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Water, Land and
Ecosystems

Similarity analysis for the Blue Nile Basin in the Ethiopian highlands



Similarity analysis for the Blue Nile Basin in the Ethiopian highlands

Catherine Pfeifer, An Notenbaert and Abisalom Omolo

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Abstract

Up until today, rainwater management practices have been promoted regardless of site-specific biophysical characteristics and regardless of the socio-economic and institutional environment. Therefore, low adoption rates and high disadoption rates of rainwater management practices are observed. In order to promote rainwater management more successfully, a paradigm change towards promotion of location-specific interventions is needed. Beyond biophysical suitability, successful implementation crucially depends on farmers' willingness to adopt a practice. Therefore, the socio-economic and institutional environment must be taken into account in a spatially explicit way. A first step towards the promotion of site-specific rainwater management requires an understanding of which sites present similar biophysical, socio-economic and institutional characteristics within a basin.

The objective of this report is twofold. Firstly, it aims at presenting the available spatial data for the Blue Nile Basin in the Ethiopian highlands. Secondly, it develops a methodology that allows identifying locations within a landscape that have similar biophysical, infrastructure, socio-economics, and governance characteristics relevant to rainwater management.

The authors would like to thank Nancy Johnson and Tilahun Amede for their constructive comments.

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1 Introduction

Like in large parts of sub-Saharan Africa, most farmers in the Ethiopian highlands base their livelihood on unreliable rainfed agriculture. Climate variability as well as the lack of water management explains to a large extent the prevailing food insecurity and poverty (Hanjra and Gichuki 2008; de Fraiture et al. 2010). Consequently, improving rainwater productivity is an appealing solution to alleviate hunger in the region (Hanjra and Gichuki 2008; Hanjra et al. 2009).

Integrated rainwater management is a recently developed concept that abandons the differentiation between irrigated and rainfed agriculture (Rockström et al. 2003; Humphreys et al. 2008; Rockström et al. 2010). It encompasses any bundle of practices, referred to as a strategy that aims at increasing rainwater productivity. These strategies enable actors to systematically map, capture, store and efficiently use runoff and surface water emerging from farms and watershed in a sustainable way for both productive and domestic purposes (Amede et al. 2011). Rainwater management strategies (RMS) include practices such as increasing soil water holding capacity, enhancing crop and livestock water productivity, improving efficiency of small-scale irrigation, efficient use of ground water wells, diversion, or water harvesting (Hanjra and Gichuki 2008; Johnston and McCartney 2010; Rockström et al. 2010).

RMS are relatively low cost and can potentially be made available to many farmers and communities. Despite of all these benefits, adoption rates of RMS practices are low and disadoption is high. Indeed, up until today, RMS practices have been promoted regardless of site-specific biophysical characteristics and regardless of the socio-economic and institutional environment (Faures and Santini 2008). For a more successful promotion of RMS, a paradigm change towards promotion of location-specific interventions is needed (Faures and Santini 2008). Beyond biophysical suitability, successful implementation crucially depends on farmers' willingness to adopt a practice. Therefore, the socio-economic and institutional environment must be taken into account in a spatially explicit way. A first step towards the promotion of site-specific RMS requires an understanding of which sites present similar biophysical, socio-economic and institutional characteristics within a basin.

The primary objective of this paper is, therefore, to develop a methodology that allows identifying locations within a landscape that have similar biophysical, infrastructure, socio-economics, and governance characteristics relevant to RMS. This methodology is applied to the Blue Nile Basin in the Ethiopian highlands. Furthermore, this paper aims at presenting the currently available spatial data for the study area.

2 Methodology

2.1 Study area

The Nile Basin Development Challenges (NBDC) program aims at targeting RMS in the Blue Nile Basin in the Ethiopian highlands. Within the Blue Nile Basin, specific study landscapes representing dominant farming systems in the Ethiopian highlands will be the basis for this research. Smaller action research sites (ARS) are further embedded within these study landscapes providing a nested set of sites for learning and research at a variety of physical and social scales. Based on expert consultation and discussion within the NBDC project team, the following criteria were used for selecting these study landscapes:

- Represent diversity found in the Ethiopian Blue Nile in terms of:
 - Agro-ecologies
 - Livelihood strategies including important cropping systems, perennial and agropastoral systems and off-farm income
 - Water availability
 - Socio-economic status
 - RWM challenges
 - Market access
 - Diversity of actors
 - State of transition—desperate or blooming?
- Synergy and complementarities with other initiatives, building on not duplicating
- Ability to demonstrate results
- Presence of partners to work with
- Accessibility for at least one site to serve as CPWF show case
- Containing examples of both SLM and AGP *woredas*

Based on these criteria, three study landscapes, differing in state of development, agro-ecology (reflecting water availability and different production potentials), important livelihood systems and opportunities for RMS, namely Jeldu, Diga and Fogera, were identified (Figure 1).

2.2 The overall approach

In order to identify similar locations within the Blue Nile Basin, two types of similarity analysis can be performed as shown in Figure 2, i.e. an analysis of individual characteristics for which data are available and an analysis of a set of characteristics requiring an aggregation from individual characteristics.

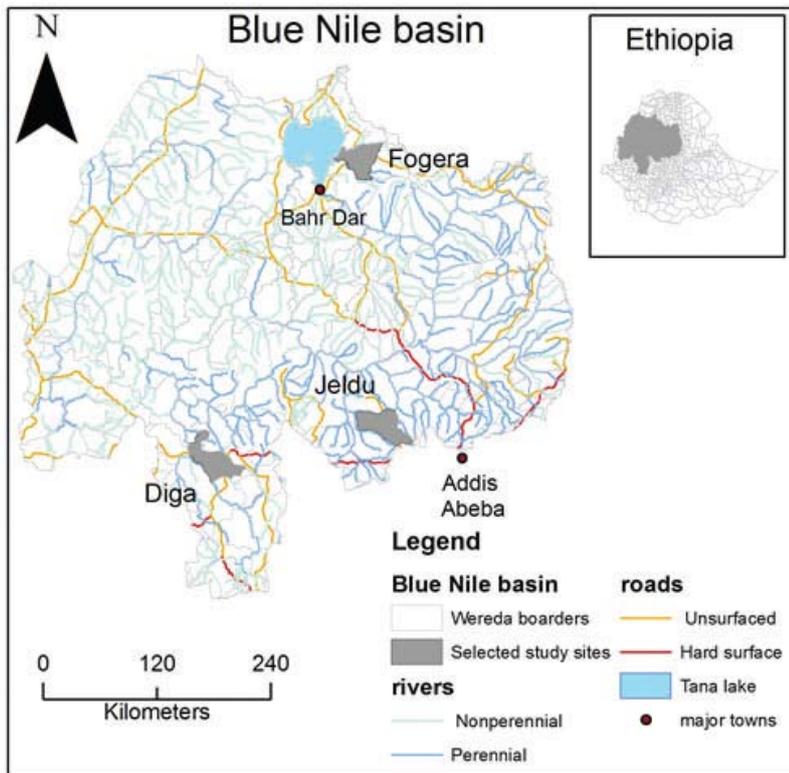


Figure 1. The Blue Nile Basin in the Ethiopian highlands and the selected study sites: Jeldu, Diga and Fogera

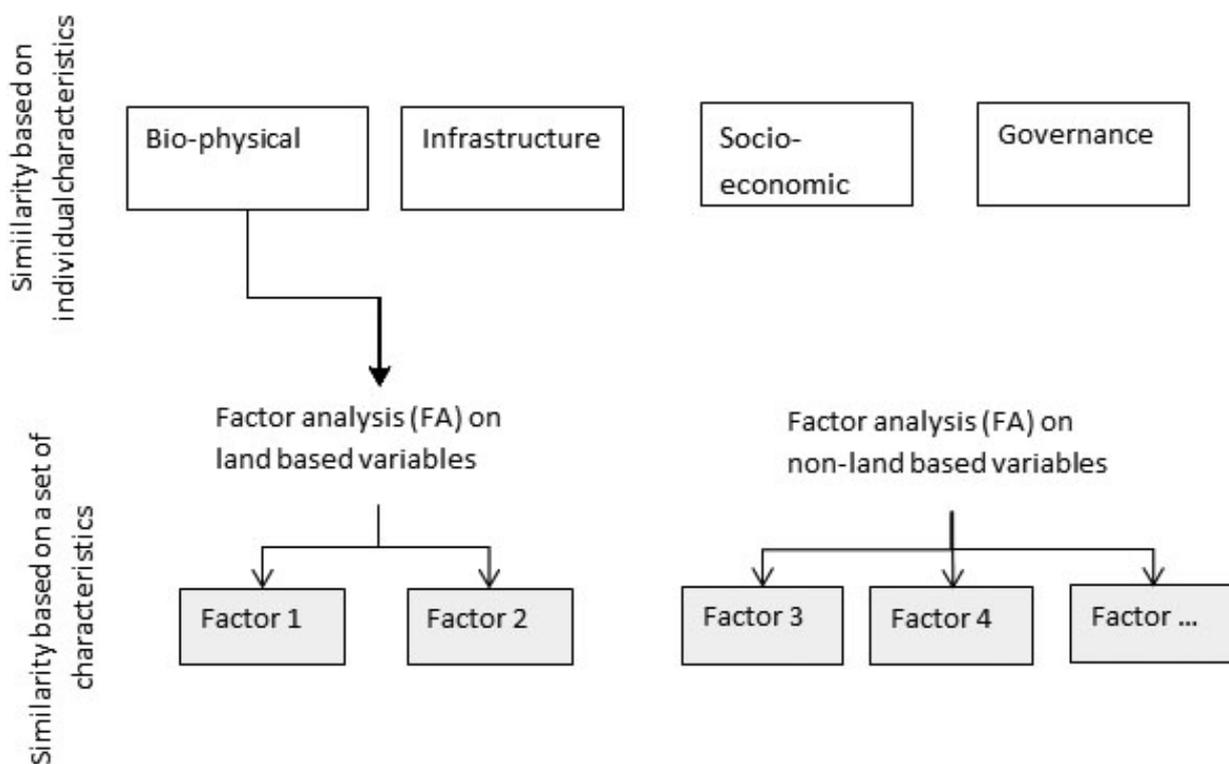


Figure 2. Link between the similarity analysis on the individual characteristics and the similarity analysis on the aggregated characteristics

In a first step, potential drivers of successful adoption for RMS practices need to be identified. Beyond biophysical drivers that are relatively well understood, literature identifies human dimensions, namely socio-economic and institutional environment as well as infrastructure as potential drivers for adoption of RMS (Baguma et al. 2010; de Fraiture et al. 2010). Therefore, individual characteristics can be classified into

four categories: biophysical, infrastructure, socio-economic and institutional, reflecting different disciplines, environmental science, landscape planning, economics/sociology and policy, respectively. Institutional characteristics are difficult to measure in a spatially explicit way. However, governance, that is how institutions impact on any transaction (Williamson 2000), can be seen as measurable proxy for institutions in a socio-economic context. This approach has been retained in this paper.

Biophysical data and infrastructure data are usually collected at different spatial and temporal scale than socio-economic and governance data. Also socio-economic data tend to adjust much faster to new events and trends than biophysical and infrastructure variables. Therefore, the data has been classified into land-based and non-land based variables, in order to acknowledge difference in scales and potential of quick adjustments.

In order to aggregate these individual characteristics, a factor analysis (FA) is used as data reduction method. This approach allows to identify underlying structures, also referred to as unobserved structure and reduces the individual characteristics into a data driven number of factors. Given that land based and non-land based variables change at different time and spatial scales, a similar unobserved construct cannot be assumed for both types of variables. Therefore, FAs on land-based and on non-land based data are run separately.

2.3 Similarity analysis on individual characteristics

Geo-referenced data or proxy data, covering the whole Ethiopian side of the Nile Basin, need to be found for each potential driver of success. For the similarity analysis, the data for each characteristic, from now on referred to as variable, needs to be classified. Sites can then be said similar when they fall into the same class. For a relevant similarity analysis, the selection of the right classification technique is, therefore, crucial. Table 1 shows different classification techniques for different types of data. For some of the variables, classification is not an issue, as the data is collected in a finite numbers of categories. Classification becomes more difficult with data that has too many categories to be visualized or can take any value. In this case one can rely on expert knowledge to define the classes. When no expert knowledge is available then different classification techniques can be applied: equal interval, quantile and natural breaks. The equal interval cuts the distribution of the data at equal breaks and fails to reveal the distribution of the data. Quantile classification cuts the population in equal group size and, therefore, allows visualizing the distribution of the data. However, gaps between classes can be important when the data contains outliers. The Jenk's natural break technique is a data driven approach. It seeks to reduce the variance within a class and maximize the variance between the classes. This approach depends on the a priori defined number of classes, but when these are selected carefully this classification techniques identifies 'depressions' in the distribution of the data and groups together data with similar characteristics. It is, therefore, a promising technique for a similarity analysis.

