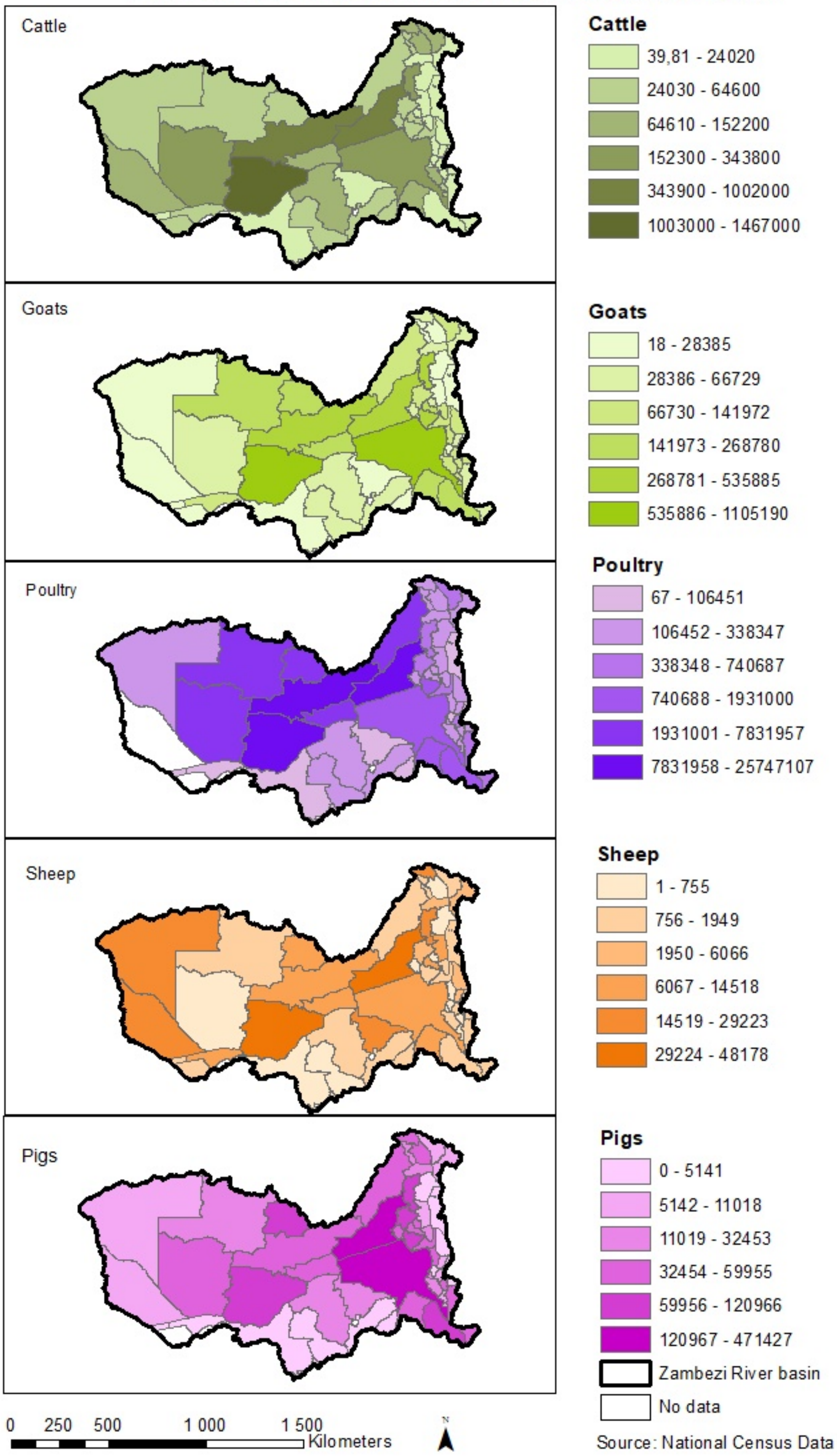

Figure 4 – Example maps of reported livestock distribution (headcounts) per administrative unit in the Zambezi River Basin

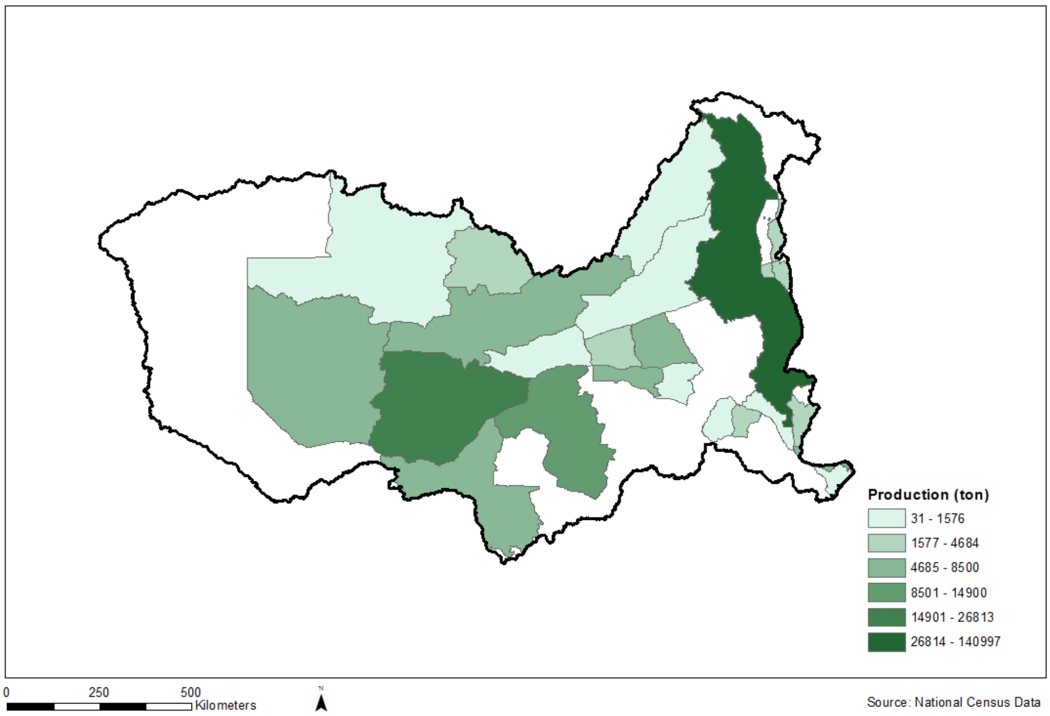

Figure 5 – Map of reported fish production per administrative unit in the Zambezi River Basin

2.1.2 Biophysical Land Units (BLUs)

Biophysical Land Units (BLUs) are the target zones to which agricultural activities as reported in the statistical datasets (Section 2.1.1) are assigned to by means of spatial disaggregation in order to achieve a spatial distribution of these activities in line with reality. Biophysical Land Units (BLUs) are defined based on subbasin, soil mapping unit, slope and land use through the ArcSWAT-extension for ArcGIS 10.4 and next combined with climate zone. ArcSWAT delineates and subdivides the river basin in sub-basins starting from a digital elevation model (DEM) with or without the hydrographical network, and next identifies the so-called Hydrological Response units (HRUs) within those sub-basins. HRUs within sub-basins and further stratified for climate zone are further used as the target BLUs, to which the agro-statistical source data (Section 2.1.1) are dis-aggregated. Each BLU is assumed to be spatially uniform in land use, soil, topography and cli-mate.

Geospatial data

The following datasets were used for generating sub-basins, HRUs and ultimately BLUs:

- Digital Elevation Model: SRTM at 90 m resolution (Source: https://earthexplorer.usgs.gov/)
- Climate zones for the basins are at 9 km resolution (Source: http://www.yield-gap.org/web/guest/sub-saharan-africa)
- Soil maps and associated soil characteristics for major soils for Africa - FAO 1:5 Million soil map (source: http://www.fao.org/geonetwork/srv/en/metadata.show?id=29031&currTab=simple)
- Land use at 20 m resolution (source: http://2016africalandcover20m.esrin.esa.int/)

Digital Elevation Model (DEM)

ArcSWAT uses the DEM as a basis to resample all other spatial inputs like the soil and land use maps to the same resolution as the DEM. For ZRB all the spatial inputs in raster formats were resampled from the source resolution (90 m) to 400 m resolution. Figure 6 shows the topography and main rivers of the Zambezi River Basin based on the SRTM data on the source resolution.

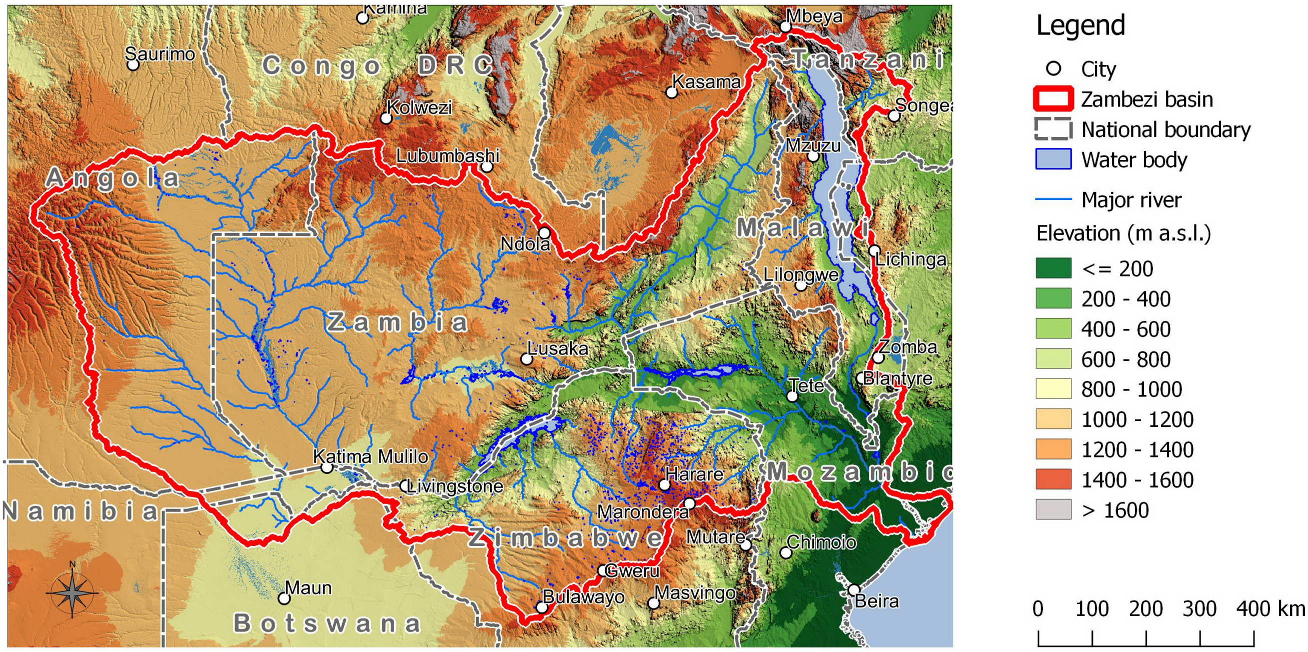

Figure 6 – Topography of the Zambezi Basin based on DEM derived from SRTM data

Land Cover/Land Use

The African land cover 20 m dataset (ESA, 2017) was used to develop the land use map for the ZRB as shown in Figure 7, by resampling it at 400 m horizontal resolution using the nearest neighbour method in ArcGIS. Table 5 gives the land use categories and the area covered under each category.

Table 5 – Land use categories and their area share in the ZRB

VALUE	**Land cover of map of Africa**	**Land use in ArcSWAT**	**Basin Area [%]**
1	Trees cover areas	Forest Deciduous (FRSD)	36.2
2	Shrubs cover areas	Range Brush (RNGB)	21.3
3	Grassland	Range Grasses (RNGE)	23.8
4	Cropland	Agriculture (AGRL)	15.5
5	Vegetation aquatic or regularly flooded	Wetlands (WETL)	0.1
8	Built up areas	Urban (URBN)	0.1
10	Open water	Water (WATR)	3.0

Soil

The FAO Harmonized World Soil Database v1.2 – which has a resolution of *ca*. 900 m (30 arc-second) – was resampled to 400 m resolution to meet the resolution of the DEM (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). The Harmonized World Soil Database (HWSD) is a raster database that combines existing regional and national updates of soil information worldwide and from which 111 Soil Mapping Units (SMUs) were extracted for the Zambezi basin as shown in Figure 8.

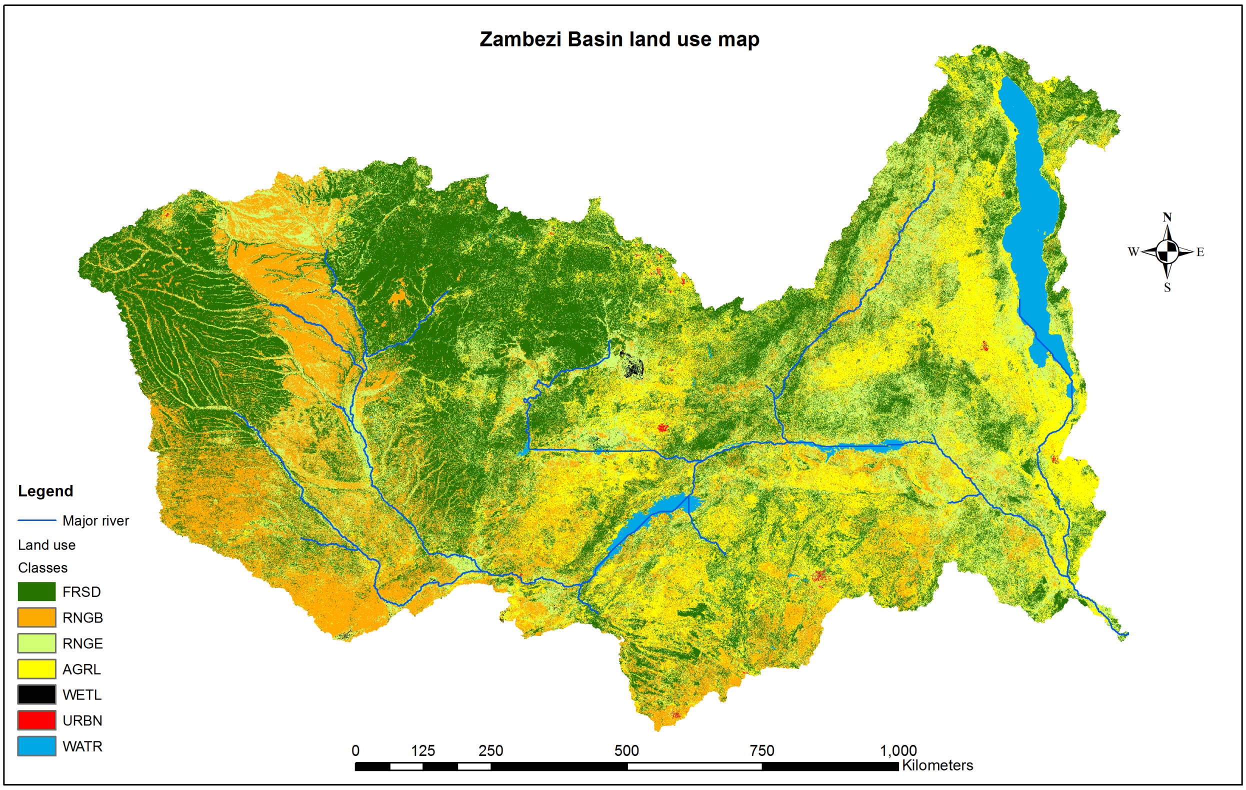

Figure 7 – Land use distribution in the Zambezi Basin at 400 m resolution (adapted from ESA, 2017)

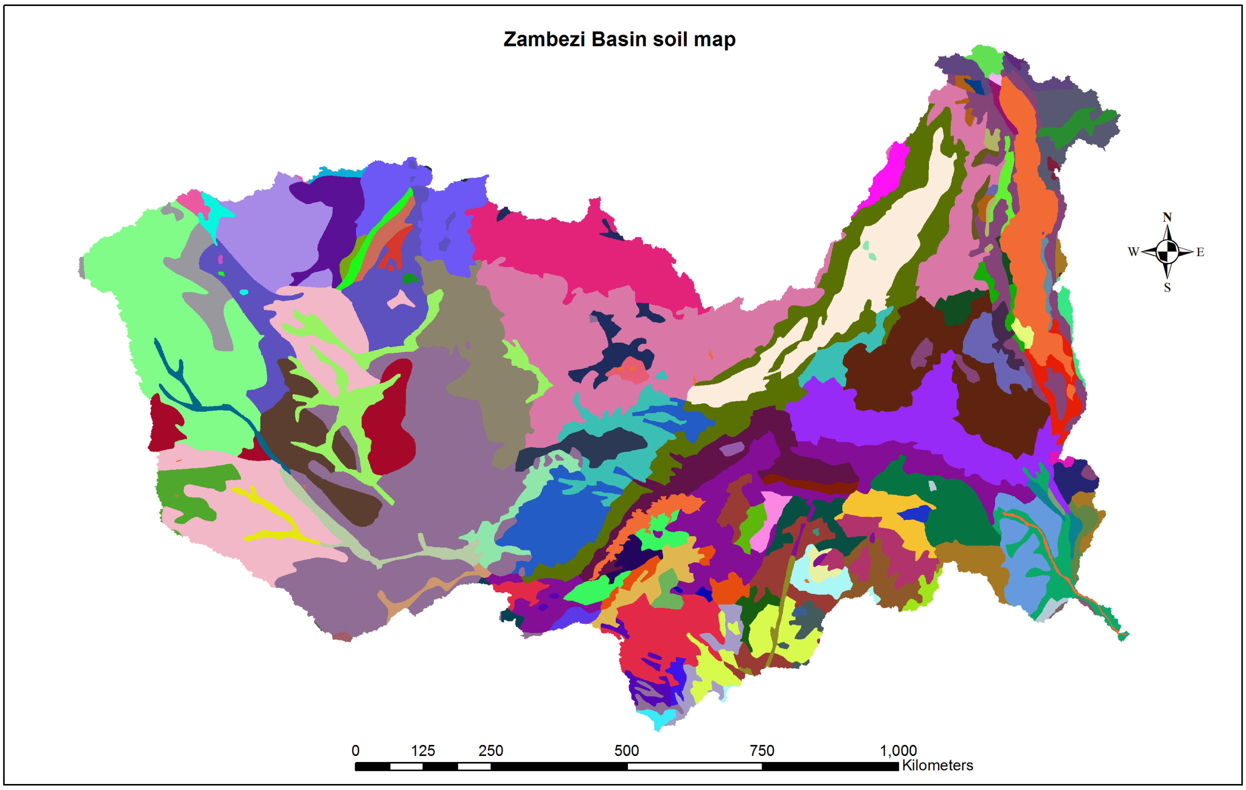

Figure 8 – Soil map of the Zambezi Basin at 400 m resolution (each colour in the map symbolises one of the 111 SMUs in the ZRB) (adapted from FAO/IIASA/ISRIC/ISSCAS/JRC, 2009)

Slope

The slope layer is derived from the DEM using the eight-direction (D8) algorithm (O'Callaghan and Mark 1984). The slope map is shown in Figure 9. Five slope classes were distinguished in line with the ones prescribed by FAO.

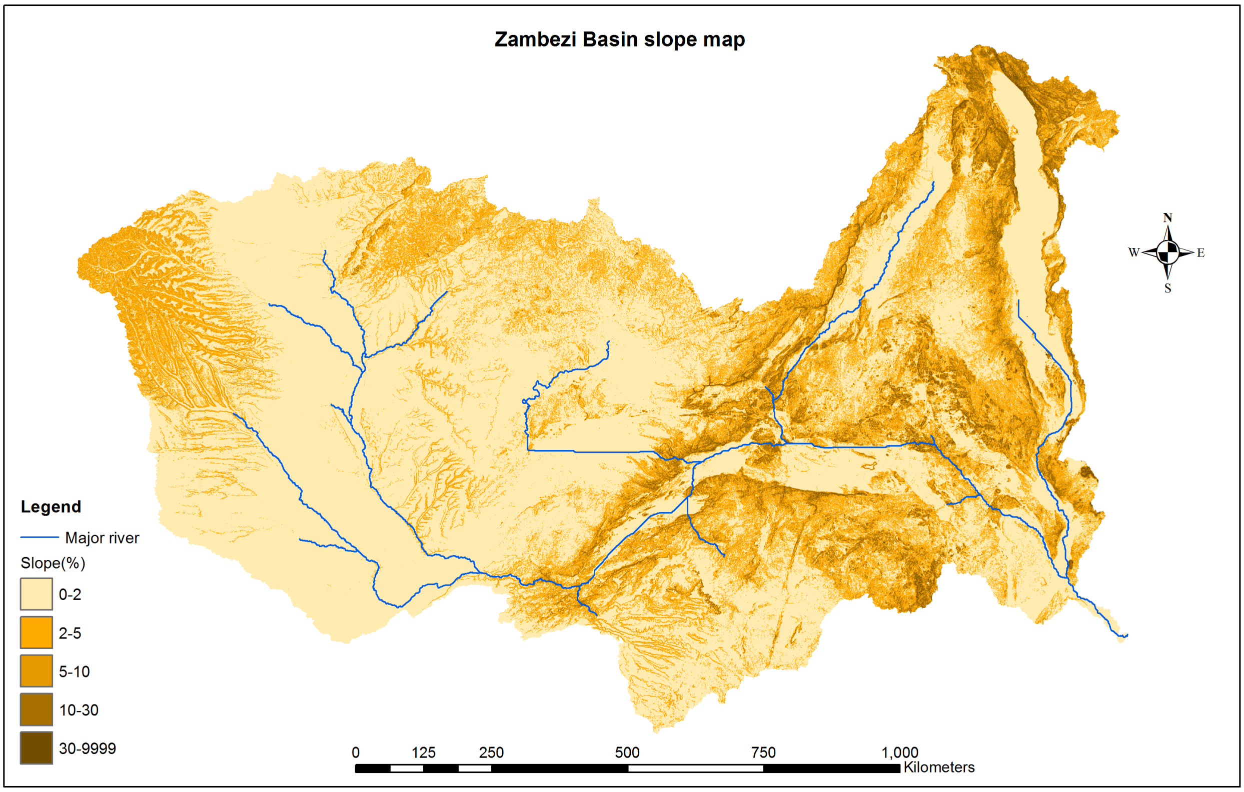

Figure 9 – Slope map of the Zambezi Basin at 400 m resolution (based on SRTM 90 m resolution data – https://earthexplorer.usgs.gov/)

Hydrologic Response Units (HRUs)

Each HRU is defined as a subdivision of a sub-basin based on slope class, landcover class and soil mapping unit. The HRUs are derived from the DEM, landcover layer, soil mapping units layer and the slope layer used by means of the ArcSWAT tool. The procedure comes upwith 5111 HRUs, the smallest of which is 0.16 km^2 and largest 28,174 km^2.

Climatic zones

By further subdividing the HRUs according to climatic zones, land-units are identified which can be assumed to be homogenous in agro-ecological potential and can hence serve as a base for spatially allocating and modelling of agricultural, livestock and/or fishery production and water use. The Climatic zones layer obtained from the Global Yield Gap Atlas (GYGA) project for sub-Saharan Africa (http://www.yieldgap.org/cz-ted) was used after resampling from the 9 km source resolution to a 400 m resolution. GYGA defines climate zones in terms of growing degree days, temperature seasonality and an annual aridity index. For the Zambezi River Basin this results into 35 distinct climatic zones (Figure 10).

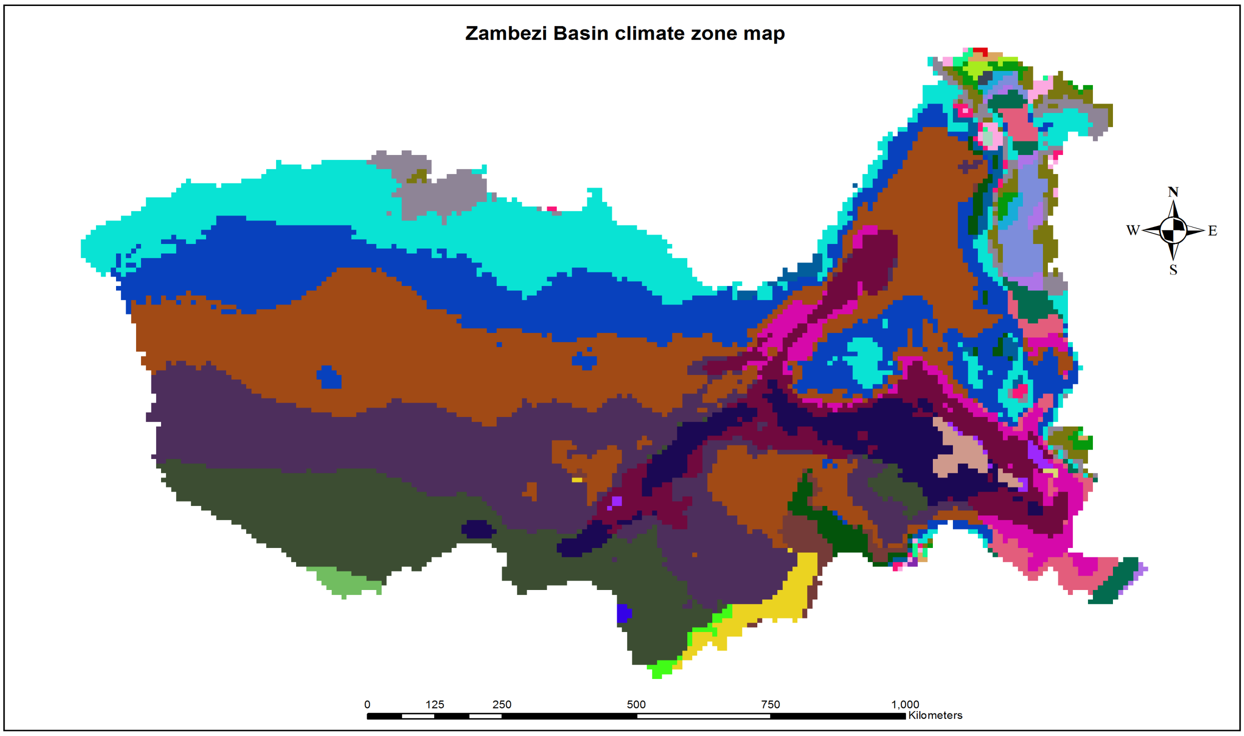

Figure 10 – Climatic zones the Zambezi Basin (each colour in the map symbolises one of 35 climate zones in the ZRB defined in terms of growing degree days, temperature seasonality and an annual aridity index) (adapted from Global Yield Gap Atlas - http://www.yieldgap.org/cz-ted)

Land Units

The final biophysical land units were derived by combining the cell attribute value of the HRU layer with those of the climatic zones layer. For the ZRB 15084 land units were generated consisting of unique combinations of a sub-basin, a land use type, a soil class, a slope class and a climatic zone.

2.1.3 Disaggregation of production data from the administrative to the biophysical land units

Now that the biophysical land units are available (section 2.1.2), the statistical data which are available per administrative unit (section 2.1.1) could be disaggregated towards these BLU. The procedure required the following steps:

1. Topological overlay of the administrative unit datasets as described in section 2.1.1 with the biophysical land unit dataset obtained through section 2.1.2;
2. Computation of the area share of each land unit in each administrative unit;
3. Establishment of a set of decision rules that determine which agricultural activities are possible in which type of land units. A rationale comparable to Campling et al. (2005) has been used;
4. Correction of the area share of each land unit in each administrative unit, taking the decision rules into account. Without correction, a land unit which occupies 10% of an administrative land unit would be assigned 10% of the agricultural area or production of this administrative unit. In case the decision rule states that crop production is not possible in this type of land unit, the share will be set to 0% and the shares of the other land units in the same administrative unit will be proportionally adjusted;
5. Use of the corrected area shares to assign fractions of the area, production values of crops, livestock, and fish attached to the administrative unit, to the considered land units.

Table 6 – Decision rules for assigning shares of agricultural areas and production as available per administrative unit to biophysical land units

Landunits (LUs)
LUs < 500 ha are merged with that neighbouring LU that has the longest shared border
Crop statistics
Statistics for administrative units partly within the ZRB are decreased proportionally to the area fraction of the administrative unit within the basin
If LUs with land use type (LUT) ‘AGRL’ are present in the administrative unit: crop statistics are all assigned to LUs with LUT ‘AGRL’, proportionally to their size
If no LUs with LUT ‘AGRL’ are present in the administrative unit: crop statistics are assigned to LUs with LUT ‘RNGB’ OR ‘RNGE’ AND slope ≤ 10%, proportionally to their size
Livestock statistics
Statistics for administrative units partly within the ZRB are decreased proportionally to the area fraction of the administrative unit within the basin
Cattle, goats and sheep statistics are assigned to LUs with LUT ‘RNGB’, ‘RNGE’, ‘AGRL’ OR ‘WETL’, proportionally to their size
Pigs and poultry statistics are assigned to LUs with LUT ‘RNGB’, ‘RNGE’, ‘AGRL’, ‘WETL’ OR ‘URBN’, proportionally to their size
If the statistics for sheep and goats are combined as a single statistic for a certain administrative unit, the statistic is equally divided between sheep and goats
Fish statistics
Statistics for administrative units partly within the Zambezi are decreased proportionally to the area fraction of the administrative unit within the basin
No distinction is made between fish farming and aquaculture
If no distinction is made between aquaculture and fish catch, statistics for fish are equally divided between fish catch and aquaculture
If LUs with LUT ‘WATR’ are present in the administrative unit: 90% of fish catch statistics are assigned to these LUs, proportionally to their size. 10 % of fish catch statistics are assigned to LUs with LUT ‘FRSD’, ‘RNGB’, ‘RNGE’, ‘AGRL’, ‘WETL’ OR ‘URBN’, proportionally to their size
If LUs with LUT ‘WATR’ are present in the administrative unit: 90% of aquaculture statistics are assigned to these LUs, proportionally to their size. 10 % of aquaculture statistics are assigned to LUs with LUT ‘FRSD’, ‘RNGB’, ‘RNGE’, ‘AGRL’, ‘WETL’ OR ‘URBN’, proportionally to their size
If no LUs with LUT ‘WATR’ are present in the administrative unit: 100% of fish catch statistics are assigned to LUs with LUT ‘FRSD’, ‘RNGB’, ‘RNGE’, ‘AGRL’, ‘WETL’ OR ‘URBN’, proportionally to their size. These LUS are then aggregated for the sub-basin they are part of
If no LUs with LUT ‘WATR’ are present in the administrative unit: 100% of aquaculture statistics are assigned to LUs with LUT ‘FRSD’, ‘RNGB’, ‘RNGE’, ‘AGRL’, ‘WETL’ OR ‘URBN’, proportionally to their size. These LUS are then aggregated for the sub-basin they are part of

2.2 RESULTS

Figure 11 to Figure 13 show some of the results of the disaggregation process for the ZRB. The results for the other crops, livestock and fish categories are available in the DAFNE-Dropbox. In subsequent work (a.o. in subtask 2.2.5 of WP2) these numbers will be converted into available calories and proteins and compared with the demand for food by the current and expected populations in the basin. Moreover they determine the applicable crop-soil-climate combinations and provide production reference data fro crop production modelling to be undertaken with the AquaCrop and with the integrated Topkapi-ETH model coupled to AquaCrop.

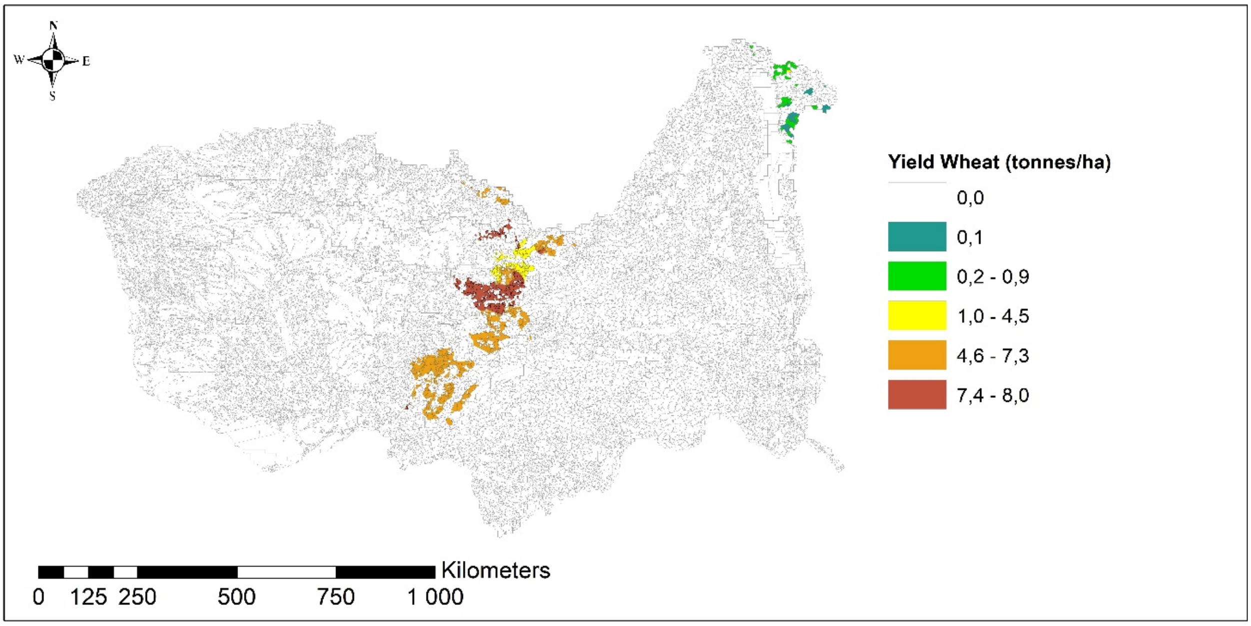

Figure 11 – Yield of wheat (in tonnes/ha) for the LUs of ZRB based on regional statistics and the decision rules presented in Table 6