Table 1. Classification technique for different types of data

| Type of data | Grouping technique | Examples |
|---|---|---------------------------------|
| Categorical data with a finite number options | No grouping | Dominant soil Types of roads |
| Data with expert knowledge over range | Group into categories based on expert knowledge | High and low soil degradation |
| Data without any expert knowledge | Equal interval Quantiles Natural breaks | Income |

2.4 Similarity analysis based on a set of characteristics

Similarity analysis based on a set of characteristics aims at identifying dimensions within which locations differ and calls for an aggregation of the various characteristics. But environmental and social processes in a landscape are complex and interlinked (Burel and Baudry 2004), and, therefore, the variables chosen for assessing these processes are likely to be correlated. FA is a tool that allows data reduction. It describes variability among observed variables in terms of a potentially lower number of unobserved variables called factors. FA searches for such joint variations in response to unobserved latent variables, also referred to as an unobserved construct. The observed variables are modelled as linear combinations of the potential factors, plus 'error' terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset.

Results from FA are: the factor scores, the transformed variable values and the loadings, the weight by which each standardized original variable should be multiplied to get the factor score. Usually the loadings are the result of a geometrical rotation to minimize the variability within the factor and maximize variability between factors.

FA and principal component analysis (PCA) though related and often giving very similar results, are not the same. FA estimates how much of the variability is due to common unobserved construct. PCA does not assume any construct and consequently takes all variability of the variables into account. When the unexplained variability ('error') of all the variables is equal, FA is a particular case of PCA and both approaches yield to the same result. Beyond data reduction, FA has the advantage to identify an underlying structure, which is particularly interesting for identifying socio-economic dynamics.

The application of FA to spatial data, raises the issue of the spatial scale at which the analysis is run. Whereas biophysical data are often detailed and available at high resolutions, socio-economic data is often available at administrative level. One strategy is to aggregate all the data to the smallest common spatial unit of the data. For Ethiopia, this implies the *woreda* level (districts) for which socio-economic data is available. As a consequence, a certain degree of spatial variability of biophysical variables is lost when aggregated to the *woreda* level. Standard deviation, maximum and minimum values can be presented as indicators for the lost variability.

The FA on *woreda* level results in loadings defining each factor. These loadings can be used to predict the factor scores for each *woreda*, which can then be mapped. The natural break classification technique enables a data driven classification of locations that are similar.

3 Results for individual characteristics

3.1 Selection of relevant characteristics

A comprehensive review of RMS in Ethiopia identifies a whole set of biophysical, infrastructure, socio-economic and institutional characteristics as drivers of adoption of RMS (Merrey and Gebreselassie 2010). This list has been expanded with expert knowledge collected from ILRI and IWMI experts. Many geo-referenced variable or proxy variable for these drivers could be found. Table 2 shows the chosen variables as well as their source.

Table 2. Chosen variables, sources and grouping techniques for similarity analysis

| Variables | | |
|---------------------------------|------------------------------------|--------------------------|
| Biophysical | Source | Classification technique |
| Rainfall | Jones and Thornton (2000) | Expert |
| CV rainfall | Jones and Thornton (2000) | Expert |
| Rivers | FAO geonetwork | None |
| Wetlands | FAO geonetwork | None |
| Elevation | SRTM* | Expert/FAO |
| Slope | SRTM | Expert/FAO |
| Soil type | Harmonized world soil database FAO | None |
| Soil texture | Harmonized world soil database FAO | None |
| Soil drainage | Harmonized world soil database FAO | None |
| Land degradation | Bai et al. (2008) | None |
| Temperature mean | Worldclim | Expert |
| Minimum temperature °C | Worldclim | Expert |
| Maximum temperature °C | Worldclim | Expert |
| Length of growing period | Jones and Thornton (2000) | Expert |
| Malaria prevalence | MARA/ARMA Snow et al. (2005) | Expert |
| Infrastructure | | |
| Roads | ESRI* | None |
| Travelling time to major cities | IFPRI (Schmidt and Kedir 2009) | Expert |

| Variables | | |
|---|-------------------------------------|--------------------------|
| Biophysical | Source | Classification technique |
| Density of primary school (number of schools/population) | IFPRI REA* | Quantile/5 classes |
| Density secondary schools | IFPRI REA | Quantile/5 classes |
| Socio-economic | | |
| Percentage of population living below poverty line | CSI* | Equal interval |
| Population density | IFPRI REA | Equal interval |
| Proportion of female-headed agricultural households | IFPRI REA | Equal interval |
| Literacy level for agricultural population aged 15 to 30 | IFPRI REA | Quantile/5 classes |
| Proportion of household heads fully engaged in agricultural activity | IFPRI REA | Quantile/5 classes |
| Percentage of holders utilizing hired labour | IFPRI REA | Quantile/5 classes |
| Household size | IFPRI REA | Quantile/5 classes |
| Livestock production systems | Thornton et al. (2002) | None |
| Livestock densities | Gridded livestock of the world, FAO | Expert |
| Major crops yield | IFPRI REA | Equal interval |
| Major crop utilization (share of crop that is sold on market) | IFPRI REA | Equal interval |
| Governance | | |
| Percentage of holders utilizing credit services | IFPRI REA | Quantile/5 classes |
| Percentage of holders utilizing advisory services | IFPRI REA | Quantile/5 classes |
| Holding fragmentation—average number of parcels per holdings | IFPRI REA | Quantile/5 classes |
| Proportion of land area under smallholders that is rented | IFPRI REA | Quantile/5 classes |
| Percent of crop holders who have land holding size of 1 hectare or less | IFPRI REA | Quantile/5 classes |

CSI: <http://www.cgiar-csi.org/data>

ESRI: <http://www.esri.com/data/free-data/index.html>

FAO geonetwork: <http://www.fao.org/geonetwork/srv/en/main.home>

MARA/ARMA: <http://www.mara.org.za/>

IFPRI REA = rural economy atlas (2006): <http://www.ifpri.org/node/3763>

SRTM: <http://srtm.cgiar.org/>

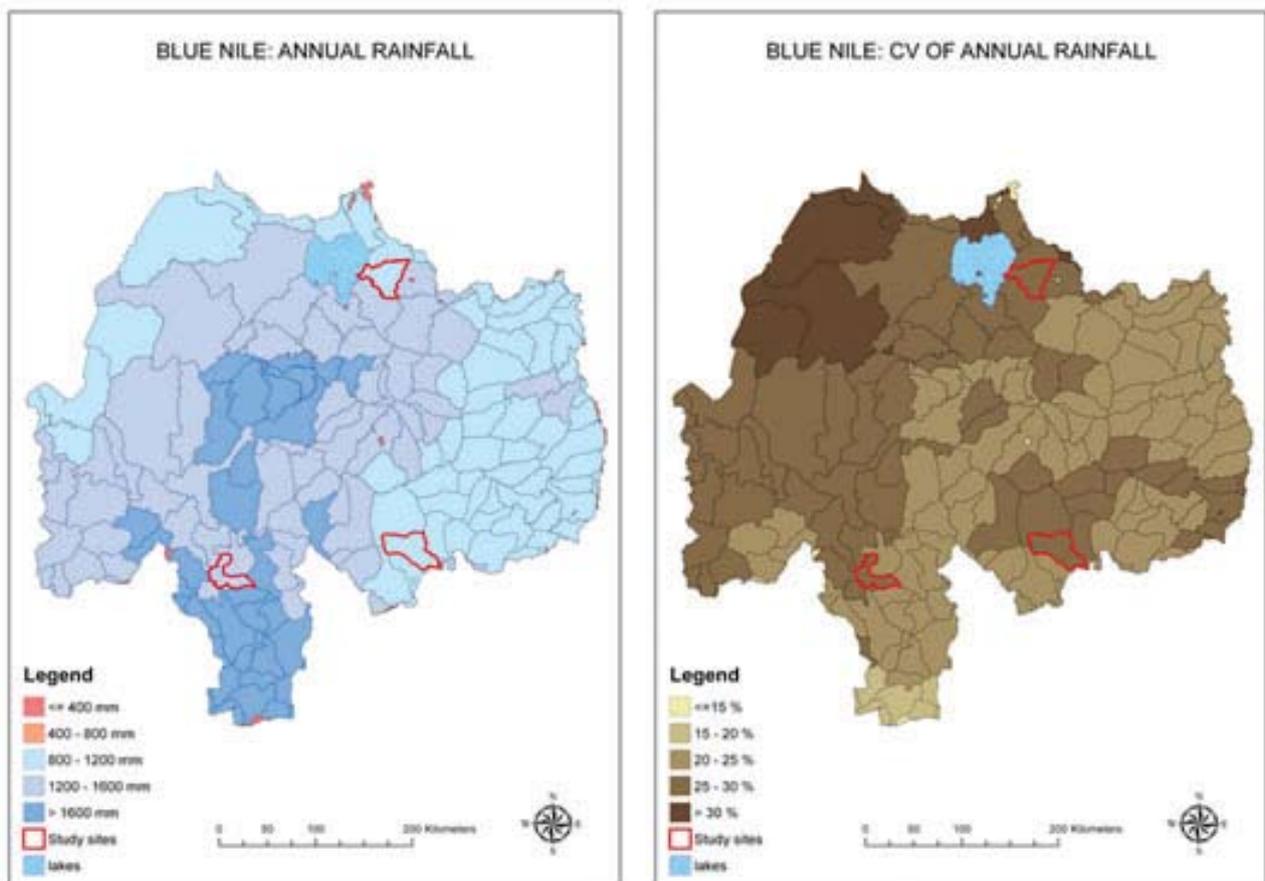
Worldclim: <http://www.worldclim.org/download>

In a rural area context, governance encompasses proxies related to property rights such as holding size, land fragmentation, land rented as well as proxy governmental intervention, in this case access for credit and advisory service.

A number of characteristics were mentioned by experts for which no geo-referenced data could be found. These characteristics included: a detailed land cover map, areas under land certification, proximity to veterinary support. Maps of individual characteristics.

Figure 3 shows rainfall and its coefficient of variation for the Blue Nile Basin. Locations with higher rainfall have the tendency to have less variable rainfall. Jeldu and Fogera have a similar rainfall patterns while Diga has slightly higher rainfall. All three study sites have the same rainfall variability.

Rainfall



Source: Jones and Thornton (2000).

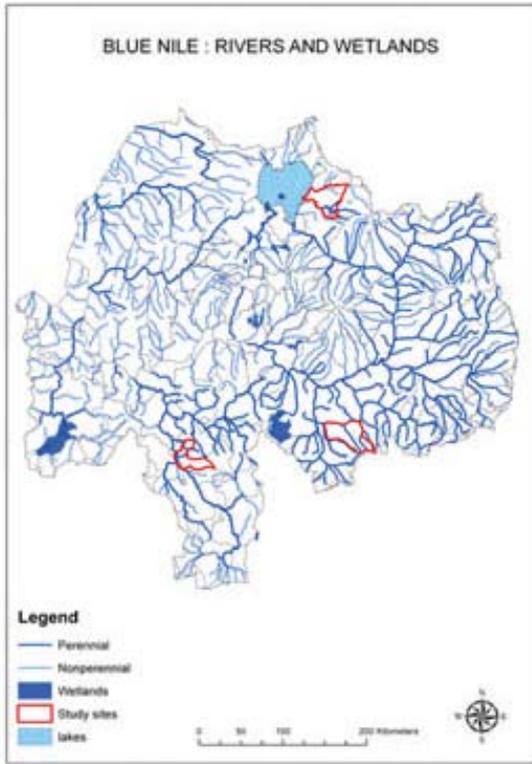
Figure 3. Rainfall (left) and coefficient of variation of rainfall (right) in the Blue Nile Basin with the three woredas: Fogera, Jeldu and Diga

Rivers, wetlands

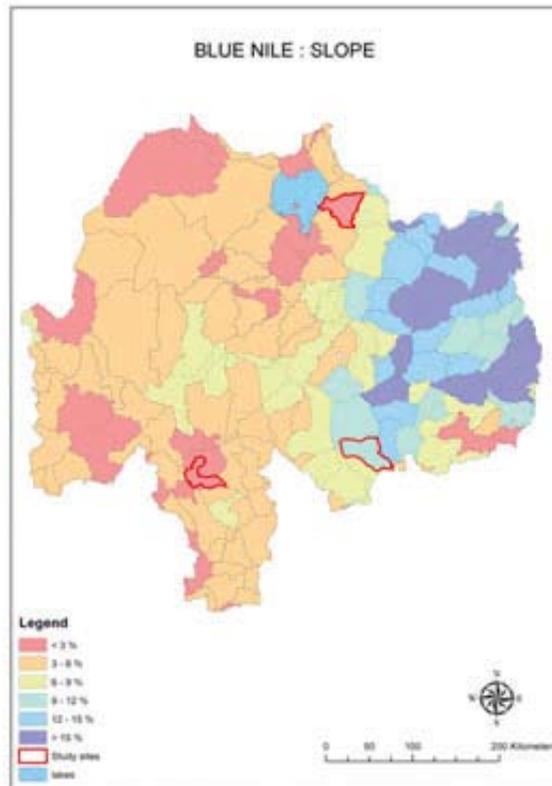
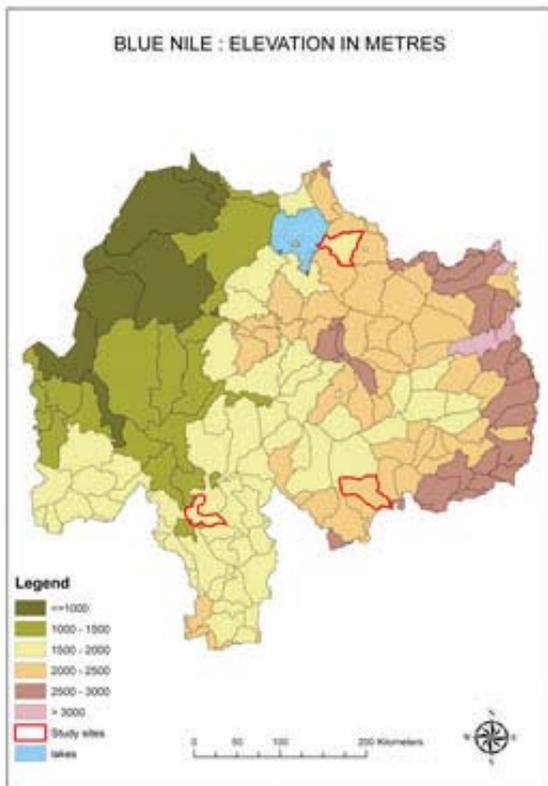
Figure 4 shows rivers and wetlands in the basin. It shows that all three study sites are crossed or bordered at least by one perennial river. In addition the study site Fogera shores with Lake Tana. Furthermore, there are no wetlands in the chosen study sites.

Elevation and slope

Topography in the Blue Nile Basin follows a gradient from the flat lowlands in the West to mountainous areas in the East as shown in Figure 5. A flat highland plateau crosses the basin from Lake Tana in the North to the South. Diga and Fogera have a similar elevation and slope, while Jeldu is slightly higher and hillier than the other two sites.

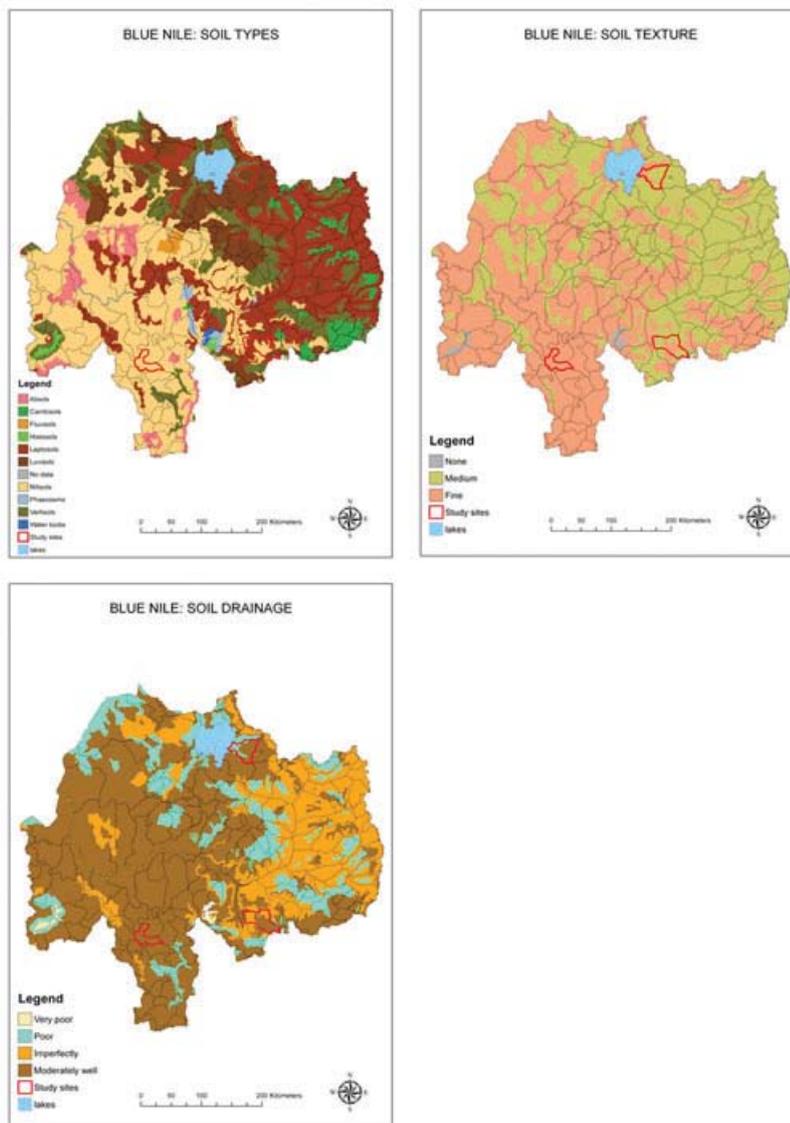


Source: Geonetwork.
Figure 4. Rivers and wetlands in the Blue Nile Basin



Source: SRTM.
Figure 5. Elevation and slope in the Blue Nile Basin

As shown in the left of Figure 6, the western Ethiopian highlands are dominated by Nitisols, the so called ‘red tropical soil’. Its stable porous soil structure permits deep rooting of plant and makes it generally less prone to erosion. Internal water drainage, water holding capacity and workability are good. It is a soil that is moderately to highly productive under a wide range of crops (Driessen and Dudal 1991). The eastern part is dominated by Leptosols. These soils are relatively shallow and prone to erosion. Consequently, these soils are unattractive for agriculture and have a limited potential for tree production and extensive grazing (Driessen and Dudal 1991). On the highland plateau Vertisols can be found. Vertisols are heavy clay soils. They generally have a fine structure and poor internal drainage. Because of these characteristics, workability of the soil is low. Soil need to be well managed in order to be suitable for agriculture. Therefore, Vertisol plains lend themselves better to mechanized agriculture than for low technology agriculture. In contrast, for Vertisols on slopes, contour bunding improves agricultural productivity significantly. Also around Lake Tana extensive Luvisols can be found. These soils are fertile and suitable for a wide range of agricultural uses. The selected study sites are rather different in terms of soils. Jeldu consists mainly of fine and relatively well drained Leptosols and moderately fine and imperfectly drained Nitisols, while Diga is dominated by fine well drained Nitisols. Fogera is dominated by relatively well drained and fertile Luvisols and poorly drained Vertisols directly adjacent to Lake Tana. It is also worth mentioning that the FAO soil map has a low level of detail, and that soils are likely to be more diverse within the different sites.

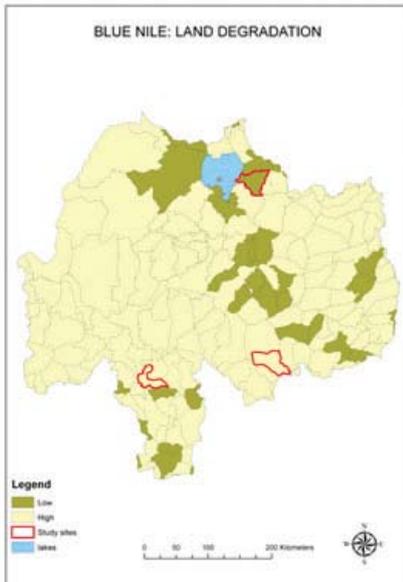


Source: FAO.

Figure 6. Soil type (left) soil texture (middle) and soil drainage (right) in the Nile Basin

Land degradation

Data behind the land degradation layer is the so called restrend maps from ISRIC (Bai et al. 2008). It makes use of the error between the observed normalized difference vegetation index (NDVI) with a predicted NDVI computed based on the NDVI correlation with rainfall. The analysis of the trend of the error, indicated locations where there is human induced land degradation. Human induced land degradation takes place almost in the whole basin, except for the flatter areas near to Lake Tana including Fogera as shown in Figure 7.

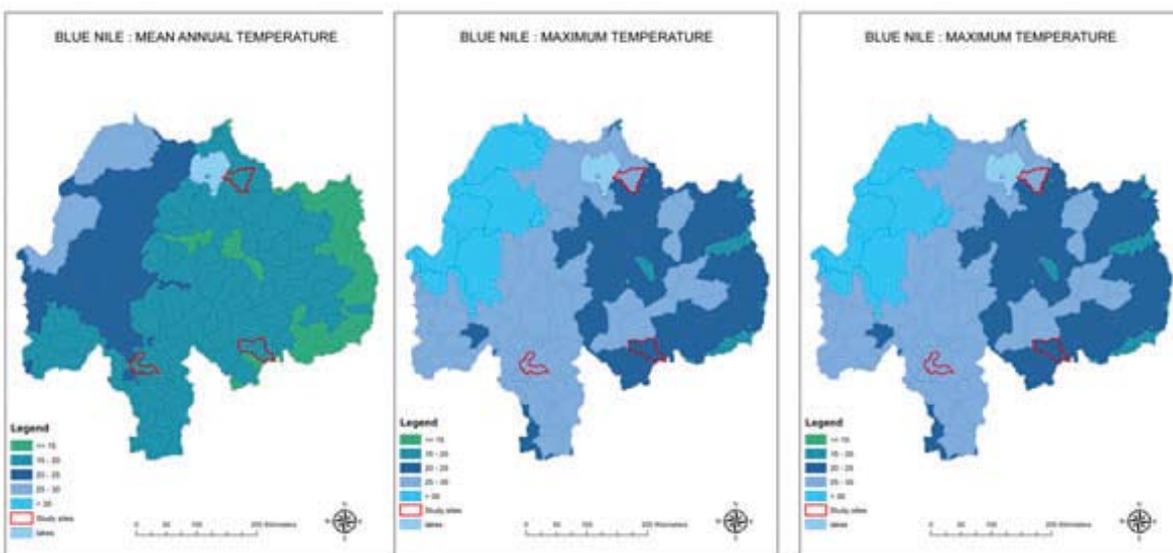


Source: Bai et al. (2008).

Figure 7. Land degradation in the Nile Basin

Temperature

Annual mean, maximum and minimum temperature show approximately the same spatial pattern than elevation (Figure 8). All three study sites have similar annual temperature, while minimum and maximum temperatures do show differences with Jeldu being the coolest area, and Diga the warmest.

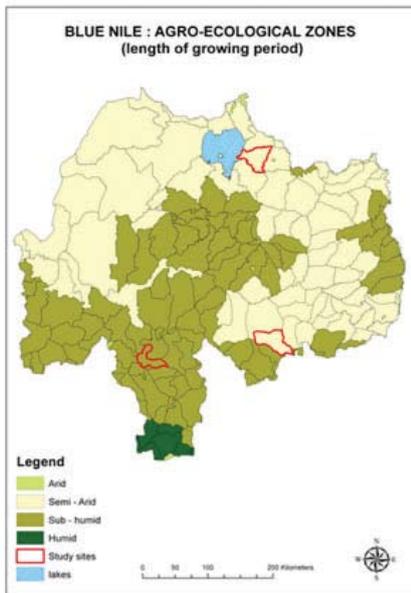


Source: Worldclim.

Figure 8. Annual mean temperature (left), maximum temperature (middle) and minimal temperature (right)

Agro-ecology

Agro-ecological zones map combines the patterns of rainfall and temperature (Figure 9). The humid highlands, such as Diga, have the longest growing period. Jeldu and Fogera are in the semi-arid areas and have a shorter length of growing period.