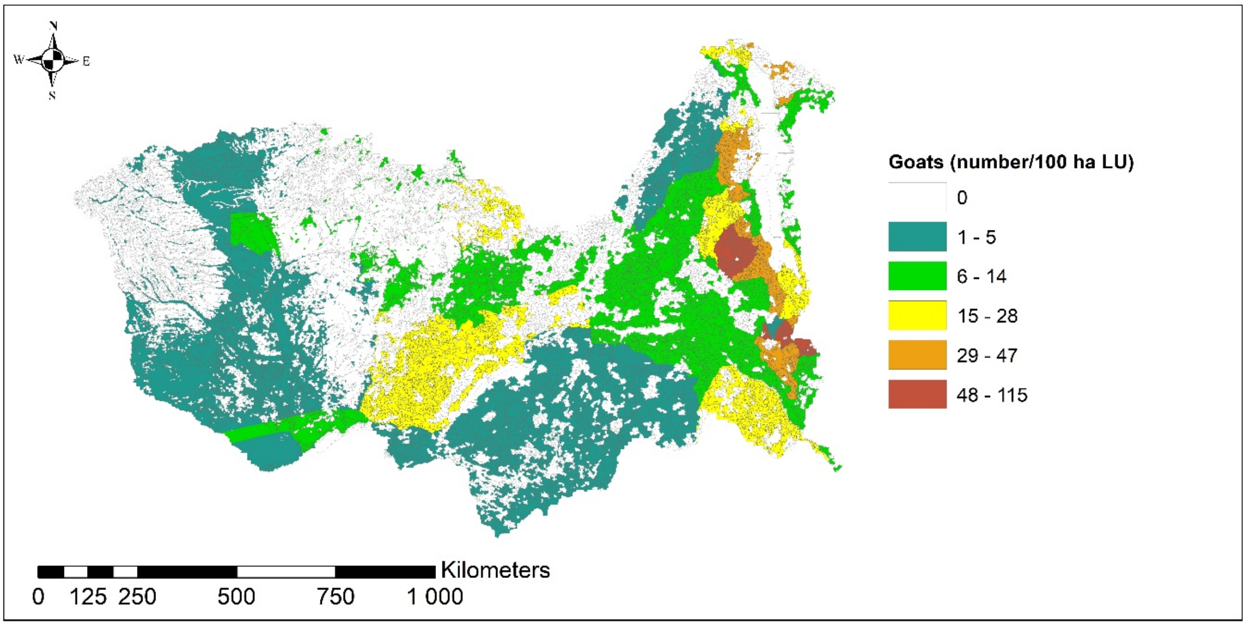

Figure 12 – Number of goats (per 100 ha LU) for the LUs of ZRB based on regional statistics and decision rules presented in Table 6

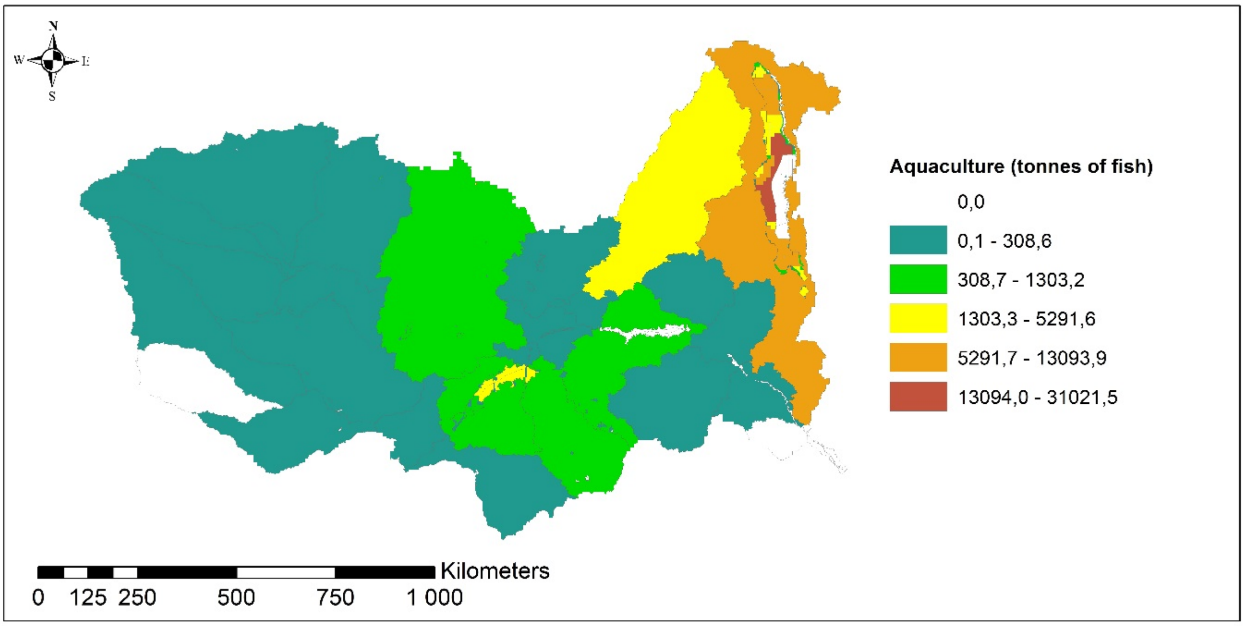

Figure 13 – Tonnes of fish produced through aquaculture in the sub-basins of the Zambezi river basin as derived from regional statistics and the decision rules presented in Table 6

2.3 DISCUSSION

2.3.1 Effect of disaggregation data per land unit

The GIS-based modelling of the spatial distribution of agricultural activities and their productivity allows to estimate where crop production, livestock husbandry, fish catch and fish farming is most like practiced. This estimate is based on the available administrative data on areas under cultivation and production of crop types practiced in the region. Similarly, data on livestock production and fisheries and fish farm production was disaggregated and assigned to biophysical LUs. These LUs are more informative for the actual locations where crop production, animal husbandry and fish catch or fish farming take place. Further, the LUs are created based on and thus coupled to soil mapping units, slope percentages, HRUs, and climate zones. By assigning crop production, livestock and fish production to specific LUs, these LUs can later be used as input for AquaCrop in order to model water usage and subsequent production. In this section, the comparison is made between maize and wheat production, and cattle headcounts per area unit before and after disaggregation in the ZRB to illustrate the effect of the disaggregation.

Figure 14 illustrates the outcome of disaggregating data on maize production per administrative units according to LUs. Disaggregating crop production into land units allows us to make a spatial assessment of where crop production, and in this case maize production, is actually taking place. Before disaggregation of the crop statistics, the numbers were available per administrative area and maize is seemingly produced all over the Zambezi river basin. After disaggregation, maize production is assigned to specific LUs that are suited for agriculture. This results in a 'concentration effect' which can be seen in the higher production values per area unit after disaggregation. Further it is also noticeable that after disaggregation, maize production is concentrated in five major areas in the ZRB, i.e. the part of Botswana that is part of the ZRB, the upper Zambezi region of Zambia, the copper belt and the Kafue sub-basin, the area around Lake Malawi and the area around Lake Kariba particularly in Zimbabwe. This type of information is of importance for establishing the baseline situation of the WEF-nexus and for the process of definition of the pathways to development, which is expected to take place in WP5.

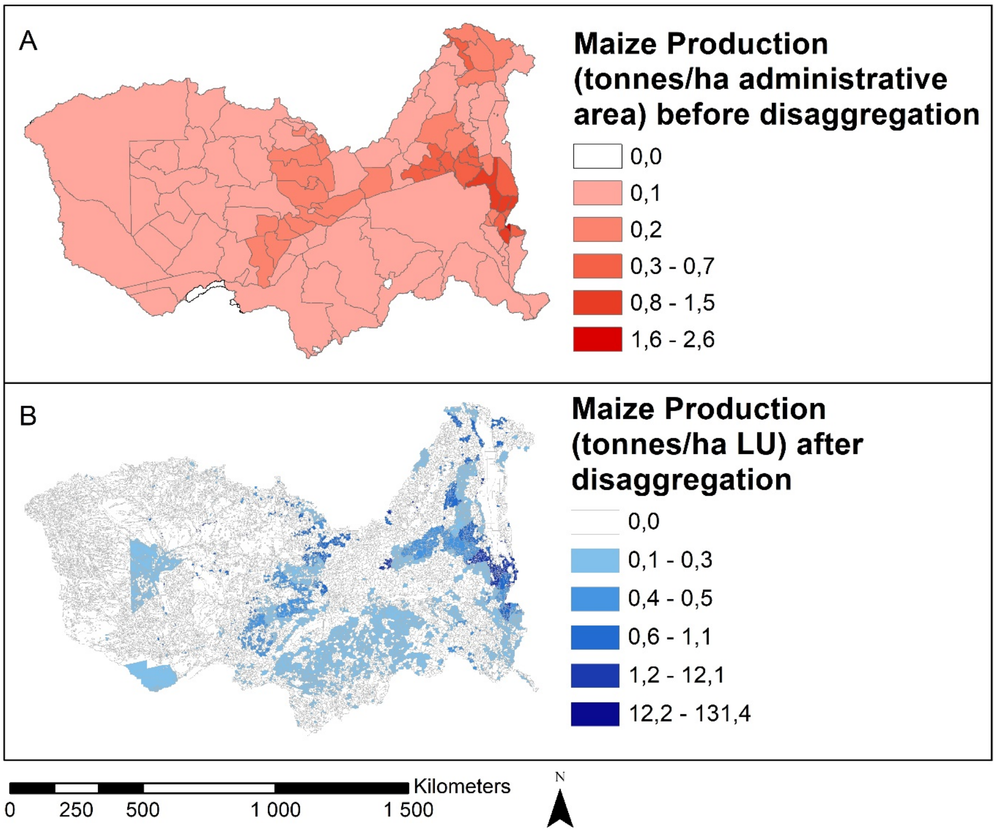

Figure 14 – Maize production in the ZRB (A) per surface area administrative area before disaggregation, and (B) per surface area LU after disaggregation.

For wheat production in the ZRB, it is already clear before disaggregation that production is mainly concentrated in the centre of the Zambezi river basin, the Kafue sub-basin (Figure 15, A). Disaggregation into LUs however assigns production numbers to specific LUs in which agriculture is possible within this area, which again leads to the same concentration effect as for maize production (Figure 15, B).

For cattle headcounts per area unit, disaggregation has a less pronounced effect than it has on crop production (Figure 16). This because livestock is assumed to occur on a higher number of LUs than crop cultivation and therefore there is a less pronounced concentration effect for livestock. After disaggregation, it can be seen that cattle is assigned to LUs all over the ZRB but the numbers are higher in the Luangwa and Kafue sub-basin, and around Lake Kariba and Lake Malawi, while almost no cattle is assigned to LUs in the Kabompo, Kafue and Barotse sub-basin and in the western part of the Upper Zambezi, the Lunga and the Chobe sub-basin. Also these results provide estimates that have implications in the definition of the pathways to development to be implemented in the DAF.

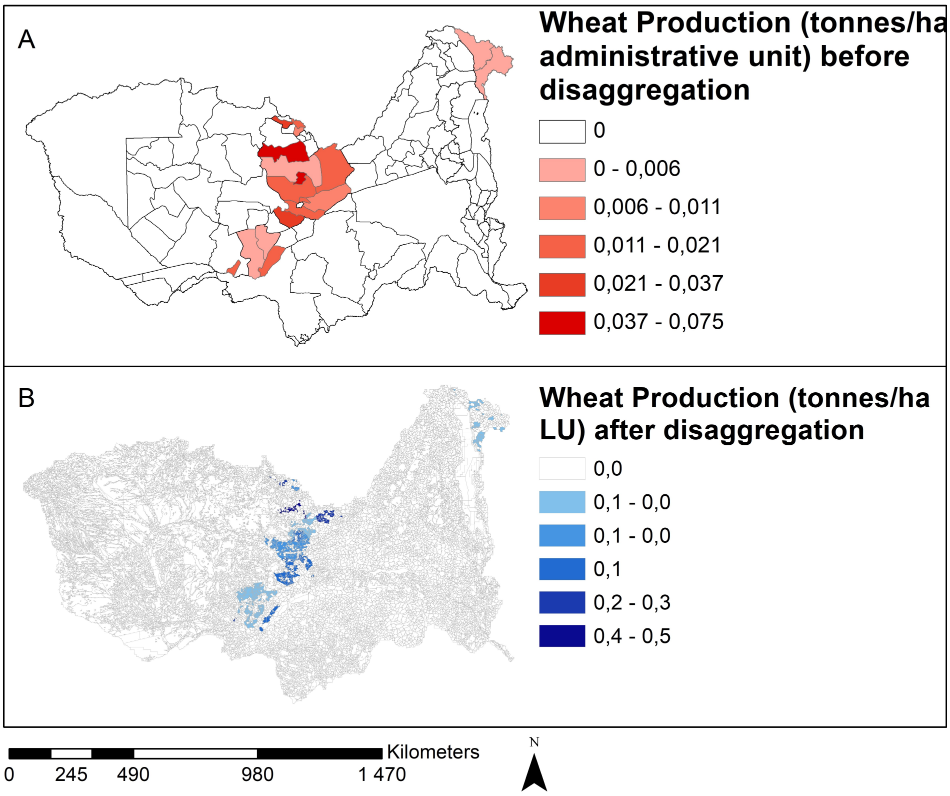

Figure 15 – Wheat production in the ZRB (A) per surface area administrative area before disaggregation, and (B) per surface area LU after disaggregation.

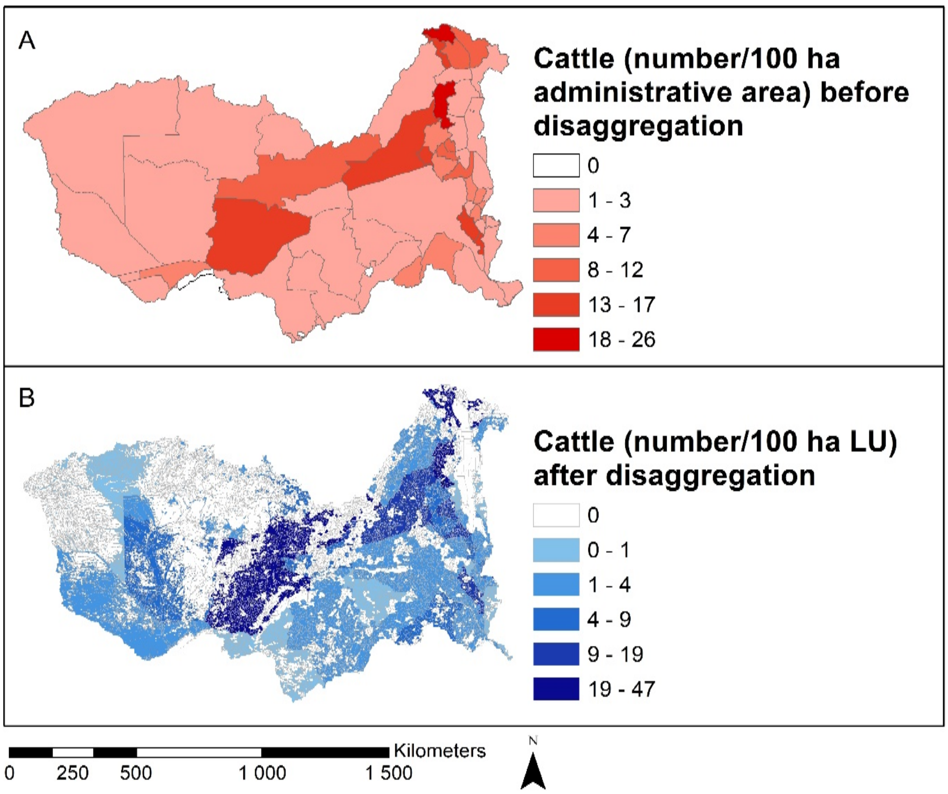

Figure 16 – Number of cattle in the ZRB (A) per 100 ha surface area administrative area before disaggregation, and (B) per 100 ha surface area LU after disaggregation.

2.3.2 Agrostatistical data and implications of pre-processing assumptions

The procedure of disaggregating data available at administrative unit level towards the identified BLUs required some assumptions and/or limitations, which one must be aware of to correctly interpret the results. These are:

- The distinction between 'no activity' and 'missing data' is not always unambiguous;
- The heterogeneity regarding the temporal validity (year of survey) of the data and regarding the level and size of the administrative units;
- The fact that several livestock species have been aggregated in one class (e.g. traction, dairy and meat cattle);
- The fact that no distinction could be made between small-scale and commercial farms nor between irrigated and non-irrigated agriculture;
- The fact that sources report data about fish farming on the one hand and aquaculture on the other hand but that the distinction between both is not clear. Moreover available data on fish catches are limited;
- Errors related to rounding in case of national averages and sub-national household numbers and when applying area proportions to assign fractions of a variable at administrative level to a land unit;

The lower quality data found and used for the more peripheric ZRB-countries (Angola, Botswana, Namibia) is probably not affecting the results to an important extent, mainly because of the relatively low absolute numbers. For Angola, e.g., livestock production in the few provinces covered by the ZRB is more than marginal and represents less than 2.6% of the meat production of the country (Ministério da Agricultura, 2009), which is already not very high.

Moreover, some rounding errors occur when the agricultural statistics are disaggregated towards the LUs. The resulting deviations between the value of a variable (e.g. area devoted to wheat production) before and after disaggregation cumulated over all land units ranges between 3.78 % (Production area of millet) to 0% (Production area of barley; headcount of cattle). Overall these deviations are small and confirm the consistency of the disaggregation procedure.

2.3.3 Land unit definition

Since the ZRB covers a huge territory, land units were derived from relatively low resolution geodatasets even if pre-processing was done on a compromise resolution of 400 meters. Hence, 16 hectares is the minimal mapping unit but, due to the low resolution of some of the source datasets, the real minimal mapping unit is larger.

2.3.4 Decision rules

In order to disaggregate the crop production statistics and assign them to biophysical land units, both LUT and slope class were taken into account. If LUs with LUT 'AGRL' are present in the considered administrative unit for which crop statistics are available, the crop production statistics were assigned to these LUs, proportionally to the size of that LU compared to the total area of the administrative unit that it is part of. However, when no LU with LUT 'AGRL' is present within the administrative unit, crop production statistics were assigned to LUs with LUT 'RNGB' OR 'RNGE' AND slope ≤ 10%. This was done because it is assumed that crop production within forests, wetlands, urban areas, or open water is limited or absent altogether. Agriculture on slopes higher than 10% was assumed to be limited due to the difficulties associated with land preparation and cultivation practices. Differences in crop productivity between various soil mapping units and climatic conditions were not taken into account in this exercise.

For the disaggregation of livestock statistics over the biophysical LUs, only LUT was taken into account. Cattle, goats and sheep were assumed to be present in LUs with LUT 'RNGB', 'RNGE', 'AGRL' or 'WETL'. Pigs and poultry were assumed to be also present in LUs with LUT 'URBN' since they are know the be kept in proximity of human settlements. For some administrative units, the statistics on goats and sheep came as aggregated. For these areas, the combined statistics were equally divided into individual numbers for goats and sheep. This was done because no information was available about the actual proportions of total number of goats over total number of sheep within these LUs while the proportions differed greatly in LUs for which individual numbers were available.

Finally, some assumptions were made to obtain an estimation on the location where fish catch and aquaculture are taking place within the river basins. No distinction was made among different types of aquaculture and between aquaculture and fish farming and were for simplicity all referred to as aquaculture. Further, it was assumed that if LUs with LUT 'WATR' were present in the administrative unit for which fish production statistics are available, 90% of the fish farming and aquaculture and fish catch was assumed to take place in these LUs. The remaining 10% was assumed to be distributed, proportionally to area, over the remaining LUs. If no LUs with LUT 'WATR' are present within the administrative unit for which fish production statistics are available, it was assumed that fish farming and aquaculture and fish catch is divided over the LUs proportionally to their area. By dividing the fish farming and aquaculture and fish catch statistics over the different LUs aggregation to the sub-basins was easy since the creation of the different LUs was, among other things, based on the delineation of the sub-basins.

3 AGRICULTURAL PRODUCTIVITY IN THE OMO TURKANA BASIN

3.1 MATERIALS AND METHODS

The approach used for the ZRB region was used also for the Omo-Turkana basin.

3.1.1 Source data

Crop production

The number of crops reported on varies across the two riparian countries. Production and yield statistics of 59 crops were collected (Table 7). The year of data collection and country for which the statistics were available varied from crop to crop. Production and yield values were all available on district level for Ethiopia and county level for Kenya. Only these crops were retained for which production was higher than 1000 tonnes in at least one district or county. A total of 38 crops has been retained.

Livestock

Available data encompass a varying selection of livestock species. The same categories as for the Zambezi river basin have been retained: cattle, sheep, pigs, goats and poultry.

For Kenya, data on poultry was reported as headcounts indigenous poultry and headcounts commercial chicken. Both values were summed up and are reported as 'poultry' in Table 8, and used as such in the modelling exercise.

Fisheries and aquaculture

For Ethiopia, fishery statistics reported by the FAO for 2013 were used. Fish catch statistics (in t/year) were reported for Lake Tana, Lake Ziway and Lake Langano, Lake Chamo, and Lake Abaya. However, none of these lakes are located in the OTB. Further, it was reported that 26% of the total fish landings occurred in the remaining part of the country. It was reported that no aquaculture took place in Ethiopia in 2013. The geographical location of the Ethiopian lakes for which fishery statistics were available was extracted from the 'Natural Earth' data which is primarily derived from the CIA World DataBank II (Patterson and Kelso, 2016).

For Kenya, fishery statistics reported in the Fisheries Annual Statistical Bulletin 2014 (Republic of Kenya 2014) were used. It was reported that the majority of the fresh water fish production took place in Lake Victoria (80.85%) in 2013, which is not part of the OTB. Lake Turkana only accounted for 2.81% of the total fresh water fish production. Fish farming accounted for 15.24% of fresh water fish production in 2013. This production was from 69194 ponds with an area of 2076 ha, 161 tanks measuring 2.3 ha and 124 reservoirs with an area of 74.4 ha. No specific location of these ponds, tanks and reservoirs was reported. The geographical location of the Kenyan lakes for which fishery statistics were available was extracted from the FAO's Africover dataset (FAO – GeoNetwork 2006).

Table 7 – Overview of crops and related data, and data sources per country

	Ethiopia				Kenya			
Crop	**Area (ha)**	**Production (tonnes)**	**Crop Year**	**Data source**	**Area (ha)**	**Production (tonnes)**	**Crop Year**	**Data source**
Grain Crops	**4869691.25**	**6359524.43**			**1242664.05**	**8147838.60**		
Teff	945702.47	1604647.34	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Barley	197517.79	405135.35	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	1647.00	620.00	2011	(Ministry of Agriculture 2012)
Wheat	296845.46	772453.84	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	103509.45	35875.00	2011	(Ministry of Agriculture 2012)
Maize	720687.32	2825366.73	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	1122444.90	369179.00	2011	(Ministry of Agriculture 2012)
Sorghum	257324.15	686688.16	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	10330.56	20815.00	2011	(Ministry of Agriculture 2012)
Millet	25168.45	63397.27	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	4558.14	5770.00	2011	(Ministry of Agriculture 2012)
Oats	1213.42	1835.74	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Rice	0.00	0.00	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	174.00	65.00	2011	(Ministry of Agriculture 2012)
Pulses	**366390.80**	**670095.59**			**172494.82**	**86233.42**		
Faba bean	134964.07	276659.207	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Field pea	78387.56	125327.775	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Beans	NDA	NDA			171586.00	84027.42	2011	(Ministry of Agriculture 2012)
* White Haricot bean	754.68	830.97	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Red Hari-cot bean	67263.09	81207.23	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Chick pea	50343.15	112152.82	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Lentil	11744.71	19455.11	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		

Crop	Ethiopia				Kenya			
	Area (ha)	Production (tonnes)	Crop Year	Data source	Area (ha)	Production (tonnes)	Crop Year	Data source
Grass pea	22302.78	53892.43	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Soya bean	0.00	0.00	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Fenu-greek	630.76	570.05	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Mung bean	0.00	0.00	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	400.68	868.00	2011	(Ministry of Agriculture 2012)
* Gibto	0.00	0.00	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Cowpea	NDA	NDA			499.59	1313.00	2011	(Ministry of Agriculture 2012)
* Pigeon pea	NDA	NDA			8.55	25.00	2011	(Ministry of Agriculture 2012)
Oilseeds	176153.09	210196.34			2035.00	1316.00		
Neug	136844.14	167443.39	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Linseed	12826.59	14717.98	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Ground-nut	8353.27	12667.80	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	2016.00	1305.00	2016	(Agriculture and Food Author-ity 2014)
* Safflower	125.61	165.35	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Sesame	16157.05	13328.78	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	19.00	11.00	2016	(Agriculture and Food Author-ity 2014)
* Rape-seed	1846.43	1873.04	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Cashew	NDA	NDA			NDA	NDA		
* Coconut	NDA	NDA			NDA	NDA		
Vegetables	**39107.04**	**250737.11**			**187653.00**	**8701.00**		
* Lettuce	0.00	0.00	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0.00	2014	(Agriculture and Food Author-ity 2015)
Cabbage	892.67	5598.17	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	29522.00	1268.00	2011	(Ministry of Agriculture 2012)
Ethiopian Cabbage	17046.25	175366.98	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Tomato	427.64	1272.51	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	108312.00	4164.00	2011	(Ministry of Agriculture 2012)

Crop	Ethiopia				Kenya			
	Area (ha)	Production (tonnes)	Crop Year	Data source	Area (ha)	Production (tonnes)	Crop Year	Data source
Green pep-per	2529.76	16661.95	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Red pep-per	18192.06	51790.93	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Swiss chard	18.66	46.57	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Kale	NDA	NDA			49819.00	3269.00	2011	(Ministry of Agriculture 2012)
* Carrot	91175.36	2201880.13	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	272226.00	20138.20	2011	(Ministry of Agriculture 2012)
Onion	320.36	2930.03	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	4.00	1.20	2014	(Agriculture and Food Author-ity 2015)
* Beetroot	42.07	111.02	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	1573.00	453.00	2014	(Agriculture and Food Author-ity 2015)
Garlic	1096.64	8870.18	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	29602.00	1127.00	2014	(Agriculture and Food Author-ity 2015)
Root Crops	9678.58	151875.43			164278.00	10200.00		
Potato	3504.58	37197.51	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0.00	2011	(Ministry of Agriculture 2012)
Yam	1536.65	12066.57	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	25.00	4.00	2011	(Ministry of Agriculture 2012)
Taro	44669.38	1161582.71	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0.00	2011	(Ministry of Agriculture 2012)
Sweet po-tato	30327.10	827246.67	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	56352.00	6410.00	2011	(Ministry of Agriculture 2012)
Cassava	NDA	NDA			20392.00	1943.00	2011	(Ministry of Agriculture 2012)
Fruit Crops	**45850.05**	**378230.59**			**24725.00**	**994.00**		
Avocado	11576.58	49812.99	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Author-ity 2015)
Banana	24969.07	233413.59	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Author-ity 2015)
* Guava	111.66	124.24	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Author-ity 2015)
* Lemon	133.34	943.15	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Author-ity 2015)
Mango	6855.31	58994.75	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Author-ity 2015)

	Ethiopia				Kenya			
Crop	**Area (ha)**	**Production (tonnes)**	**Crop Year**	**Data source**	**Area (ha)**	**Production (tonnes)**	**Crop Year**	**Data source**
Orange	846.35	8757.15	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Authority 2015)
Papaya	1341.78	26178.89	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	24725.00	994	2014	(Agriculture and Food Authority 2015)
* Pineapple	15.96	5.83	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	0.00	0	2014	(Agriculture and Food Authority 2015)
Other	**280605.83**	**767642.92**			**0.00**	**0**		
Chat	17241.10	28243.55	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Coffee	249536.55	182182.76	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
* Hop	2298.46	2173.36	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		
Sugar Cane	11529.72	555043.26	2016/ 2017	(Central Statistical Agency of Ethiopia 2017)	NDA	NDA		

* Not selected for disaggregation modelling exercise

Table 8 – Overview of livestock categories and related data, and data sources per country

	Ethiopia			Kenya		
Type of Livestock	**Number of animals**	**Year**	**Data source**	**Number of animals**	**Year**	**Data source**
Cattle	15489220	2015	(Central Statistical Agency of Ethiopia 2016)	4729295	2009	(Kenya National Bureau of Statistics 2010)
Sheep	6463444	2015	(Central Statistical Agency of Ethiopia 2016)	6555910	2009	(Kenya National Bureau of Statistics 2010)
Goats	6221479	2015	(Central Statistical Agency of Ethiopia 2016)	10557107	2009	(Kenya National Bureau of Statistics 2010)
Poultry	14764203	2015	(Central Statistical Agency of Ethiopia 2016)	4173078	2009	(Kenya National Bureau of Statistics 2010)
Pigs	NDA			27246	2009	(Kenya National Bureau of Statistics 2010)

Table 9 – Overview of fish catch and aquaculture and related data, and data sources per country

	Ethiopia			Kenya		
Fish production type	**Production (ton)**	**Year**	**Data source**	**Production (ton)**	**Year**	**Data source**
Inland catch	694.37	2013	(FAO 2014)	4397.93	2013	(Republic of Kenya 2014)
Inland aquaculture	0	2013	(FAO 2014)	2441.28	2013	(Republic of Kenya 2014)

Boundaries of the administrative units

Alike for ZRB, administrative boundaries for GIS applications[4] were downloaded from the Global Administrative Areas Database (GADM), version 2.8, November 2015. Vertical integration of boundaries is entirely assured. Boundary geometries were delivered as not projected and after assembling the partial source datasets, have been projected to the transverse Mercator projection WGS 1984 UTM Zone 37N.

For crops, livestock and fisheries separate base maps have been created accounting for the fact that for groups of key variables data was available at differing levels of detail. The two national sets have been assembled using the function *merge*. Masks of the basins have been used in the tool *clip* as to exclude areas outside the OTB. To account for the fact that administrative boundaries do not always coincide with the OTB boundaries, for every administrative unit the ratio of the area within the basin and the total surface has been computed. Due to the lack of further information, an equal distribution of the considered variables was assumed.

As in the case of the ZRB elaborations, classification rules for all maps in this chapter follow the Jenks Natural Breaks Algorithm (Jenks, 1967).

[4] All spatial analyses have been conducted using the software ArcGIS 10.4.

Example maps of pre-processed source data

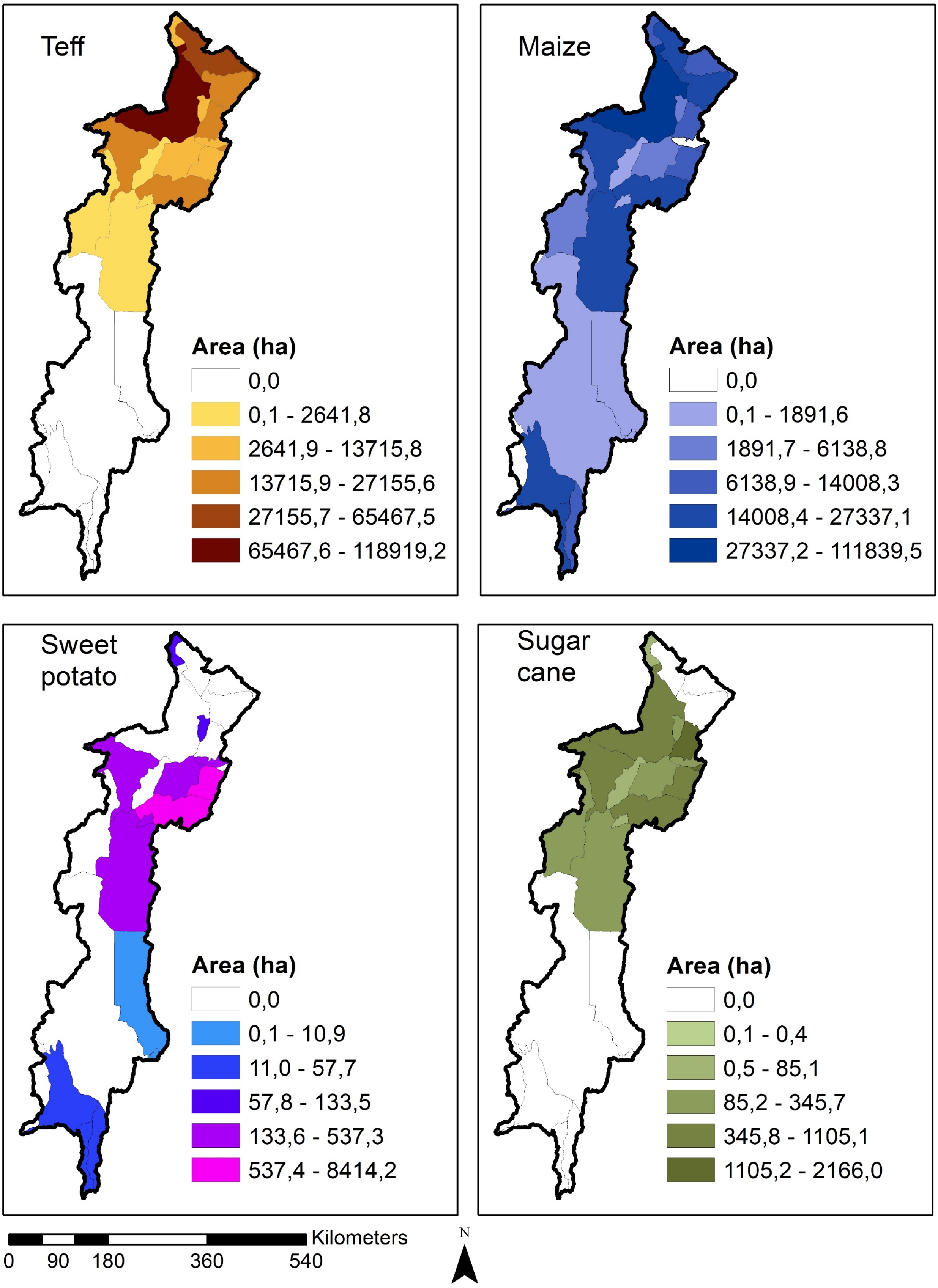

Figure 17 – Example maps of reported crop areas per administrative unit in the Omo-Turkana Basin

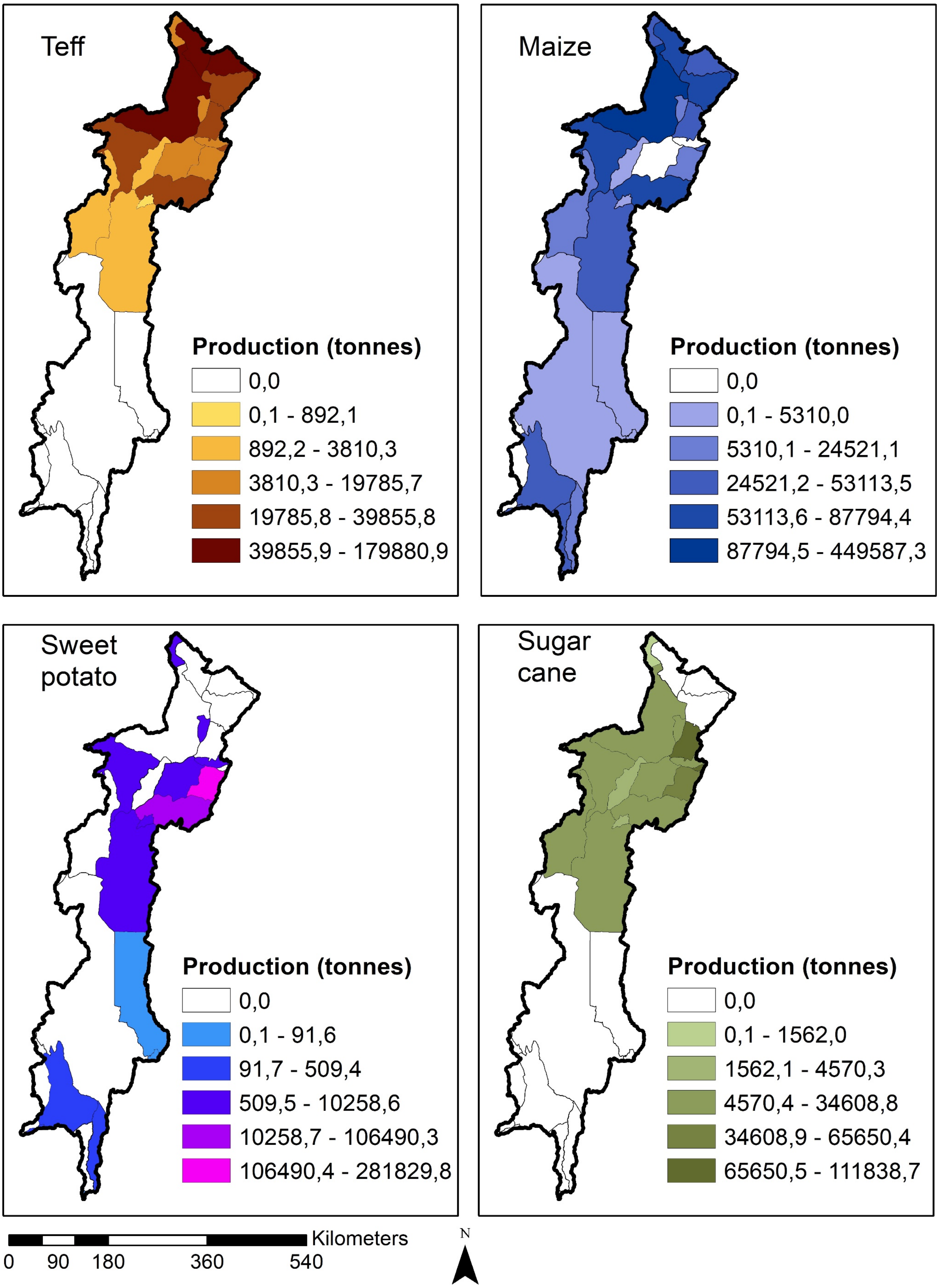

Figure 18 – Example maps of reported crop production per administrative unit in the Omo-Turkana Basin