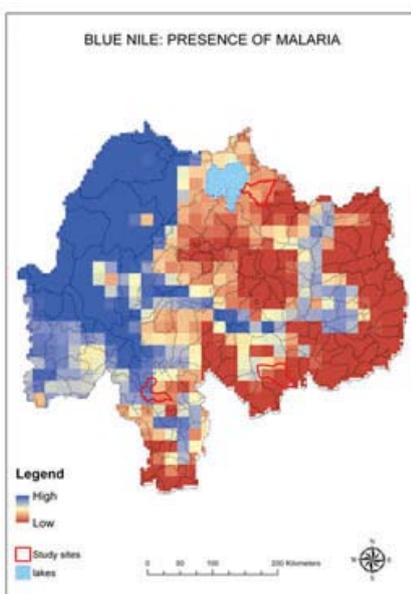


Source: Jones and Thornton (2000).

Figure 9. Agro ecological zones based on the length of growing period

Malaria prevalence

Malaria prevails mainly in the lowlands in the west as well as the in the valleys in the west (Figure 10). All study areas are only moderately affected by malaria. Diga being located in the lower and warmer locations has the highest probability of malaria.

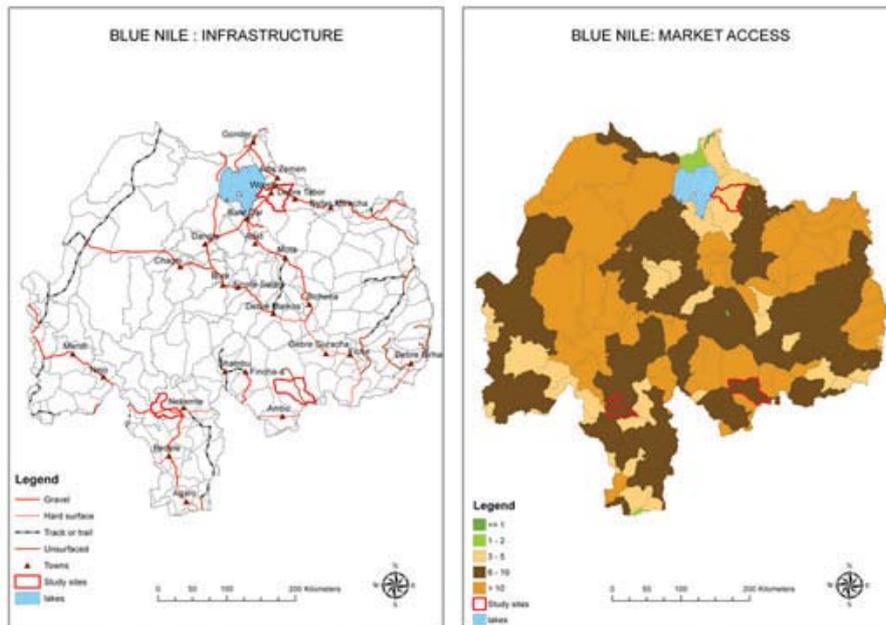


Source: Snow et al. (2005).

Figure 10. Prevalence of malaria in the Blue Nile Basin

Remoteness

Most of the roads link Addis Ababa to the Lake Tana region, as well as to the west (Figure 11). Fogera is the study site with the best market access, while Diga and Jeldu are less accessible. Nevertheless, this comparison should be taken with caution as new surface roads are being built at the time of this study making Jeldu more accessible already as well as Diga in the near future.

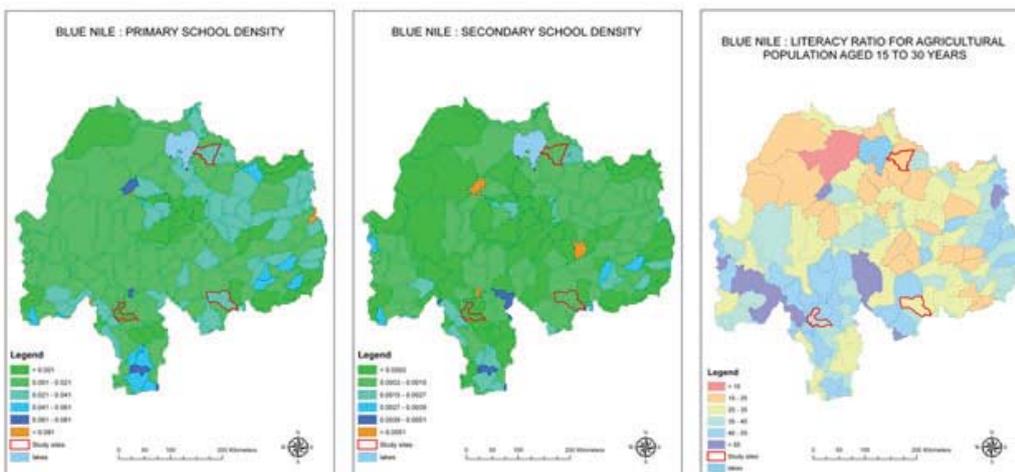


Source: Schmidt and Kedir (2009).

Figure 11. Road map (on the left) and travelling time to major market/towns (on the right)

School density

Figure 12 shows the school density (number of school/area). First of all, the density of primary schools is higher than the density of secondary schools. Also the east and the south have a higher school density than the west. Interestingly the density of schools does not seem to be correlated with literacy. The south seems to be more literate than the rest of the area. Jeldu and Fogera have a similar density of primary and secondary schools. Diga has a lowest density but nonetheless has the highest literacy ratio.

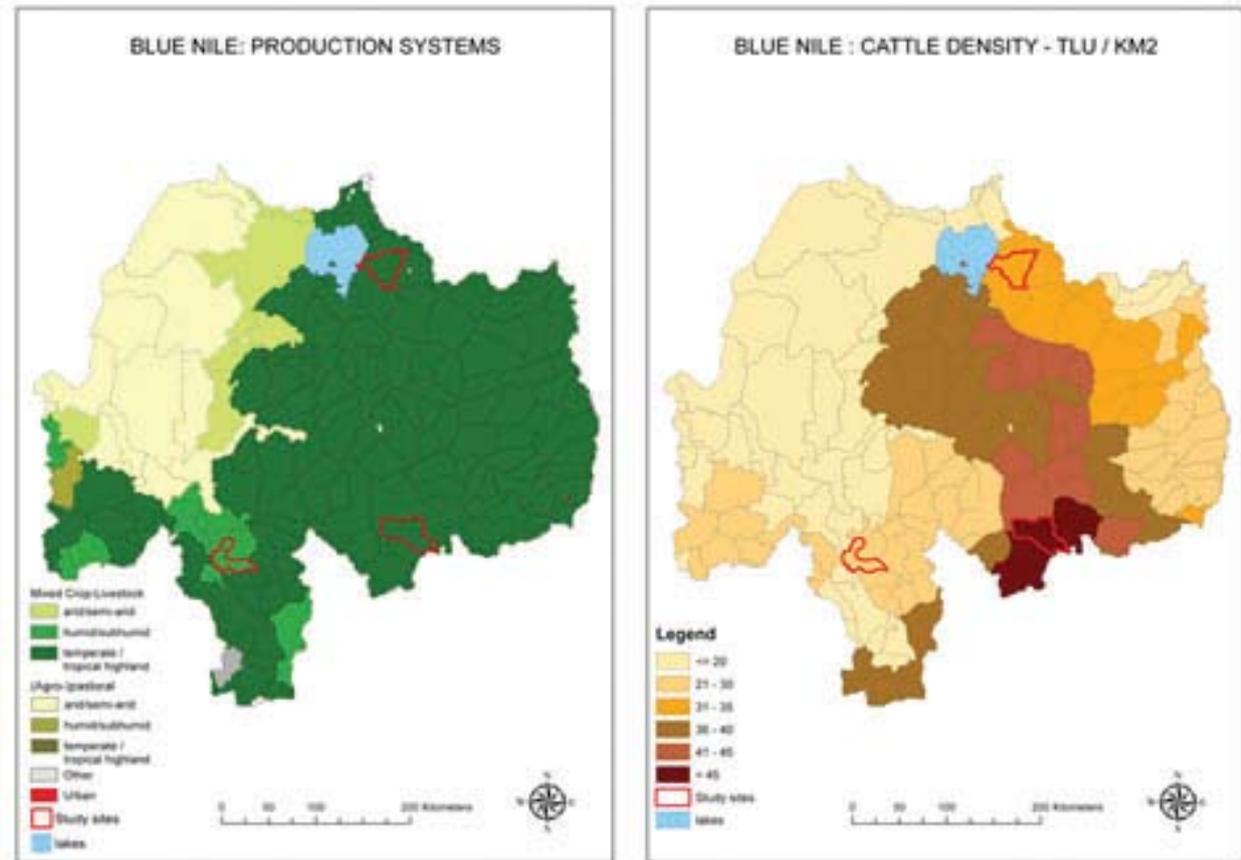


Source: IFPRI REA.

Figure 12. Primary (left) and secondary (middle) school density, and literacy ratio (right)

Livestock

Figure 13 suggests that the mixed crop–livestock system have higher livestock densities than the (agro-) pastoral areas within the Blue Nile Basin. All three study areas are mainly under mixed cropping and livestock keeping. Both Jeldu and Fogera are in the temperate/tropical highland agro-ecological zone (AEZ). Diga is located in the humid/subhumid AEZ.



Sources: Jones and Thornton (2000) and FAO.

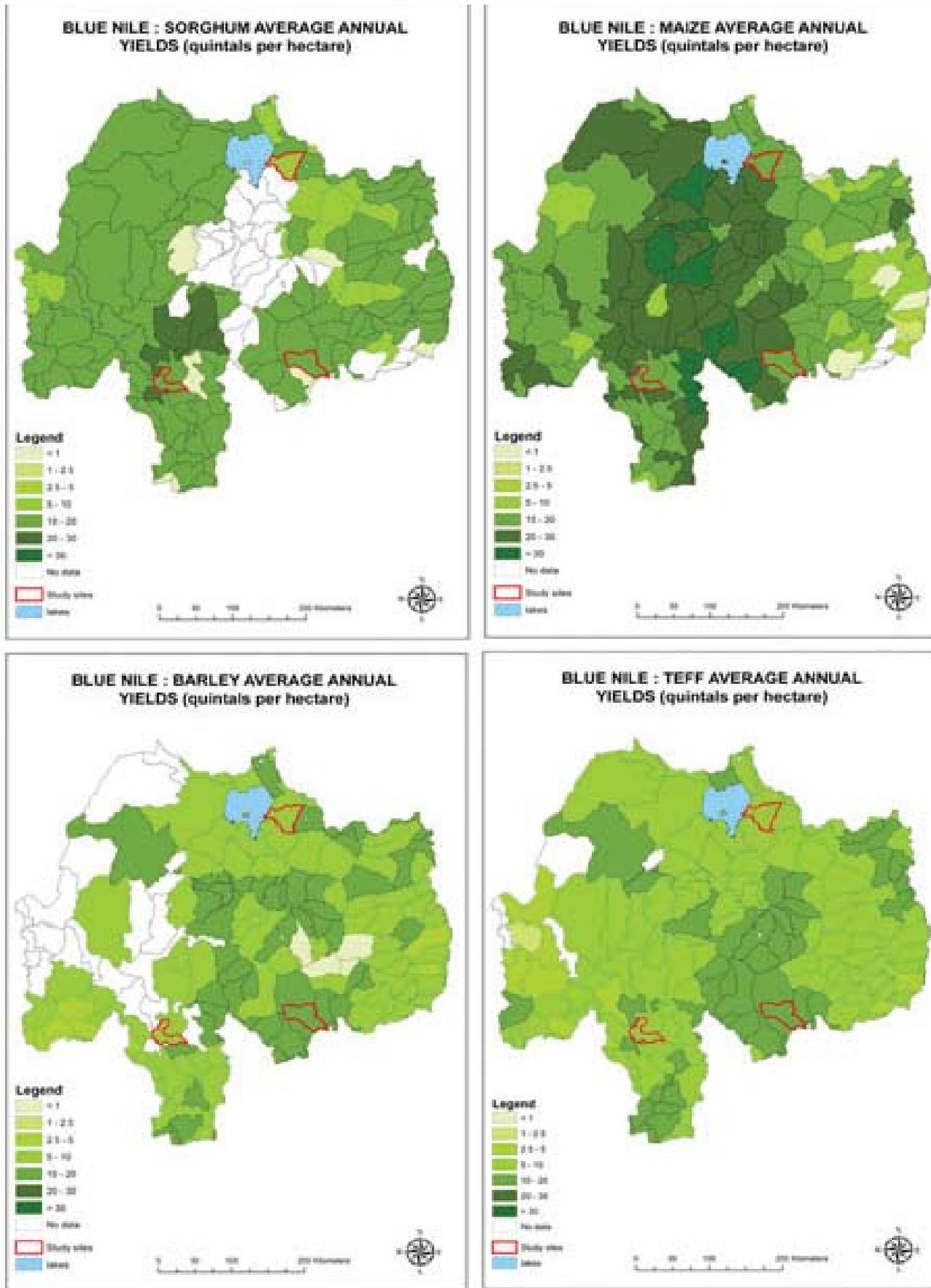
Figure 13. Livestock production systems (left) and cattle density (right)

The areas that are located near to Addis Ababa and along the Addis Ababa–Bahir Dar road seem to have the highest cattle density. From the three study landscapes Jeldu has the highest cattle densities. Around Lake Tana the livestock density is lower but still higher than in Diga *woreda*.

Crop yield and utilization

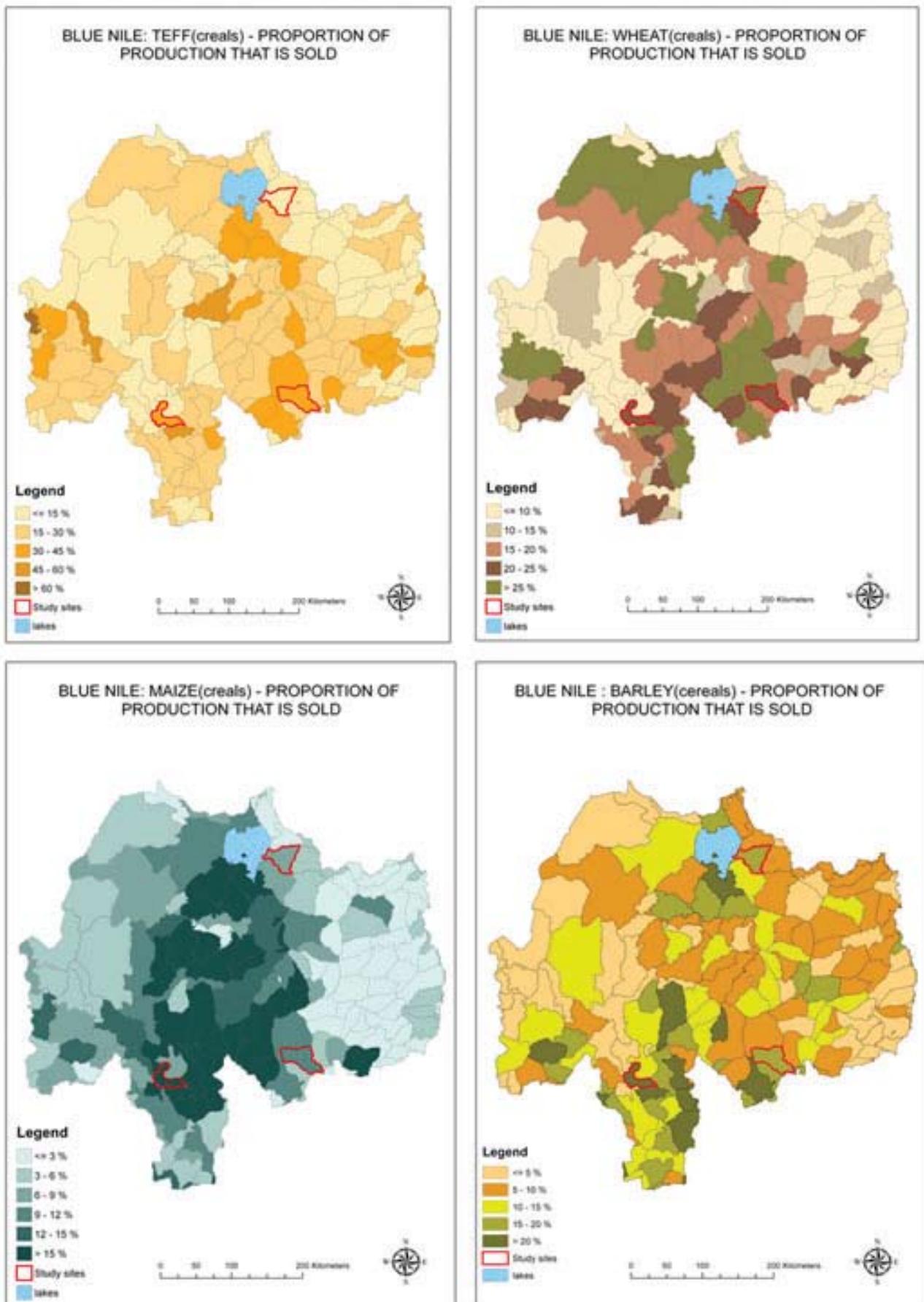
Figure 14 shows the different yield (quintal per hectare) of the major crops, namely sorghum, barely, maize and teff. Sorghum is mainly grown in the dry areas, while maize is most productive in the humid areas grown in almost the whole area and as its highest yield in the higher elevation with medium rainfall. Barley is grown mainly in the eastern part of the basin, with the highest yields in the subhumid agro-ecological zone.

Figure 15 suggests that for all major crops, the proportion sold on the market is higher in the temperate humid areas with longer growing period, where also yields are generally higher. In Fogera and Jeldu a relatively high proportion of wheat and barley is sold, while maize is not sold. Also teff is not sold in Fogera and Diga, an important share of all the cereals is sold on the market.



Source: IFPRI REA.

Figure 14. Crop yields for sorghum (top left), barley (top right), maize (bottom left) and teff (bottom right)

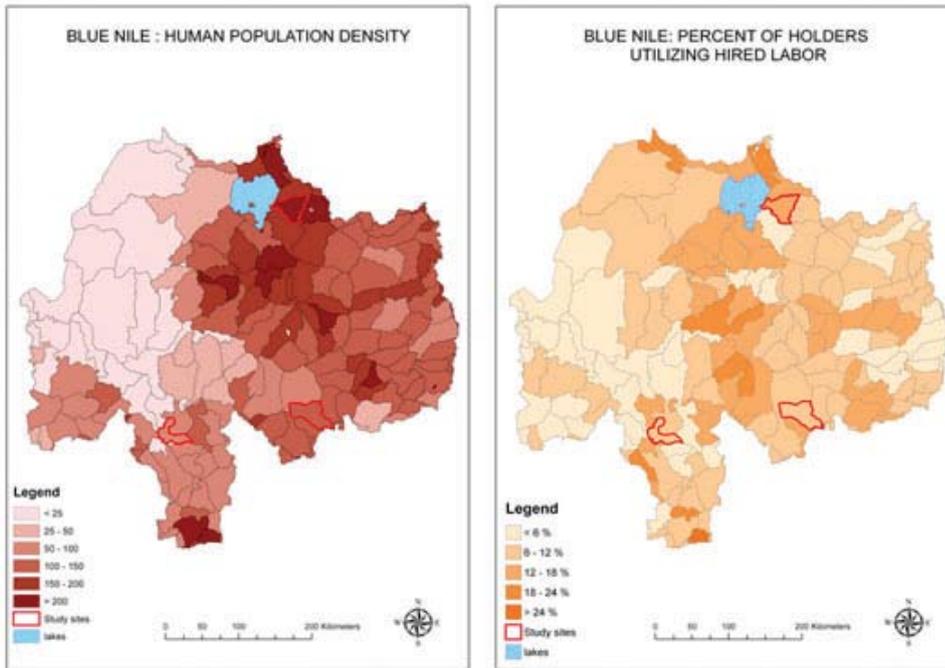


Source: IFPRI REA.

Figure 15. Proportion of crop production that is sold: Teff (top left), wheat (top right), maize (bottom left), barley (bottom right)

Population density

Figure 16 shows that population density is highest around Lake Tana as well as on the highland plateau. Consequently Fogera is the most densely populated study site, followed by Jeldu and then Diga. The dry lowlands are the least populated areas. Also in terms of percentage of hired labour used, the Fogera study site differs from the two others, with more hired labour used in this *woreda*.

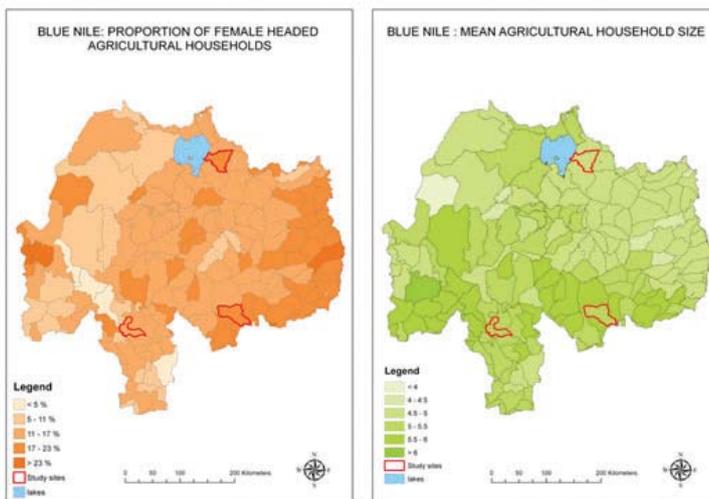


Source: IFPRI REA.

Figure 16. Population density in the Blue Nile Basin

Household composition

Figure 17 shows that female-headed households and small household size seem to be correlated, mainly in the lowlands and the mountainous areas. These are the less productive areas, where men migrate in the hope to find a job outside of their villages.

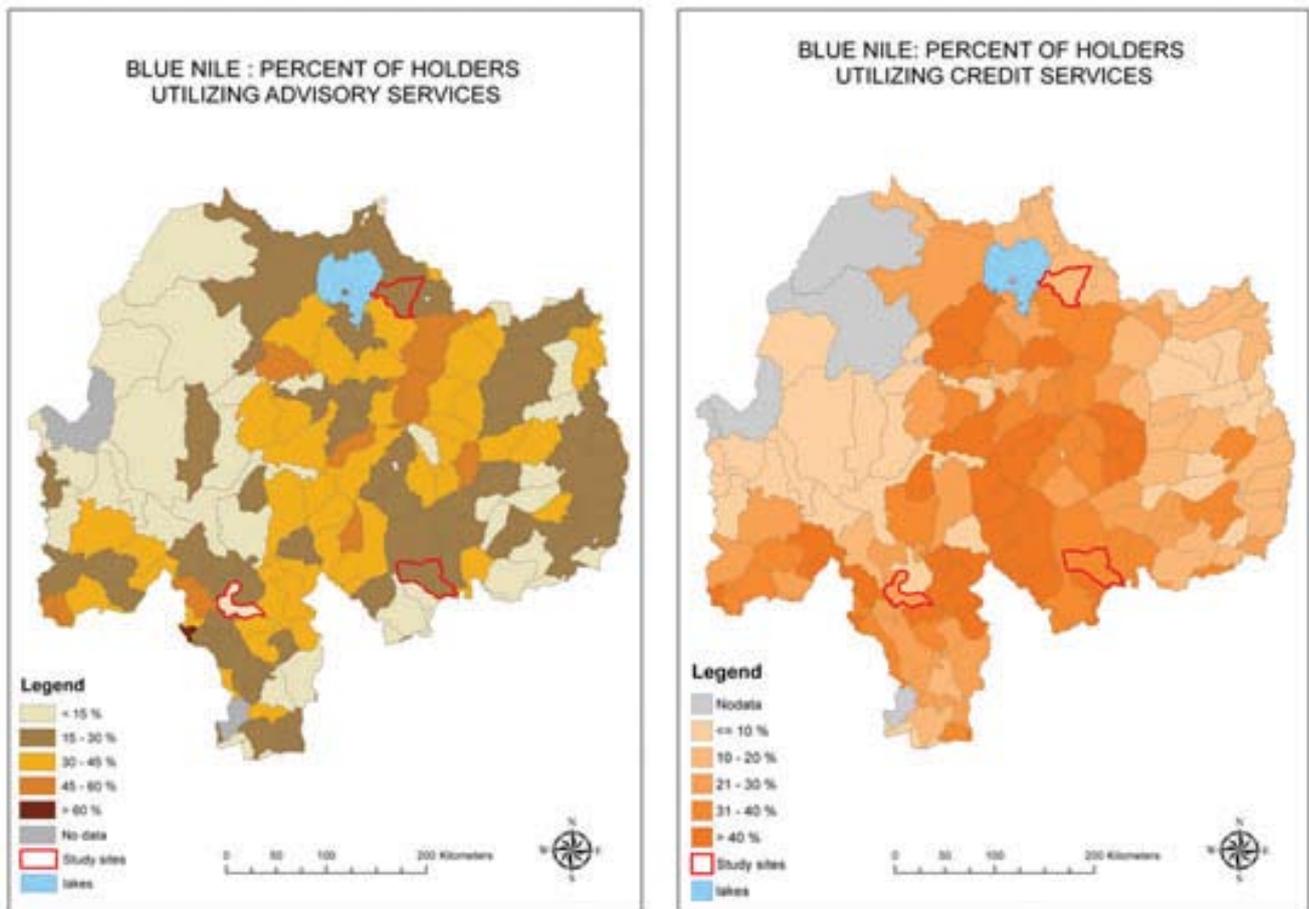


Source: IFPRI REA.