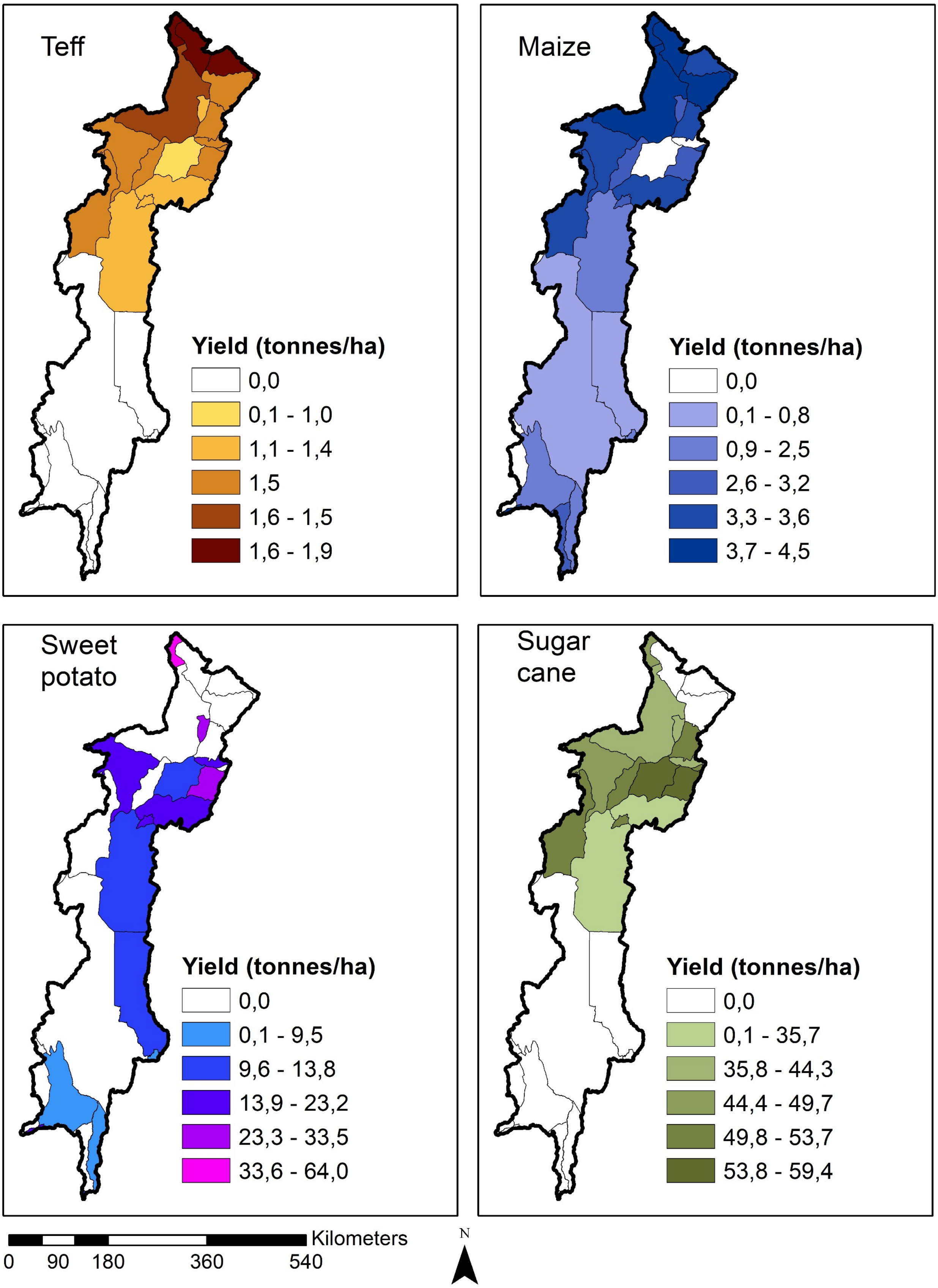

Figure 19 – Example maps of reported crop productivity per administrative unit in the Omo-Turkana Basin

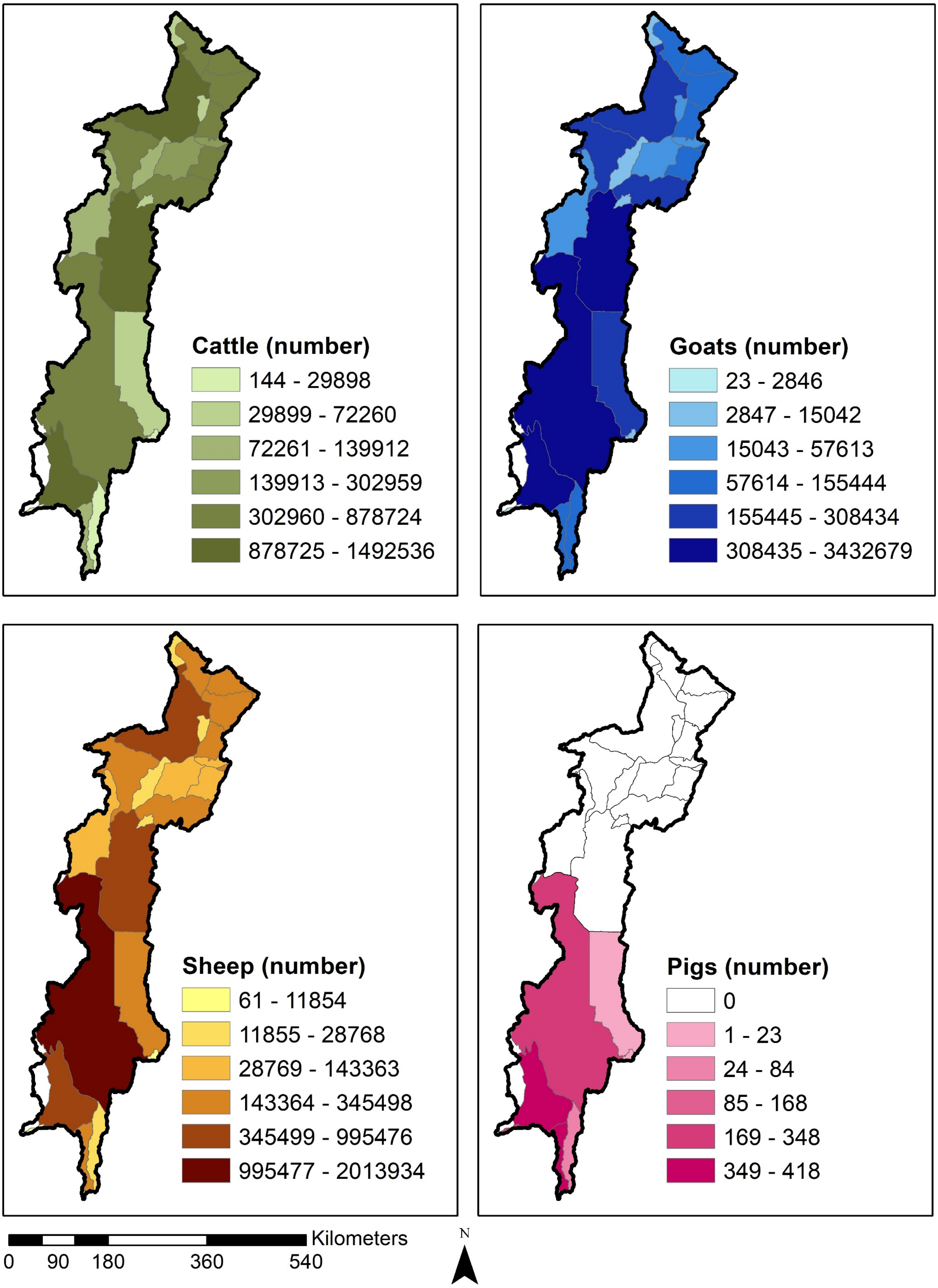

Figure 20 – Example maps of reported livestock distribution (headcounts) per administrative unit in the Omo-Turkana Basin

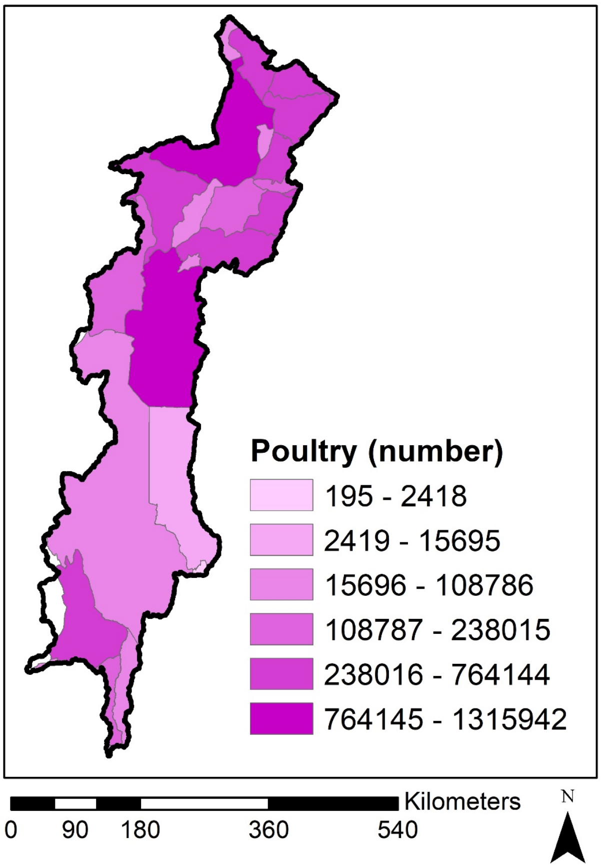

Figure 21 – Example of map of reported livestock distribution (poultry headcounts) per administrative unit in the Omo-Turkana Basin

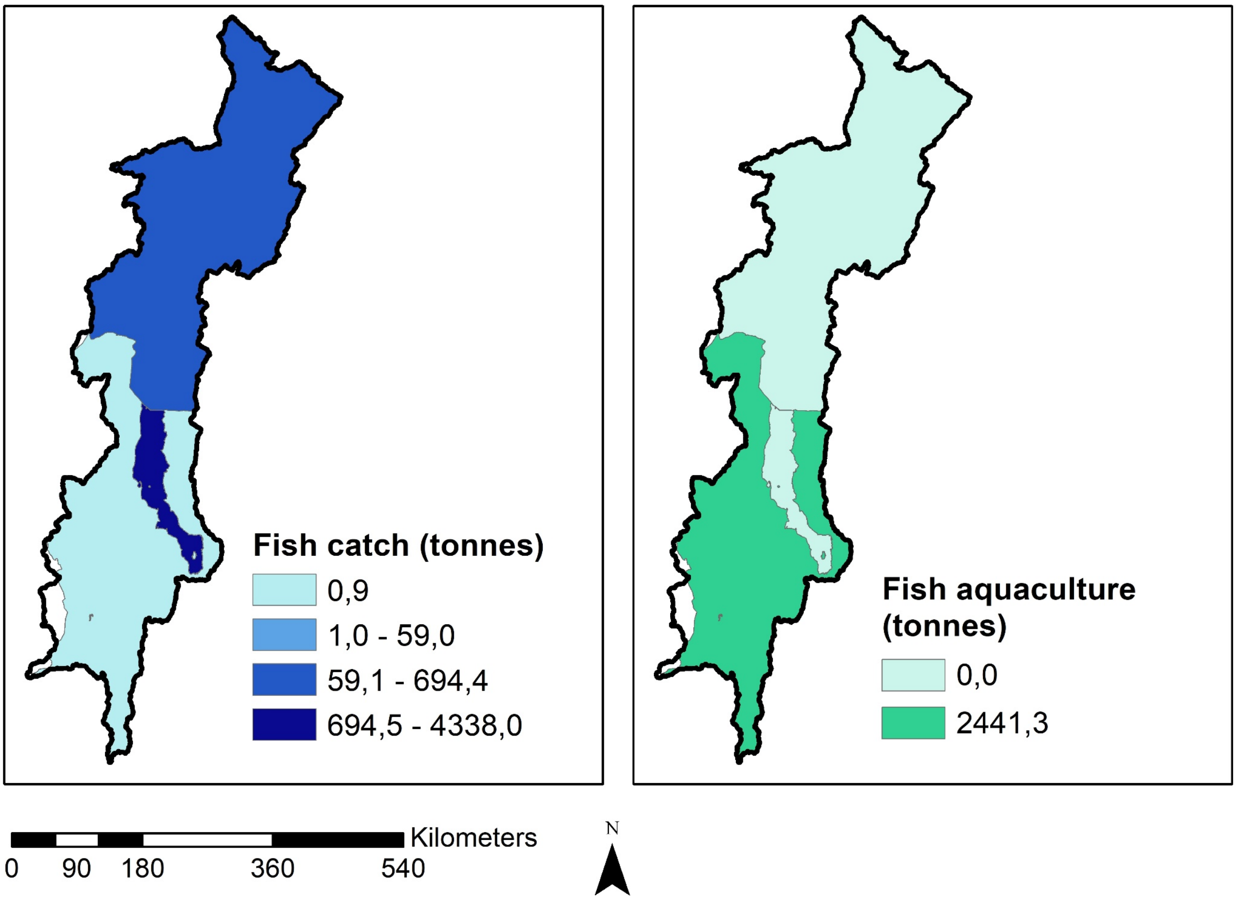

Figure 22 – Maps of reported fish production per administrative unit in the Omo-Turkana Basin

3.1.2 Biophysical Land Units

For OTB, the BLUs were defined and delineated from the same data sources and following the same procedure as done for ZRB (see section 2.1.2 for details). The only major difference is that for ZRB, the nominal spatial resolution was 400 m x 400 m while for OTB this resolution is 200 m x 200 m. The maps in Figure 24 to Figure 27 show the input geo-datasets related to the biophysical land units in OTB.

Digital Elevation Model (DEM)

A digital elevation model was used based on 90 m SRTM data (https://earthexplorer.usgs.gov/) but resampled to 200 m resolution. Figure 23 shows the topography and main rivers of the Omo Turkana Basin based on the SRTM data at the original resolution.

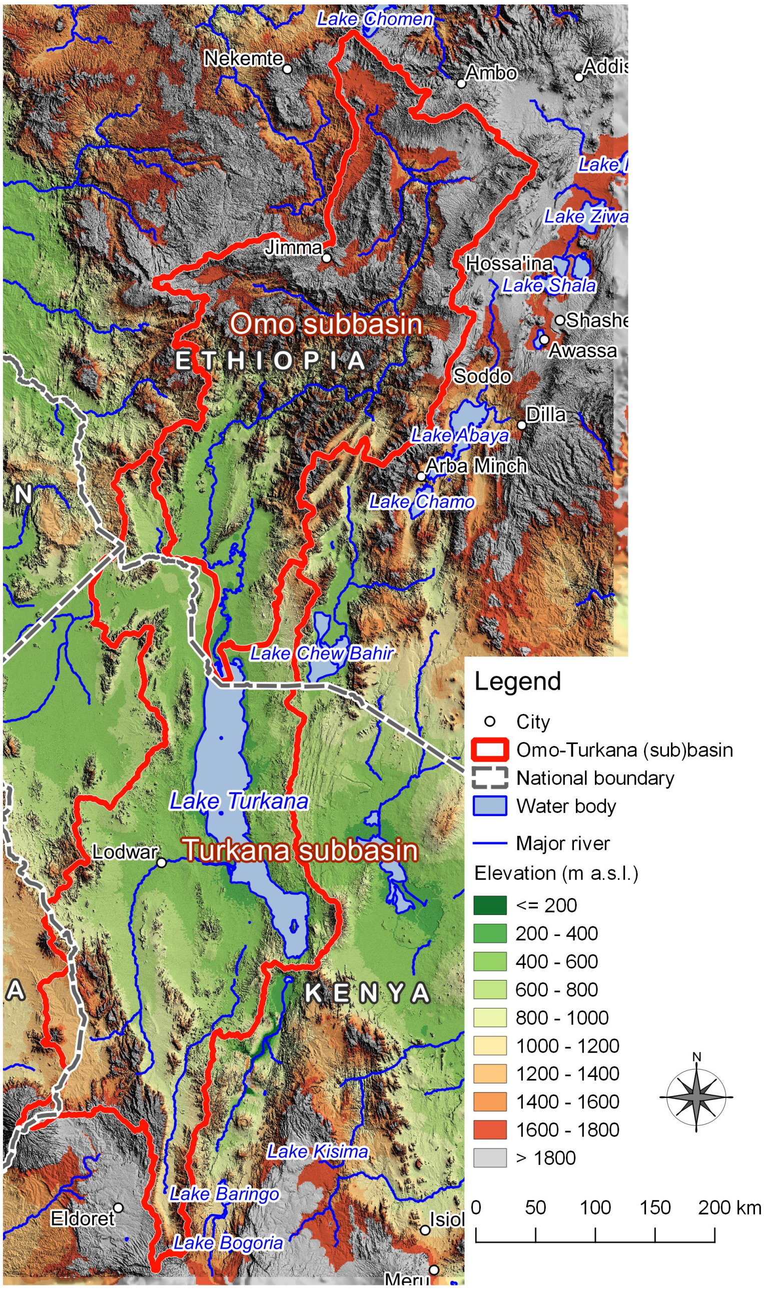

Figure 23 – Omo Turkana Basin DEM derived from SRTM data with indication of the sub-basins and the major rivers

Land cover/land use

The African land cover 20 m dataset (ESA, 2017) was used to develop, by resampling towards 200 m horizontal resolution using the nearest neighbour method, the land use map for the OTB as shown in Figure 24 and with a breakdown of relative share of area per category as used in ArcSWAT in Table 10.