Figure 17. Household composition: Proportion of female-headed households (left) and average household size (right)

Credit and advise services

Figure 18 suggests the utilization of advice services (percent of households having used advice services) and credit services (percent of households that has a credit) show similar spatial patterns. Furthermore advice and credit services are mostly used in the highland plateau where crop yield is generally higher. Interestingly, these are not the locations that have the best market access, such as Fogera, where there is a low utilization of both advisory and credit services. In Diga there is a very low utilization of advisory services. Jeldu exhibits a slightly higher utilization of credit services than the other two study sites.

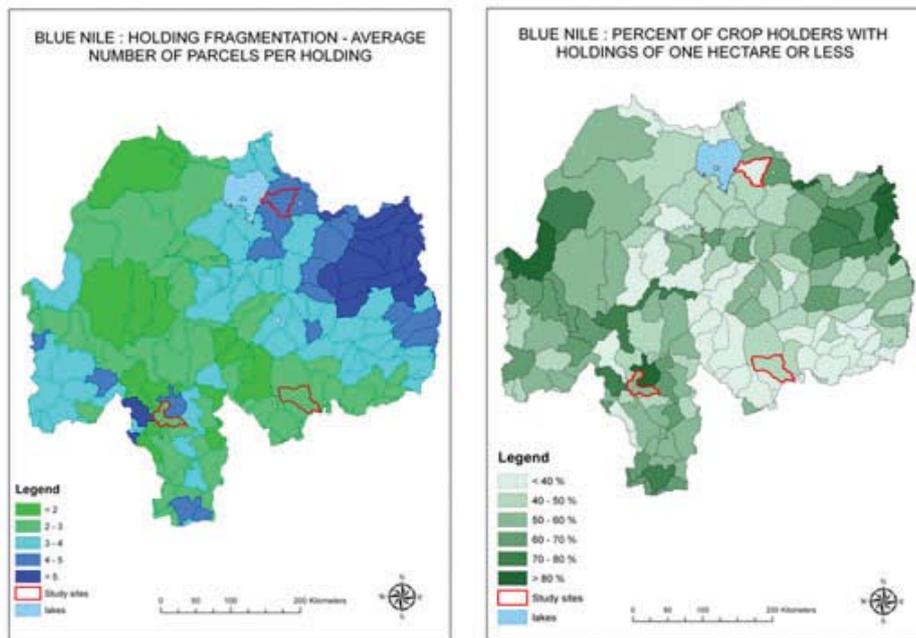


Source: IFPRI REA.

Figure 18. Utilization of advisory (left) and credit (right) services

Land holding

As shown in Figure 19, land fragmentation is high in locations where landholding is small (below one hectare). These areas also are location where population density is high and, therefore, land is scarce. In locations where land is scarce, also the share of rented land is higher. Consequently Fogera with the highest population density is most fragmented with generally small landholdings and a high share of rented land. Diga and Jeldu both have relatively bigger landholdings and are not so much fragmented.

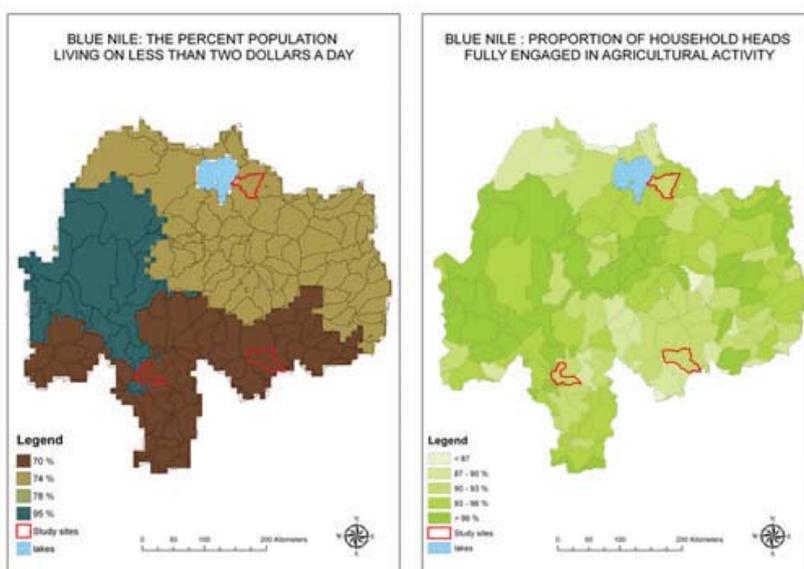


Source: IFPRI REA.

Figure 19. Land holdings: Land fragmentation (left) and landholding size less than one ha (right)

Income

Figure 20 shows that the lowlands in the west are the poorest, while the south is the richest. The areas with a high proportion of households solely dependent on agriculture show two different patterns. First the poorest households in the west do not have sufficient access to big markets and mainly depend on agriculture. In the humid highland, where the length of the growing season is longer, yields are good and the population solely dependent on agriculture are less poor. In the south, where there are more off-farm opportunities—probably also due to the proximity to Addis—and, therefore, dependency on agricultural activities is lower. The proportion of the population below the poverty line in this area is also lower.



Source: CSI and IFPRI REA.

Figure 20. Income distribution: Percent of population below poverty line (USD 2 a day) (left), and the proportion of household heads fully engaged in agricultural activity (right)

4 Results for the set of characteristics

4.1 Factor analysis

Individually assessed characteristics in the previous section have been introduced into a factor analysis. Time consistency needs to be considered, because the data used has been collected from various geo-databases, namely ILRI, IWMI, IFPRI and FAO. Socio-economic characteristics are typically changing faster than biophysical ones. It is, therefore, essential to only use data from similar years in order to avoid correlations that do not make sense. Therefore, in this report two different factor analyses were carried out; the first one on socio-economic and governance data, then a second on the rest of the variables. All the socio-economic data used was collected in 2005 for the Ethiopian Rural Economy Atlas (IFPRI 2006), ensuring time consistency in the identified non-land based factors. Land-based variables change less quickly and, therefore, time consistency between the different variables is less of an issue.

A factor analysis has been run on biophysical and infrastructure and on socio-economic and institutional data separately. In order to identify the dimension of a factor and name it, two criteria have been used: a loading above 0.5 and at least two variables.

Table 3 shows the four factors loadings for land-based variables, in bold the one used to identify the dimension captured by each factor.

Table 3. Factor loadings for biophysical and infrastructure variables

| Variables used | Factor 1.1 | Factor 1.2 | Factor 1.3 | Factor 1.4 |
|--------------------------------------|------------|----------------|------------|----------------------------|
| | Topography | School density | Remoteness | Rainfall erosion potential |
| Elevation | -0.9717 | 0.0784 | -0.0338 | 0.0216 |
| Minimum temperature | 0.9757 | -0.044 | -0.0402 | 0.0276 |
| Maximum temperature | 0.9712 | -0.0647 | 0.0401 | -0.0006 |
| Slope | -0.5344 | -0.0572 | 0.5743 | 0.2735 |
| Rainfall | -0.0085 | -0.0181 | -0.0401 | 0.9333 |
| Coefficient of variation of rainfall | 0.5766 | -0.2063 | -0.1022 | 0.3821 |
| Travelling time to market | -0.0989 | -0.0726 | 0.8498 | -0.14 |
| Road density | -0.3456 | 0.1299 | -0.7484 | -0.0098 |
| Primary school density | -0.0986 | 0.9704 | -0.0728 | -0.0181 |
| Secondary school density | -0.0432 | 0.9782 | -0.0563 | -0.0208 |

The factor topography identifies locations on low elevation, with high temperatures, without steep slopes and a high variability of rainfall. The factor school density encompasses the density of primary and secondary schools. The factor remoteness indicates location with low road densities and long travelling time to major cities. These are also the more hilly areas, as suggested by the importance of the slope variable. Finally the factor rainfall

erosion encompasses rainfall, variation of rainfall and slope. A high factor indicates location with high rainfall, high variability of rainfall and important slopes. These are areas where rainfall is likely to provoke important erosion. On the other extreme a low factor indicates locations with low rainfall, with low variability in flat area. These are areas where rainfall is less likely to provoke erosion. An intermediary factor results from low rainfall with high variability or high rainfall with low variability in hilly area, which are areas in which rainfall will provoke moderate erosion.

The factor analysis of socio-economic and governance variable resulted in five factors whose loadings are shown in Table 4.

Table 4 Factor loadings for socio-economic and governance variables

| Variables used | Factor 2.1 | Factor 2.2 | Factor 2.3 | Factor 2.4 | Factor 2.5 |
|---|-------------------------|----------------------|--------------------------|--------------------------------------|-----------------|
| | Agricultural dependency | Demographic pressure | Use of credit and advice | Small-sized female-headed households | Off-farm income |
| Proportion of household heads fully engaged in agricultural activity only | 0.4952 | -0.2524 | 0.054 | -0.0904 | -0.577 |
| Percentage of holders utilizing hired labour | -0.6556 | 0.3824 | 0.113 | 0.1818 | -0.2035 |
| Holding fragmentation— (average number of parcels per holdings) | 0.6924 | 0.3805 | 0.0867 | 0.3413 | -0.1792 |
| Proportion of land area under smallholders that is rented | -0.1343 | 0.6042 | 0.4531 | -0.0333 | 0.0211 |
| Percent of crop holders who have land holding size of 1 ha or less | 0.8841 | -0.0426 | -0.1564 | 0.0614 | -0.0062 |
| Percentage of holders utilizing credit services | -0.0262 | 0.2372 | 0.8714 | -0.0342 | 0.0434 |
| Percentage of holders utilizing advisory services | -0.0952 | -0.0324 | 0.8818 | 0.0417 | 0.0194 |
| Proportion of female-headed agricultural households | -0.0772 | 0.0697 | -0.0446 | 0.8255 | 0.2686 |
| Percentage of population living below poverty line (USD 2) | 0.128 | -0.8259 | -0.0576 | 0.1681 | -0.2895 |
| Average household size | -0.3045 | 0.0734 | -0.0579 | -0.72 | 0.3581 |
| Population density | 0.1272 | 0.7941 | 0.1082 | 0.2455 | -0.1164 |
| Density of cattle population | 0.0902 | 0.0315 | 0.1032 | 0.0276 | 0.8174 |

The first factor captures dependency on agricultural production. It suggests that smallholders with less than one hectare of land fragmented on different parcels depend on agriculture only and do not hire labour. The explanation of this correlation might be the result on long-term landscape dynamics. Locations in area with low off-farm opportunities, have resulted in more population staying in agriculture, and, therefore, over generations into smaller and more fragmented plots. The second factor captures demographic pressure and related processes. It suggests that locations where many people live above the poverty line (USD 2 a day), are densely populated. In these areas land is scarce resulting in a rental market for land, explaining the importance of the share of rented land in this factor. Note that these locations are also in biophysical terms the high potential areas for agriculture. The third factor captures the use of credit and advice services. The fourth factor captures small-sized female-headed households dimension related variables and indicates locations with female-headed households that have a small household size. Finally, the last factor captures off-farm income. These are locations where smallholders not solely depend on agriculture but have some off-farm income. This dimension also includes cattle population, suggesting that livestock is a form of investment when off-farm income is available.

4.2 Maps of the aggregate analysis of similarity

Each factor has been predicted for each *woreda*. The predicted factor does not have any meaning as such, but can be used to compare *woredas* among each other. In order to assess the spatial distribution of each factor, they have been mapped as shown in Figure 21. The Jenk’s classification technique was used to define categories with which *woredas* are similar.

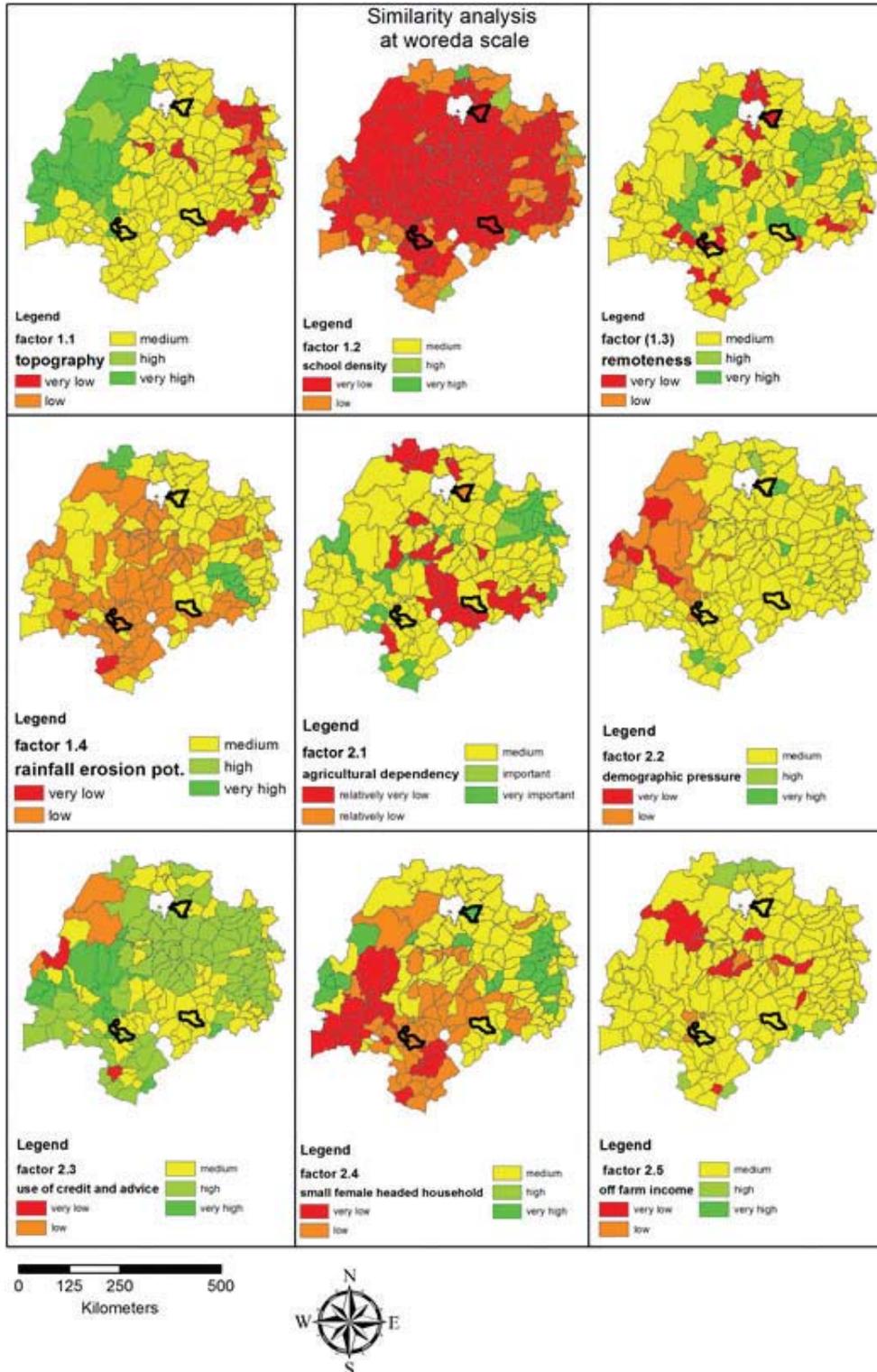


Figure 21. Spatial patterns of the different identified factors at woreda level, classified with a Jenk’s criteria

Figure 21 shows the different spatial patterns of each of the previously identified factors. Topography factor (1.1) is mainly driven by elevation, slope and temperature. It allows classifying the area into the lowlands in the west, the midlands, and in the mountainous highlands. All three study areas lie within the midland. The access to education factor (1.2) shows that most of the basin has a poor access to education, with the exception of the area near to Addis Ababa, the area that borders the basin, which are the areas that have market proximity. Also in terms of education access all the three study sites have a similarly low access to education. The remoteness factor (1.3) shows that area around Lake Tana but also in the south have a good accessibility while the rest of the area especially in the lowlands and the very mountainous areas are remote. This factor should be taken with cautions as roads are being built and urbanization is growing. Although the map indicates Jeldu *woreda* as the least accessible study site, it is nowadays the most accessible of the three study sites because of the newly built road. The factor rainwater erosion potential (1.4) shows that mainly the humid highlands are prone to rainfall erosion. Fogera and Jeldu being located in a more humid zone than Diga also have a higher potential for rainfall erosion.

The dependency of agriculture factor (2.1) shows that the central areas and areas near to Addis Ababa and Lake Tana depend less on agriculture than other areas. This can be explained by off-farm opportunities near to Addis Ababa, and the commercial farming and fishing around Lake Tana. In this perspective Fogera relies less on smallholder agriculture than the other two study sites. The factor about demographic pressure (2.2) shows that demography and its consequences on landholding and wealth is pretty similar across the basin with the exception of the lowlands where population density is low and smallholders poor. The advice and credit services factor (2.3) shows that credit and advice is mainly used in the eastern part of the basin, and very few of this services are available for the lowlands. All three study sites have a medium use of credit and advice services. The household composition factor (2.4) shows that the remote areas (lowlands and mountainous regions) have the highest amount of small-sized female-headed households. Interestingly, Fogera also has a high amount of small-sized female-headed household. The last factor (2.5) reflects off-farm income, while it is also related to livestock ownership. Locations close to Addis Ababa have the highest off-farm income and also the highest livestock ownership. All the three study sites have a similar off-farm income and livestock ownership.

5 Discussion

5.1 Similarity analysis

The classification and mapping of individual characteristic show the spatial variation of variables that have been identified as potentially important for RMS. Correlation between different variables can only be guessed. Factor analysis on the contrary is an exploratory data-driven approach that aggregates variables to form uncorrelated dimensions within which the variables vary in a similar way. It assumes an unobserved construct that generates the observed data. It allows describing different processes and consequently the interactions leading to the observed patterns. The combination of both the individual analysis and the factor analysis allows identifying areas with similar characteristics: the lowlands in the west are drought prone, have little population and are poor.

The spatial patterns observed on the factor maps allow identifying locations that are similar. The lowlands in the east have their own patterns. Compared to other areas in the basin, the lowlands have a relatively low population pressure, and a relatively low use of credit and advice services. Nevertheless they share similar patterns in terms of access to school, as well as dependency on agriculture and remoteness than the majority of *woredas* within the basin. Off-farm income and female-headed households are factors which do not have uniform spatial patterns for the lowlands.

The mountainous wet areas in the northwest have also their own patterns: remoteness, high agricultural dependency and small-sized female-headed households are all important. On the contrary, use of credit and advice services, access to schools, demographic pressure and off-farm opportunity are shared with the majority of other *woredas*.

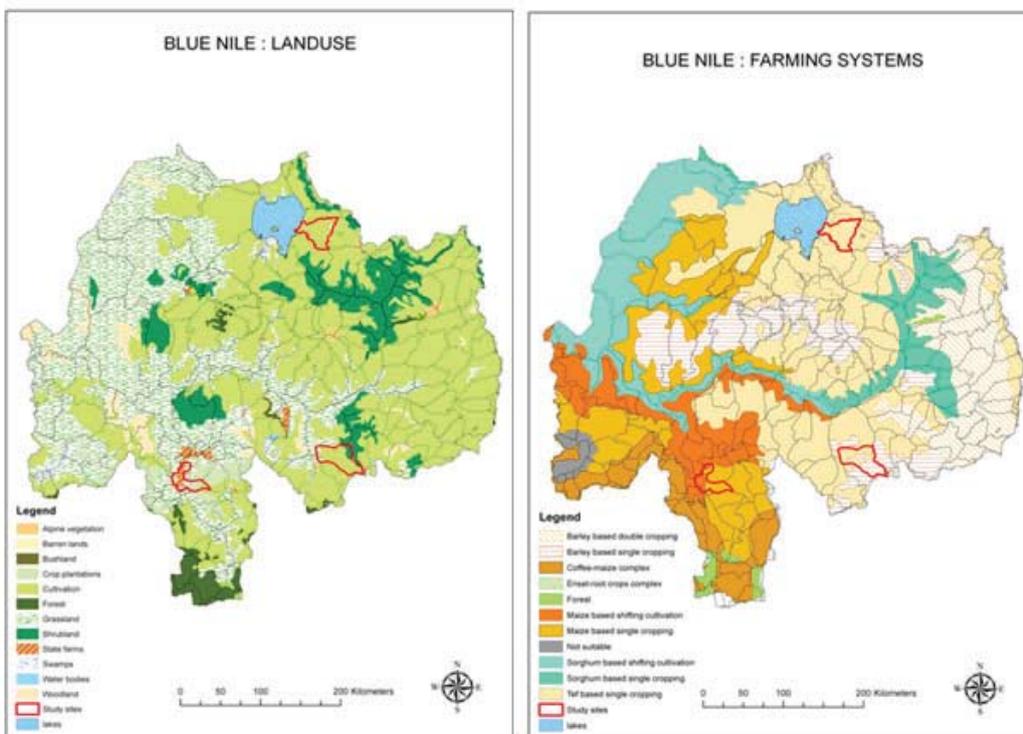
For rest of the Blue Nile Basin, each *woreda* has a specific combination of each factor, and, therefore, cannot be grouped into areas that are similar along several dimensions. However, the spatial patterns presented in Figure 21 shows for each dimension (factor) which areas are similar.

The similarity analysis suggests that in general the three study sites are very similar. They mainly differ in terms of soil types, livestock density, population and household composition. Fogera is the most populated area with the most small-sized female-headed households. It has a medium livestock density and a soil that needs to be well managed to be productive. Jeldu is the most livestock dense area on the most erosion prone soils, while Diga is the least densely populated area (due to only recent in-migration) with the lowest livestock density. It is located on relatively fertile soil and has the least amount of small-sized female-headed households.

In terms of available data, Jeldu and Fogera seem similar to each other when it comes to farming characteristics and infrastructure, such as length of growing period, density of schools, livestock holding or rainfall erosion potential. In contrast, Jeldu is much more similar to Diga in terms of socio-economic and institutional aspects, such as land fragmentation, wealth or use of credit and advice services.

This important similarity between the different study sites is surprising. Four reasons can explain this similarity: i. factor analysis yields to wrong results because of missing variables, ii. the scale chosen does not capture a sufficient level of detail, iii. the level of aggregation chosen does not represent diversity correctly, iv. the study site selection was suboptimal in terms of variability.

Firstly, in order to test the hypothesis of missing drivers, one can compare other studies that use more expert based knowledge to assess the human–nature interactions. Both farming-systems, which reflect how farmers makes use of their land, and land-use which reflects how the whole society makes use of its land, given the biophysical, socio-economic and institutional settings, can be used to assess variability. Figure 22 shows the farming systems as well as the land use map for the whole Blue Nile Basin. Based on these maps, all three study sites are surprisingly similar. In all three, single cereal production is observed, however, the major cereal varies: Diga is maize based, Jeldu and Fogera are teff based, while part of Jeldu is barley based. The land use map also suggests that both Jeldu and Fogera are mainly used for cultivation: Fogera is more intensely cultivated than Jeldu. Land use in Diga is slightly different and indicates crop plantation which refers to the mango plantation, which are usually intercropped with maize explaining the maize based farming-system. Both the land use map and the farming system map lead to a similar conclusion: Fogera and Jeldu seem to have similar patterns and Diga only slightly differs. Given that these two maps yield to similar conclusion than the factor analysis, omitted variables do not seem to be source of seemingly similar study site. Nonetheless this conclusion should be taken with caution, as both are based on relatively old sources (before 2000), and, therefore, certain patterns might have changed. Development in the Fogera plain has led to multiple cropping, including rice as a major crop, accompanied with supply chain management. State farms as suggested in Diga have been dissolved and land given to settlers. In addition given the high scale of the map, level of detail might be lost. Therefore, the maps in Figure 22 might not reflect the diversity and complexity of the current farming system and the resulting land use.