Table 10 – Land use categories and their area share in the Omo Tukana Basin

Value	**Land cover map of Africa**	**Land use in ArcSWAT**	**Basin area [%]**
1	Trees cover areas	Forest Deciduous (FRSD)	21.7
2	Shrubs cover areas	Range Brush (RNGB)	23.2
3	Grassland	Range Grasses (RNGE)	29.4
4	Cropland	Agriculture (AGRL)	20.4
5	Vegetation aquatic or regularly flooded	Wetlands (WETL)	0.2
8	Built up areas	Urban (URBN)	< 0.1
10	Open water	Water (WATR)	5.1

Soil

The FAO Harmonzied World Soil Database v1.2 – which has a resolution of ca. 900 m (30 arc-second) – was resampled to 200 m resolution (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). For the Omo Tukana Basin 46 Soil Mapping Units were extracted (Figure 25).

Slope

The slope layer is derived from the DEM using the eight-direction (D8) algorithm (O'Callaghan and Mark 1984). The slope map is shown in Figure 26. Five slope classes were distinguished in line with the ones prescribed by FAO.

Hydrologic Response Units (HRUs)

Hydrologic Response Units materialize the combination of a subbasin, a slope class, a land cover/land use type and a soil mapping unit. For the OTB 2855 HRUs were derived.

Climate zones

There are 39 different climatic zones for the Omo Tukana Basin (Figure 27) based on the Global yield gap map.

Land Units

By combining subbasins, HRUs and climate zones 9972 land units were derived for OTB.

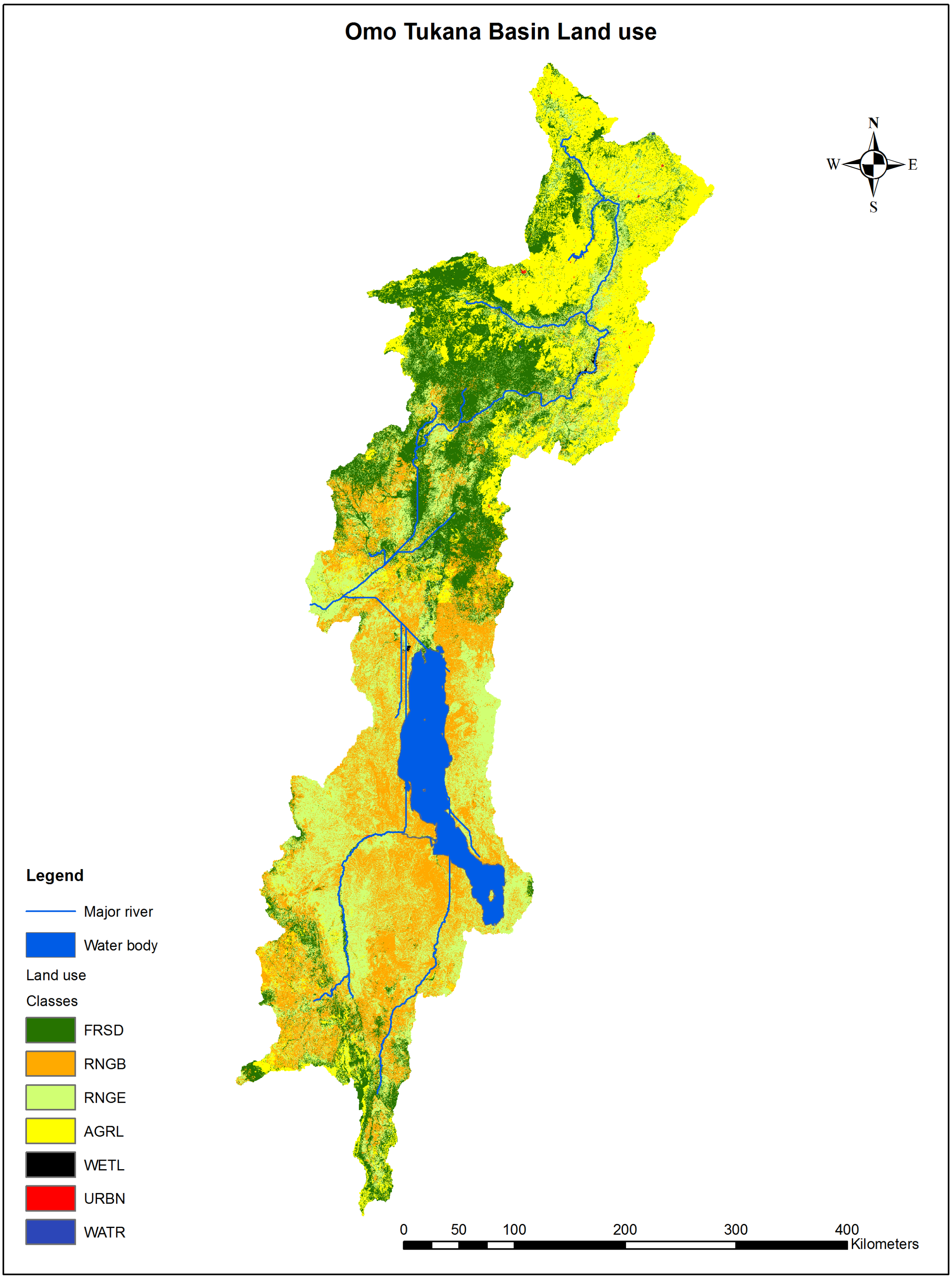

Figure 24 – Land use distribution in the Omo-Turkana Basin at 200 m resolution

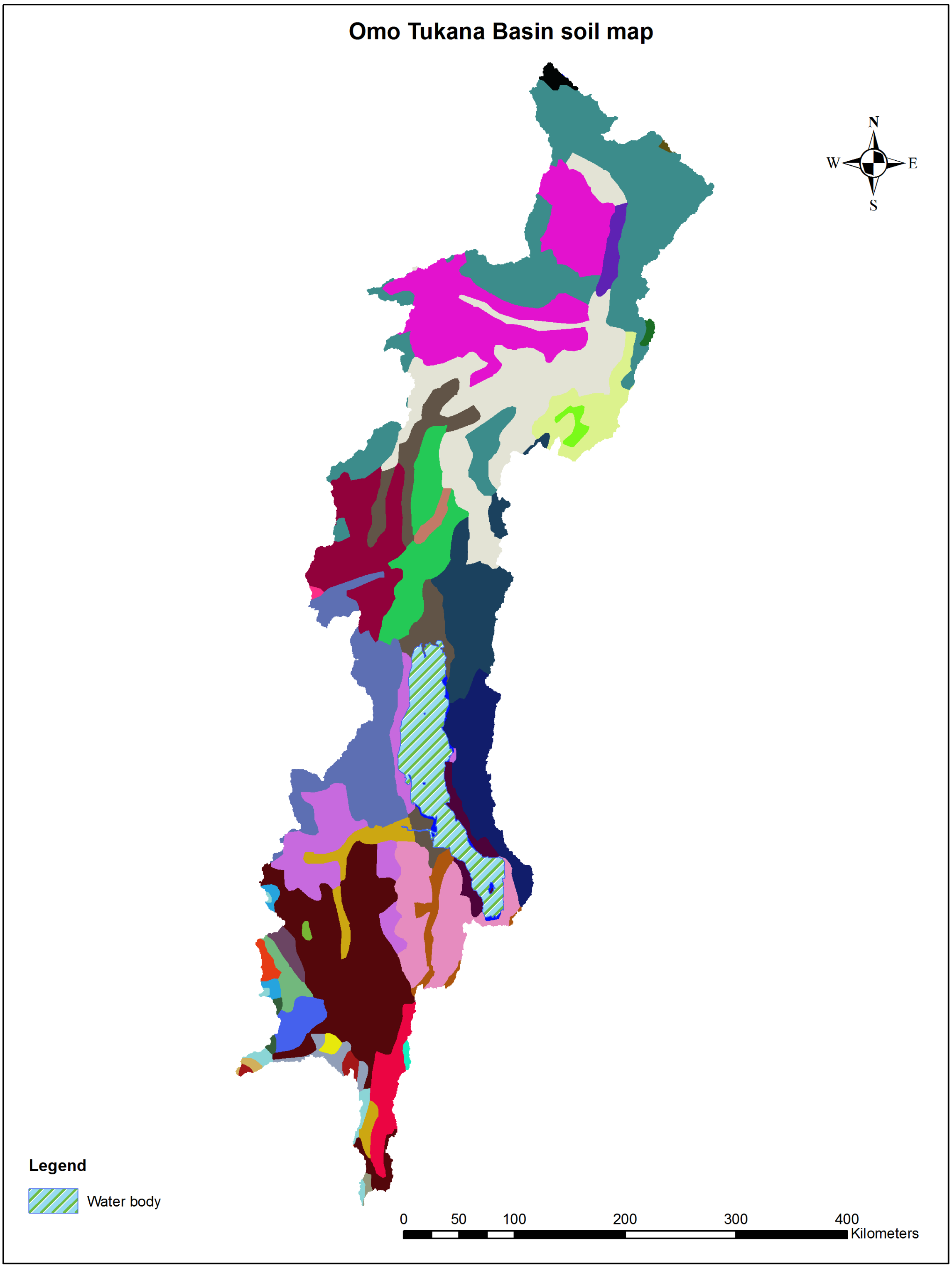

Figure 25 – Soil map of the Omo Turkana-Basin at 200 m resolution (each colour in the map symbolises one of 46 SMUs)

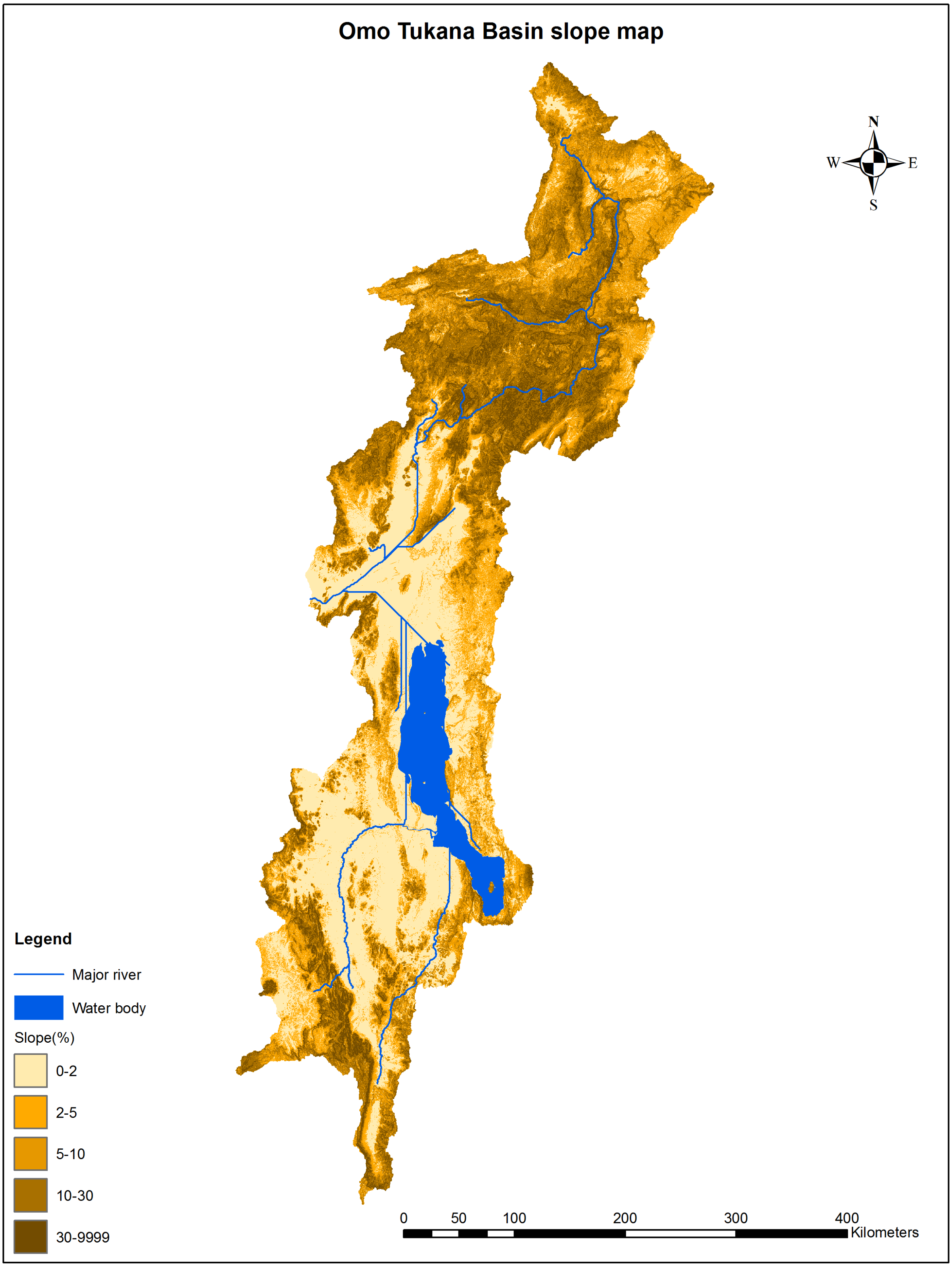

Figure 26 – Slope map of the Omo-Turkana Basin at 200 m resolution

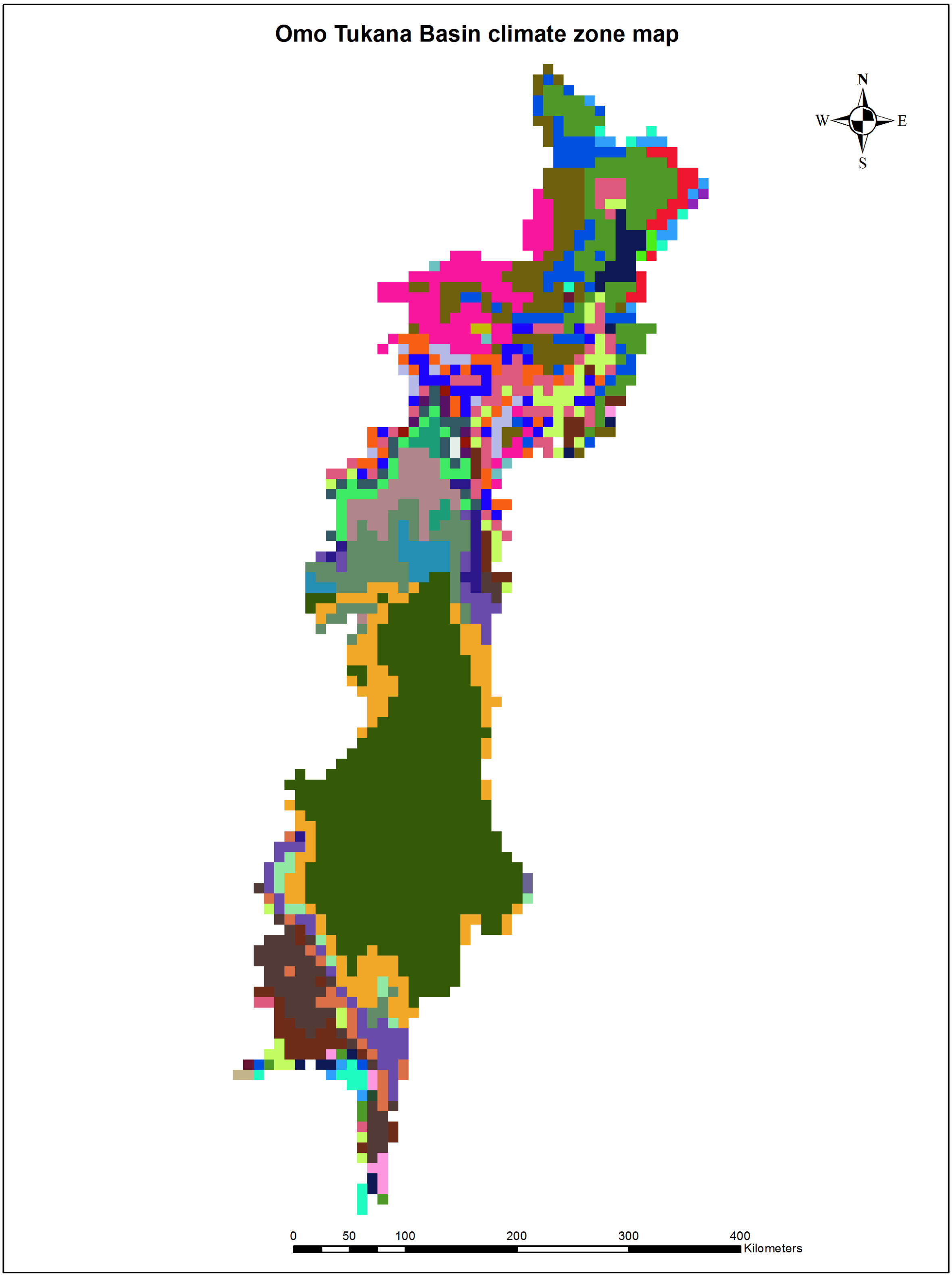

Figure 27 – Climate zone map of the Omo Turkana Basin (each colour in the map symbolises one of 39 climate zones in the OTB)

3.1.3 Disaggregation of production data from the administrative to the biophysical land units

The procedure described in section 2.1.3 for the ZRB region was applied to the data coming from sections 3.1.1 and 3.1.2 for the OTB case study. The decision rules presented in Table 11 were applied.

Table 11 – Decision rules for assigning shares of agricultural areas and production as available per administrative unit to biophysical land units in the Omo-Turkana basin

Landunits (LUs)
LUs < 50 ha are merged with that neighbouring LU that has the longest shared border
Crop statistics
Statistics for administrative units partly within the OTB are decreased proportionally to the area fraction of the administrative unit within the basin
For vegetable crops: if LUs with LUT 'AGRL' are present in the administrative unit: crop statistics are all assigned to LUs with LUT 'AGRL' OR 'URBN', proportionally to their size
For vegetable crops: if no LUs with LUT 'AGRL' are present in the administrative unit: crop statistics are assigned to LUs with LUT 'RNGB' AND slope ≤ 10%, OR 'RNGE' AND slope ≤ 10%, OR LUT 'URBN' , proportionally to their size
For non-vegetable crops: if LUs with LUT 'AGRL' are present in the administrative unit: crop statistics are all assigned to LUs with LUT 'AGRL', proportionally to their size
For non-vegetable crops: if no LUs with LUT 'AGRL' are present in the administrative unit: crop statistics are assigned to LUs with LUT 'RNGB' OR 'RNGE' AND slope ≤ 10%, proportionally to their size
Livestock statistics
Statistics for administrative units partly within the OTB are decreased proportionally to the area fraction of the administrative unit within the basin
Cattle, goats and sheep statistics are assigned to LUs with LUT 'RNGB', 'RNGE', 'AGRL' OR 'WETL', proportionally to their size
Pigs and poultry statistics are assigned to LUs with LUT 'RNGB', 'RNGE', 'AGRL', 'WETL' OR 'URBN', proportionally to their size
If the statistics for sheep and goats are combined as a single statistic for a certain administrative unit, the statistic is equally divided between sheep and goats
Fish statistics
Statistics for administrative units partly within the OTB are decreased proportionally to the area fraction of the administrative unit within the basin
No distinction is made between fish farming and aquaculture
Aquaculture is assigned to LUs with LUT 'FRSD', 'RNGB', 'RNGE', 'AGRL', 'WETL' OR 'URBN', proportionally to their size. These LUS are then aggregated for the sub-basin they are part of
If LUT 'WATR' is present in the administrative unit: 90% of fish catch statistics are assigned to these LUs, proportionally to their size. 10 % of fish catch statistics are assigned to LUs with LUT 'FRSD', 'RNGB', 'RNGE', 'AGRL', 'WETL' OR 'URBN', proportionally to their size
If no LUs with LUT 'WATR' are present in the administrative unit: 100% of fish catch statistics are assigned to LUs with LUT 'FRSD', 'RNGB', 'RNGE', 'AGRL', 'WETL' OR 'URBN', proportionally to their size. These LUS are then aggregated for the sub-basin they are part of

3.2 RESULTS

Figure 28 shows some of the results obtained for maize, cattle and fish catch. The results for the other selected crops, livestock and fish categories are available in DAFNE's DropBox. As for the

ZRB case study, they will be used in sub-sequent work (a.o. in subtask 2.2.5 of WP2) and for guiding the crop growth modelling by means of the AquaCrop model.

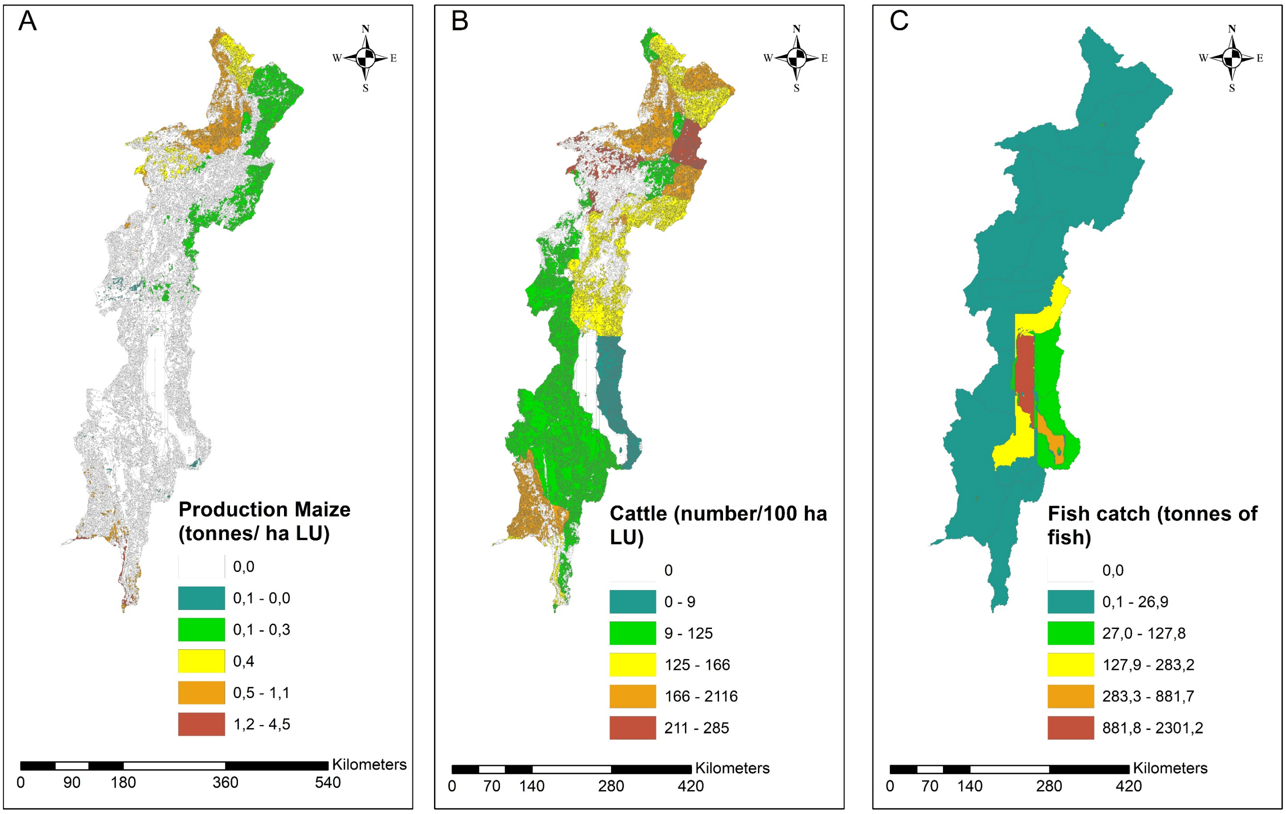

Figure 28 – Disaggregation results for the LUs of OTB based on regional statistics and decision rules presented in Table 11. (A) Production of maize in tonnes per area LU, (B) cattle in number per 100 ha LU, and (C) fish catch in tonnes.

3.3 DISCUSSION

3.3.1 Effect of disaggregation data per land unit

In this section, we discuss a few illustrative examples of disaggregating administrative level data into a spatial representation consistent with BLUs.

In Figure 29, maize production in the OTB before and after disaggregation is shown. As in the ZRB case, maize is seemingly produced all over the OTB when the regional statistics are looked at (Figure 29, A). However, after disaggregation towards the LUs, it can be seen that maize production is very limited in the OTB, except for the most northern part of the basin (Figure 29, B), i.e. the districts East Wellega and Jimma in Ethiopia.

Teff is a crop providing an important share of human nutrition in Ethiopia, but is relatively unknown elsewhere (Gebremedhin and Hoekstra 2007). This can explain why no teff production was reported for Kenya. Before disaggregation into LUs, maps show that teff is seemingly produced in all areas of Ethiopia that are part of the OTB (Figure 30, A). However, after disaggregation, it can be seen that production is mainly assigned to LUs concentrated in the districts East Wellega and Jimma, as the case was for maize (Figure 30, B).

As in the ZRB case, disaggregation has a less pronounced effect on cattle headcounts per area unit than it has on crop production (Figure 31). After disaggregation, it can be seen that cattle headcounts are assigned to LUs all over the Kenyan part of the OTB. In the Ethiopian part of the OTB, cattle headcounts are mainly assigned to LUs close to lake Turkana, around the Omo river, in the districts of the Oromia region that are part of the OTB, and the eastern districts of the SNNPR region part of the OTB (i.e. Gamo Gofa, Gurage, Hadiya, KT, and Wolayita). Cattle headcounts are scarcely assigned to the districts Dawro, Keffa and Konta. This can be explained by the high occurrence of forests including Bonga forests in these districts.

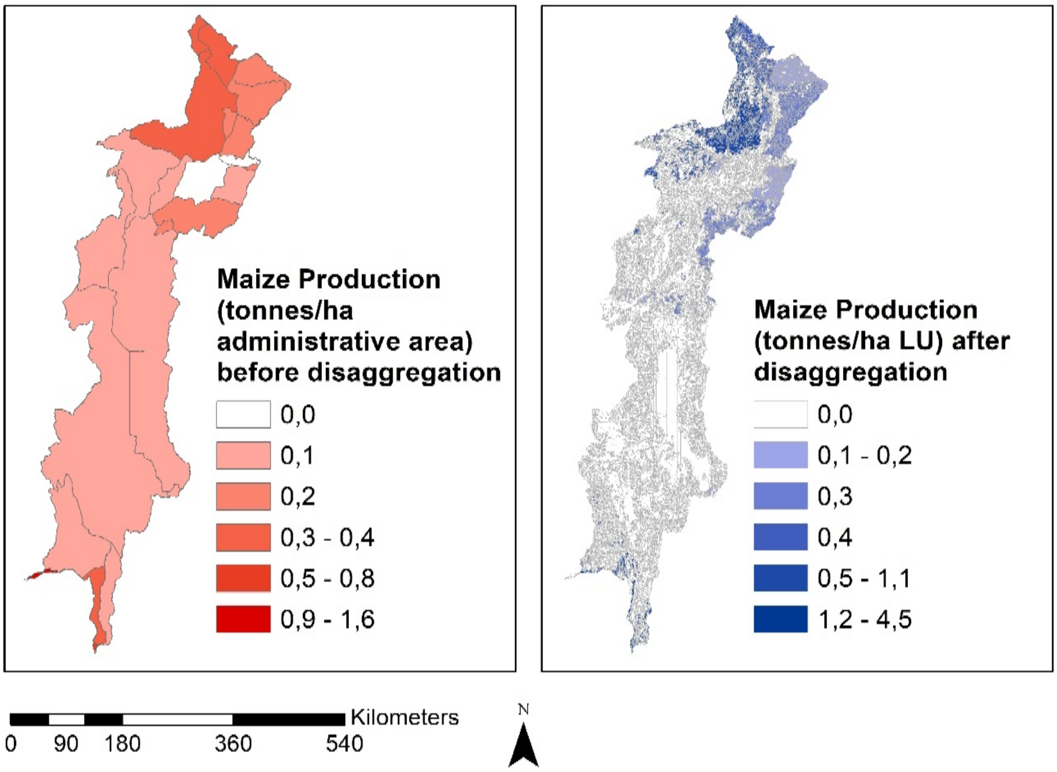

Figure 29 – Maize production in the OTB (A) per surface area administrative area before disaggregation, and (B) per surface area LU after disaggregation.

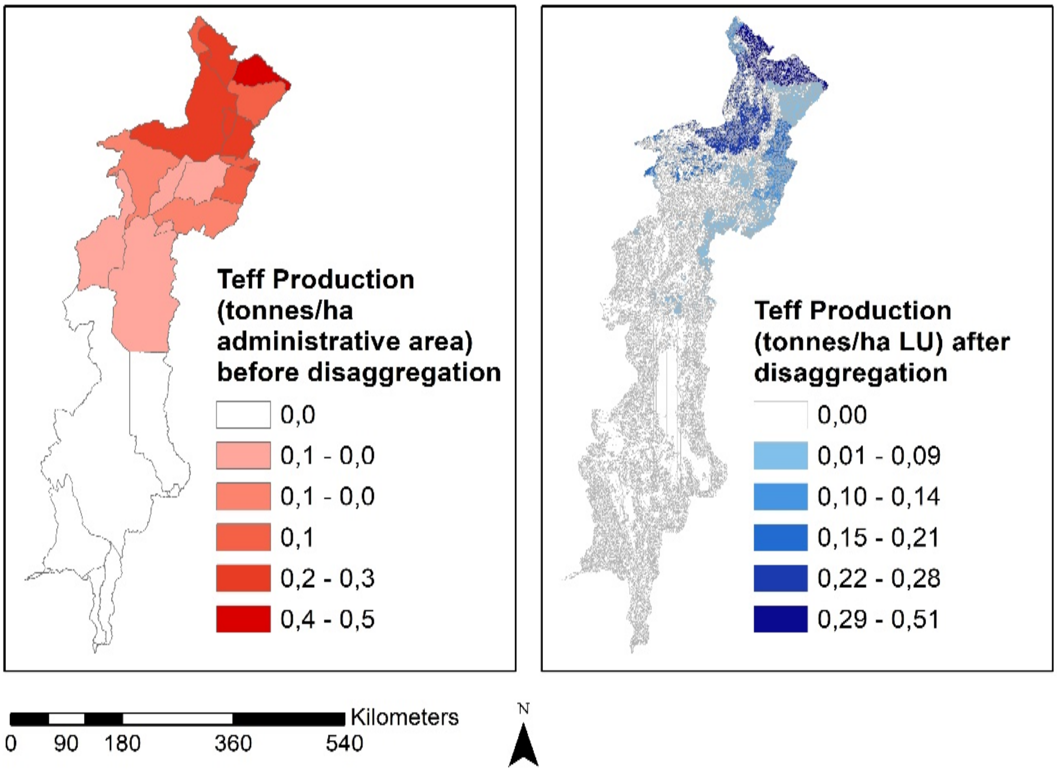

Figure 30 – Teff production in the OTB (A) per surface area administrative area before disaggregation, and (B) per surface area LU after disaggregation.

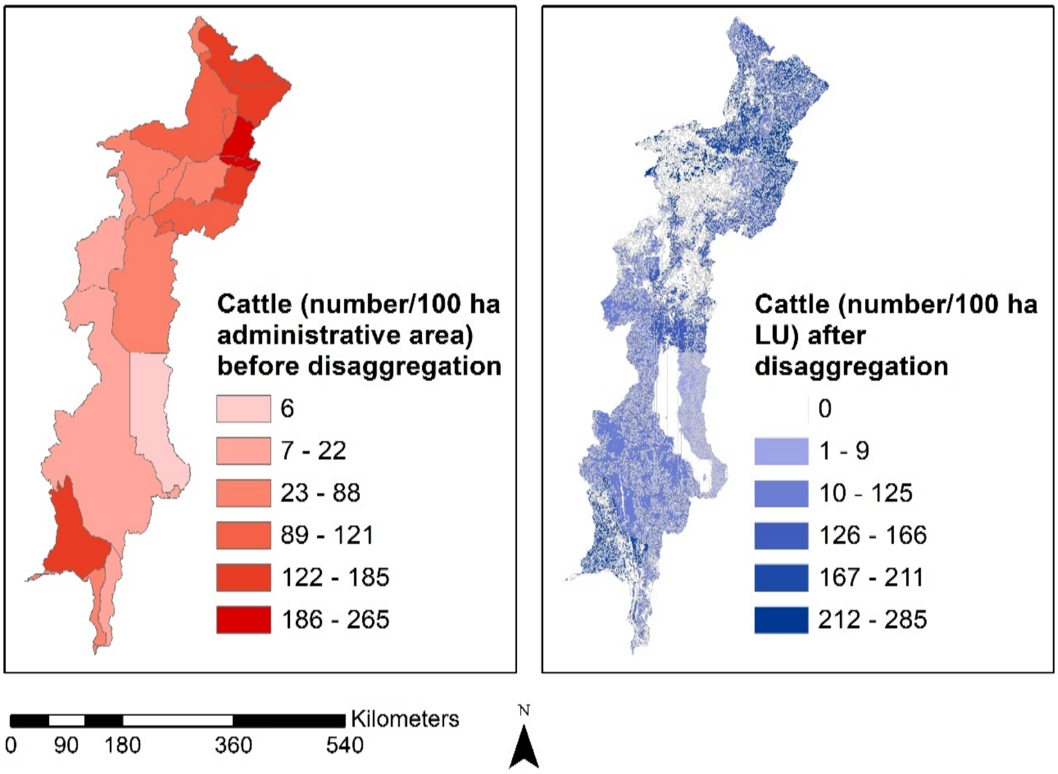

Figure 31 – Number of cattle in the OTB (A) per 100 ha surface area administrative area before disaggregation, and (B) per 100 ha surface area LU after disaggregation.

3.3.2 Agrostatistical data and implications of pre-processing assumptions

As in the case of the ZRB analyses, also for OTB rounding errors occurred in the process of disaggregating the agricultural statistics. However, the cumulative deviations computed over all land units are very small and even smaller than for ZRB due to the higher resolution of the employed land units (200m for OTB and 400m for ZRB). Only for the area (ha) and production (t) of tomato and for the area (ha) of cassava were the deviations between the cumulated values before and after disaggregation larger than 1%.

3.3.3 Land unit definition

The OTB covers a large territory but is not comparable in size with the OTB. Hence although the land units were derived from the same relatively low resolution geodatasets as for the ZRB, the compromise resolution was set to 200 meters rather than to 400 meters. This resolutions preserves more detail in the land unit definition which is reflected in their size and in the resolution of the disaggregation. One of the tangible observations is that rounding errors related to the disaggregation procedure was smaller for OTB than for ZRB.

3.3.4 Decision rules

LUs with a surface area smaller than 50 ha were merged with neighbouring LUs along its longest shared border. In the ZRB, this was done for LUs smaller than 500 ha. In the OTB it was computationally possible to retain smaller LUs than in the ZRB given the smaller size of the basin.

A distinction was made between vegetable crops and non-vegetable crops, as visible in Table 7. This was done because it was assumed vegetable crops are also grown close to urban areas, whereas other types of crops are assumed to not be cultivated near urban areas. For the ZRB, no vegetable crops were retained. Therefore, an extra decision rule was added in the model used for the OTB, i.e. crop production can occur not only on LUs with LUT 'AGRL', 'RNGB' and 'RNGE' but also on LUs with LUT 'URBN'.

Decision rules for livestock and fish catch are the same for both the ZRB and the OTB. For aquaculture, however, the decision rules were adapted to suit the data on fish production available for the OTB. No aquaculture production statistics for Ethiopia were available. For Kenya, aquaculture production reported came from fish farming activities in ponds, tanks and reservoirs, which are assumed to not occur on LUs with LUT 'WATR'. Therefore, aquaculture production statistics were only assigned to LUs with LUT different than 'WATR'.

4 THE FAO AQUACROP CROP MODEL

The spatial analysis and statistics illustrated in the above sections are an important set of reference information for the modelling of agricultural productivity from biophysical land data. Among the available models in the literature (see, e.g., Van Ittersum et al., 2013), the FAO AquaCrop model stands out because of its versatility and, at the same time, accuracy of representation of crop evolution and yield estimation. The FAO AquaCrop crop model is a water-driven simulation model (generic crop water productivity model), which requires relatively few input parameters to simulate yield response to water of most major field and vegetable crops (Raes et al., 2009; Steduto et al., 2009). AquaCrop parameters are explicit and mostly intuitive and make the model maintain a sufficient balance between accuracy, simplicity and robustness (Raes et al., 2009; Steduto et al., 2009). This subsequently makes the model easier and more widely applicable than other crop models such as CropSyst, CERES, STICS, SWAP and WOFOST, in particular for data-scarce regions such as the Zambezi Basin in particular (Hunink et al., 2011).

The model features of AquaCrop are presented in . The key features are its focus on water, the use of canopy ground cover (CC) and the use of water productivity values normalized for climate (atmospheric evaporative demand and carbon dioxide concentration). As Steduto et al. (2007) suggest, the model has an extended extrapolation capacity to diverse locations and seasons, including future climate scenarios. It uses the CC instead of LAI as a basis of calculating transpiration and separating soil evaporation from transpiration. Eventually, biomass is then calculated as the product of transpiration and a water productivity parameter.

Despite being a simple model specific attention is given to the fundamental processes involved in crop productivity and in the responses to water, from both a physiological and agronomic perspective (Raes et al., 2009). The model predicts crop productivity, water requirement, and water use efficiency under water-limiting conditions (Raes et al., 2009). AquaCrop accounts for the soil water balance, the plant development, growth and yield processes, and the atmospheric processes (i.e. thermal regime, rainfall and evapotranspiration), but, unlike many other crop models, also considers carbon dioxide concentration as an input. This makes it particularly suitable for studies of climate change effects on agricultural productivity being CO_2 a distinctive variable of climate scenarios.

In on-going work, AquaCrop is being used to simulate the crop water use and productivity for the most relevant crop-soil-climate combinations as derived in this deliverable. The reported yield data per BLUs will serve as reference value for calibration and validation in the absence of direct ground truth surveys. To enable the basin-wide estimation of (potential) water use from each BLUs, AquaCrop will be interfaced to the hydrological model Topkapi-ETH, which is the hydrological component of the integrated WEF model. To this purpose the Matlab code of the AquaCrop model (Foster et al., 2016) will be further developed to allow first an off-line coupling with Topkapi-ETH that will allow to explore its suitability for inclusion in the WEF model code.

We do not report about test simulations of AquaCrop for the ZRB and the OTB case studies. These are included in the MS29 as they are an interim product towards its inclusion into the integrated WEF model. However, AquaCrop was already applied in the ZRB and we used this as a proof of concept for its selection as reference simulation model. In a study by Mhizha et al. (2014), the FAO AquaCrop model was used in developing sowing guidelines for rainfed maize in Zimbabwe. Their study concluded that the AquaCrop model performance was satisfactory after calibration with a Nash-Sutcliffe model efficiency parameter EF = 0.81, RMSE = 15 % and R^2 = 0.86 upon validation.

Their results showed that highest maize yields depended on the climate of the site (rainfall availability), variety (length of growing cycle) and soil depth (soil water storage capacity). Similar criteria are being evaluated in the development of work for ST3.1.3 to identify the most suitable development pathways from the point of view of sustainable though productive agriculture.

In an exploratory work Fiwa (2015) has demonstrated that the AquaCrop can model reliably models crop productivity and water use in the ZRB. The model performance was excellent in simulating biomass, soil water content, canopy cover and grain yield for maize and sorghum. Fiwa (2015) calibrated and validated AquaCrop successfully for maize and sorghum for Malawi and concluded that the model can be used for formulating and evaluating different strategies and their effects on crop production. The model simulated crop yields between 1.9 to 3.0 tonnes/ha for maize and 2.0 to 2.3 tonnes/ha for sorghum.

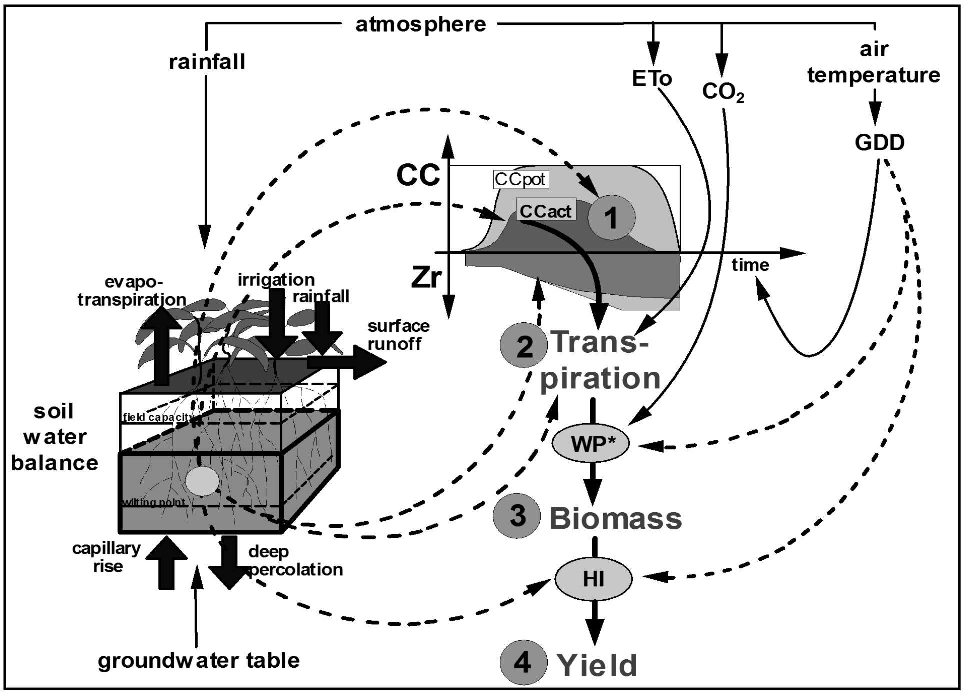

Figure 32 – Calculation scheme of AquaCrop (Raes et al., 2009)

5 CONCLUDING REMARKS

With this report and the associated database available on DAFNE's DropBox, we outline and illustrate a semi-automated methodology that allows to convert commonly and often routinely available statistical data about agricultural areas, production and productivities into numbers that pertain to biophysical land units within the ZRB- and OTB-basins rather than to administrative units. These LU are building blocks for compiling and assessing the baseline situation and possible future situations where it regards the food production and the associated water use in the basins. They do not only inform about where production activities actually take place and what their productivity is, they also provide the information necessary to design and evaluate the simulation exercises needed to assess future productivities.

Obviously, the presented results depend upon various factors among which the major are the completeness and timeliness of the input statistical data, the choices (quality of the geodatasets, spatial resolution) made to define the LU and the established decision rules. Whereas the authors aimed at maximal soundness, improvements remain possible for each of these three factors. E.g., the current decision rules do not take the soil suitability for agricultural activities into account while expert knowledge is available to do this. Caution must however be taken to not overspecify the decision rules knowing that agricultural activities are not only driven by biophysical and economic potential but also by the socio-cultural environment which is very hard to capture by the LU.

This means that the value of the deliverable is mainly in the presented methodology. Through the following milestones and towards the compilation of the baseline scenario (Deliverable 2.2) and future scenarios (Deliverable 2.3) for the two basins, each of the three factors (input data, land unit definition and decision rules) will have to be scrutinised and possibly be adapted to be in line with choices for datasets and resolutions taken in the follow-on work packages, i.e. the integrated WEF-modelling WP 3) and pathway development (WP 5) so that the cascade work in DAFNE can optimally benefit from the results and insights which can be obtained from the reported approach.

6 REFERENCES

Agriculture and Food Authority. 2014. AFA bulletin: Nuts & Oil crops. p.1. Nairobi, Kenya.

Agriculture and Food Authority. 2015. Horticulture Validated Report 2014. pp. 68. Nairobi, Kenya.

Campling, P., J.M. Terres, S. Vande Walle, J. Van Orshoven and P. Crouzet, 2005. Estimation of Nitrogen balances from agriculture for EU 15: spatialisation of estimates to river basins using the CORINE Land Cover. Physics and Chemistry of the Earth 30: 25-34

Central Statistical Agency of Ethiopia. 2016. Agricultural sample survey 2015/2016. Vol. II. Report on livestock and livestock characteristics. pp. 194.Addis Ababa, Ethiopia.

Central Statistical Agency of Ethiopia. 2017. Agricultural sample survey 2016/2017. Vol. I. Report on area and production of major crops. pp. 122. Addis Ababa, Ethiopia.

CSO. 2015. Post-harvest survey 2014/2015 Agricultural season (Small and Medium Scale Farms). pp. 58. Lusaka, Zambia.

CSO. 2017. Crop forecast survey 2016/2017. Lusaka, Zambia.

DOF. 2015. 2014 Fisheries Statistics Annual Report. pp. 46. Chilanga, Zambia.

ESA 2017. Climate Change Initiative: CCI Land cover - S2 Prototype Land Cover 20 m map of Africa 2016

FAO - GeoNetwork. 2006. AfriCover Surface Water Body Features. Available from: http://www.fao.org/geonetwork/srv/en/metadata.show?id=30932&currTab=simple

FAO 2007. FAO Fishery Country Profile - THE REPUBLIC OF NAMIBIA. 2007. Retrieved March 15, 2018, from http://www.fao.org/fi/oldsite/FCP/en/nam/profile.htm.

FAO. 2014. Fishery and Aquaculture Country Profiles. Ethiopia (2014). Country Profile Fact Sheets. Retrieved April 17, 2018, from http://www.fao.org/fishery/facp/ETH/en

FAO/IIASA/ISRIC/ISSCAS/JRC. 2009. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Fiwa, L. 2015. Improving rainfed cereal production and water productivity in Malawi: Modelling field management options in response to current and future climatic conditions. PhD Thesis. Bioscience Engineering, Soil and Water Engineering. KU Leuven.

Fletscher, R. 2018. Zimbabwe embarks on ambitious tilapia programme. Retrieved March 22, 2018, from https://thefishsite.com/articles/zimbabwe-embarks-on-ambitious-tilapia-programme

Foster, T., Brozović, N., Butler, A. P., Neale, C. M. U., Raes, D., Steduto, P., ... & Hsiao, T. C. 2017. AquaCrop-OS: An open source version of FAO's crop water productivity model. *Agricultural Water Management*, 181, 18-22.

Gebremedhin, B. & D. Hoekstra. 2007. Cereal marketing and household market participation in Ethiopia: the case of teff, Wheat and rice. pp. 243-252. In AAAE Conference Proceedings.

Genschick, Sven, Alexander M. Kaminski, Alexander S. Kefi, and Steven M. Cole. 2017. Aquaculture in Zambia: An Overview and Evaluation of the Sector's Responsiveness to the Needs of the Poor. pp.32. Lusaka, Zambia.

Hunink, J., Vila, M., & Baille, A. 2011. REDSIM: Approach to soil water modelling. Tools and data considerations to provide relevant soil water information for deficit irrigation. Unpublished report, pp 32. http://www.futurewater.nl/ (accessed 21-04-2018)

Jenks, G.F. 1967. The Data Model Concept in Statistical Mapping, *International Yearbook of Cartography* 7: 186–190.

Kenya National Bureau of Statistics. 2010. 2009 Kenya Population and Housing Census. Nairobi, Kenya.

King, A. 2016. Angola - Análise de Cenário 2016-17 Cinco Zonas de Meios de Sustento Rurais em Oito Províncias (Análise de Cenário). pp. 30. Ministério da Agricultura de Angola. Luanda, Angola.

Kolding, J., Jacobsen, N. S., Andersen, K. H., & van Zwieten, P. A. M. 2016. Maximizing fisheries yields while maintaining community structure. *Canadian Journal of Fisheries and Aquatic Sciences*, 73(4), pp. 644–655.

Mhizha, T., Geerts, S., Vanuytrecht, E., Raes, D., & Makarau, A. 2014. Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe. *Water SA*, 40(2), 233-244.

Ministério da Agricultura e Segurança Alimentar. 2014. Anuário de Estatísticas Agrárias 2012-2014. pp. 57. Maputo, Mozambique.

Ministério da Agricultura. 2009. RESULTADOS DA CAMPANHA AGRÍCOLA 2007/2008. pp. 73. Luanda, Angola.

Ministério das Pescas. 2012. Boletim Estatístico 2005-2012. pp. 44. Maputo, Mozambique.

Ministry of Agriculture. 2010. Zambezi Integrated Agro-Commercial Development Project Consolidated Feasibility Report. A report by TAHAL Group Engineering Consultants for the Government of Botswana. Botwana.

Ministry of Agriculture. 2012. Economic Review of Agriculture (ERA). Nairobi, Kenya.

Namibia Statistic Agency. 2015. Namibia Census of Agriculture 2013/2014 COMMUNAL SECTOR REPORT. pp. 120. Windhoek, Namibia.

National Bureau of Statistics Tanzania. 2016. 2014/15 ANNUAL AGRICULTURAL SAMPLE SURVEY REPORT. pp. 72. Dar es Salam, Tanzania.

NSO Malawi. 2010. National Census of Agriculture and Livestock 2006/07 Main Report. National Statistical Office (NSO), Ministry of Agriculture and Food Security pp. 152. Zomba, Malawi.

NSO. 2016. Statistical Yearbook 2016. National Statistical Office (NSO) pp. 125. Zomba, Malawi.

NSO. 2017. Malawi - Fourth Integrated Household Survey (IHS4) 2016-2017. pp.49. National Statistical Office (NSO), Zomba, Malawi.

O'Callaghan JF, Mark DM (1984) The extraction of drainage networks from digital elevation data. Computer Vision, Graphics, and Image Processing 28:323-344.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. 2009. Aquacrop-The FAO crop model to simulate yield response to water: II. main algorithms and software description. *Agronomy Journal,* 101(3), 438–447.

Republic of Kenya. 2014. Fisheries Annual Statistical Bulletin 2014. pp. 56. Nairobi, Kenya.

SOGES 2011. Aquaculture development strategy for Botswana. Support for Devising of the Aquaculture Development Strategy for Botswana and the development. pp. 109. Botswana.

STATISTICS BOTSWANA. 2016. Agricultural census stat brief 2015. pp. 14. Gaborone, Botswana.

Steduto, P., Hsiao, T. C., & Fereres, E. 2007. On the conservative behavior of biomass water productivity. *Irrigation Science*, 25(3), 189–207

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. 2009. Aquacrop-the FAO crop model to simulate yield response to water: I. concepts and underlying principles. *Agronomy Journal*, 101(3), 426–437.

Steduto, P., T.C. Hsiao, E. Fereres, & D. Raes. 2012. Crop Yield Response to Water. FAO Irrigation and Drainage Paper No 66. Rome: Food and Agriculture Organization of the United Nations.

Van Ittersum, M., Cassman K.G., Grassini, P., Wolf, J. Tittonell, P., Hochman, Z. 2013. Yield gap analysis with local to global relevance—A Review. Field Crops Research. 143, 4-17.

ZIMSTAT. 2015. Agriculture and Livestock Survey (ALS) in Old Resettlement Schemes. Zimbabwe National Statistics Agency (ZIMSTAT). pp. 166. Harare, Zimbabwe.