Source: ENTRO.

Figure 22. Land use (left) and farming systems (right)

As such the similarity between the different study sites could be the result of the scale at which the similarity analysis has been run. The factor analysis has been run at basin scale making use of data at *woreda* level. The

choice of this scale impacts our results in two ways: the extent of the data we use defines the heterogeneity that is introduced into the analysis and the resolution (*woreda* level) defines the level of detail by which this heterogeneity can be captured.

Secondly, the Blue Nile Basin boundary has been used as extent of this study, including locations in very different agro-ecologies than the three study sites, thereby increasing the overall heterogeneity within the analysis. This might increase the range of the analysis and, therefore, seemingly reduce the heterogeneity with the agro-ecologies of interest. To test this hypothesis, a factor analysis has been performed on a subset of *woredas* that have similar agro-ecologies than the three study sites. Results on the subset show the same characteristics than the basin wide analysis. This suggests that the results are robust and are not dependent on the extent of the study.

Thirdly, the resolution of the data was chosen at *woreda* level, the smallest level at which socio-economic data is available basin wide. Thus in order to model the basin extent, the heterogeneity within the *woreda* is lost. A good example of this phenomenon can be illustrated with the agricultural system map (Figure 22) that suggests that Fogera is a teff producing area, despite of the rice producing plain. This is the case since the plain is relatively small in terms of area compared to the rest of the *woreda*. There is, therefore, a trade-off between the extent of the analysis and the level of heterogeneity that can be captured. For this reason, drivers to human–nature interaction may differ depending on the scale of the analysis (Cash 2006). Whereas at basin scale household and biophysical characteristics can only be taken into account on an aggregate level, human interactions, governance such as land redistribution or market orientation, location specific natural phenomena such as erosion or termites are lost. Therefore, when analysed at *woreda*, the three study sites might seem very similar despite of the fact that they are very different from each other. To assess this scale, different data is needed from the farm as well as community and *kebele* (municipality) level. A recent study identifies livelihoods zones in Ethiopia by integrating expert knowledge from community level (USAID and Government of Ethiopia, n.d.). These zones are shown in Figure 23 and represent areas within which households on average share a similar livelihoods pattern, i.e. they have the same set of food, cash income sources and the same markets. The three study sites are all part of very different livelihood zones. Consequently, when using smaller scales and a higher level of detail, the three study sites seem to be very different. In this perspective, local action research and base-line assessment in the three sites will be important in order to identify dimensions within which the study sites differ which cannot be captured by the currently available data.

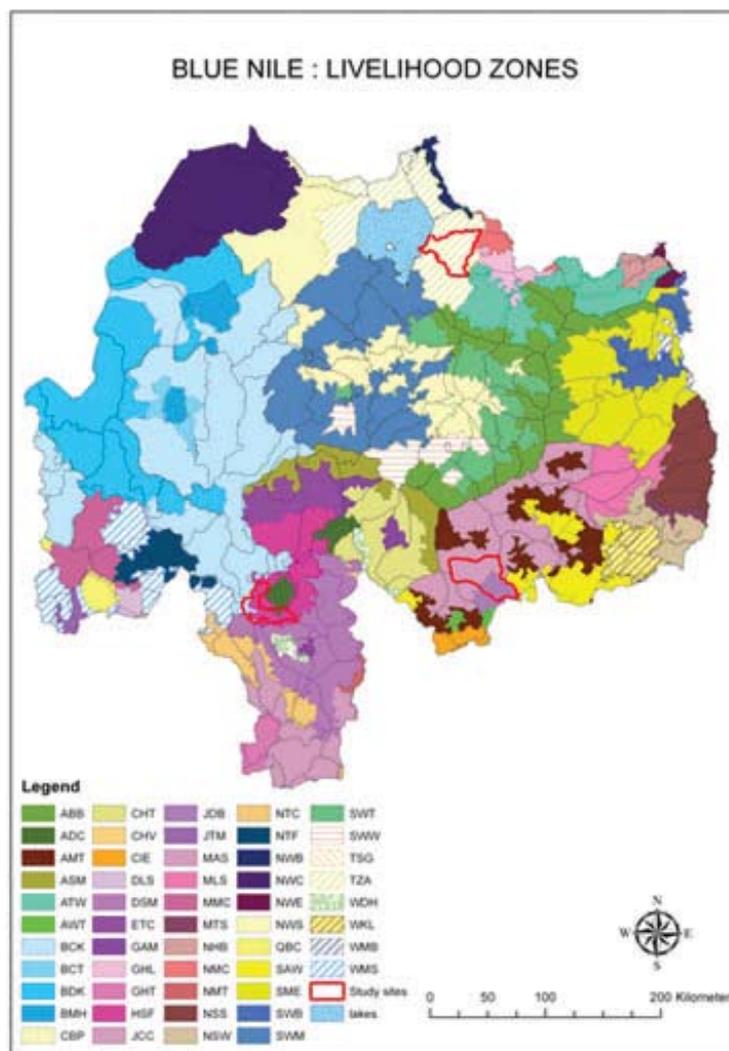
| | | | | | |
|-----|--|-----|---|-----|--|
| ABB | Abay Beshilo river basin | GHT | Gera–Setema–Sale forest, teff, honey and cattle | QBC | Keto–Begi cereals and cattle |
| ADC | Abe Dongoro–Diga–Sasiga coffee and sorghum | HSF | Anger maize, sorghum and finger millet | SAW | Selale–Ambo highland barley, wheat and horsebean belt |
| AMT | Ambo Selale Gindebert teff and wheat | JCC | Jimma Illubabur coffee, cereal and chat | SME | South Wollo meher |
| ASM | Abay Gorge sesame, maize and honey | JDB | Jaldu–Deni–Ifata barley and potato | SWB | South Wollo belg |
| ATW | Abay Tekeze watershed | ITM | Illu–Wellega–Birbir maize, pepper and sesame | SWM | Southwest maize, finger millet and teff |
| AWT | Aneya–Wolisso–Ambo teff and cattle | MAS | Muger–Abay–Jema sorghum teff belt | SWT | Southeast woyna dega teff |
| BCE | Bench Keffa cereal enset | MLS | Merhabete lowland sorghum and teff | SWW | Southwest woyna dega wheat |
| BCR | Basketo–Melo coffee and root crop | MMC | Mendi–Dabisu maize, sesame and cattle | TSG | Tekeze lowland sorghum and goats |
| BDK | ? | MTS | Minjar teff and sorghum | TZA | Tana Zuria |
| BMH | ? | NHB | North Wollo highland belg | WHO | |
| CBP | Central highland barley and potato | NMC | Northeast woyna dega mixed cereal | WKL | Wuchale–Abichu–Kembebit livestock, wild oates and barley/wheat |

| | | | | | |
|-----|--|-----|---|-----|-----------------------------------|
| CHT | ? | NMT | Nadda–Dilgel Gibe maize, teff and sorghum | WMB | South Wollo meher and belg |
| CHV | Cheffa valley | NSS | North Shewa highland sheep and barley | WMS | Wellega coffee, maize and sorghum |
| CIE | ? | NSW | North Shewa highland wheat and teff | | |
| DLS | Dale–Lalo sorghum and maize | NTC | ? | | |
| DSM | Didessa–Gibe Wama valley sorghum, maize and oil crop | NTE | North Wollo East Plain | | |
| ETC | Ebantu–Limu teff and cattle | NWB | N Highland wheat, barley and sheep | | |
| GAM | Guduru–Amuru maize, teff and cattle | NWC | Northwest cash crop | | |
| GHL | Guna highland | NWS | Northwest sorghum belt | | |

Source: USAID.

Figure 23. Blue Nile livelihood zones

It might be that the *woreda* level does capture diversity correctly. The livelihood zone (Figure 23) might capture diversity of the different area better than *woredas* as they regroup locations within which similar livelihoods patterns are observed. Therefore, the factors have been spatially re-aggregated into these livelihood zones as shown in Figure 24.



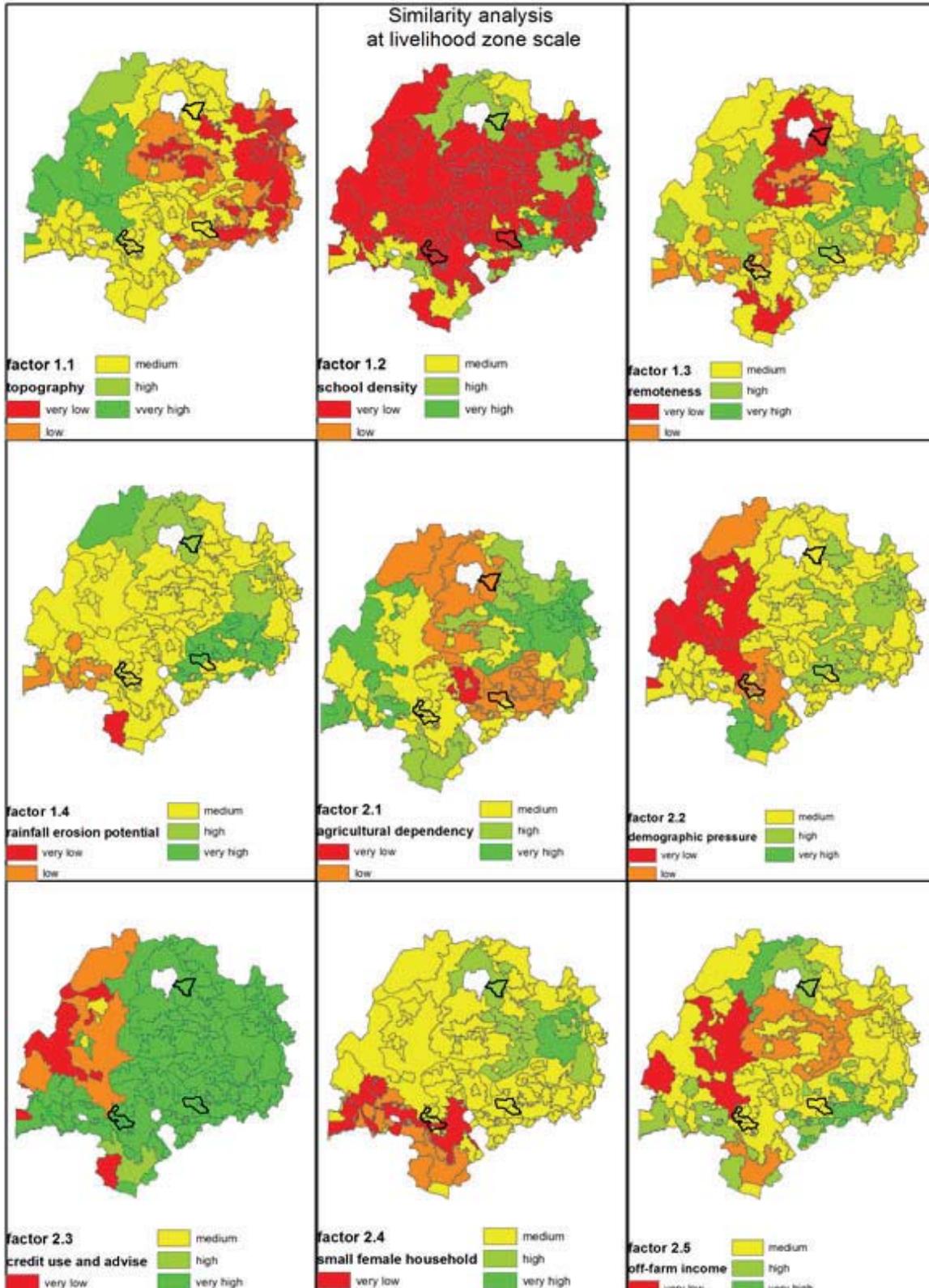


Figure 24. Spatial patterns of the different identified factors at livelihood zones level, classified with a Jenk's criteria

Whereas the spatial patterns are relatively similar for the land based variables, most of the non-land based variables show different patterns when re-aggregating the factors into livelihood zones. Agricultural dependency, demographic pressure and off-farm income present a more diversified pattern. Use of credit and advices services is re-classified differently whereas small-sized female-headed household kept similar spatial

patterns. This suggests that the scale at which the similarity analysis is run has important consequences and scale needs to be carefully chosen for scaling out rainwater management strategies.

Finally, it could be noted that the site selection is suboptimal in terms of variability. Two hypotheses can be formulated to explain why these sites have been selected. Firstly, the selection was made by experts based on hydrological characteristics and the availability of partners to work. Experts might have looked at some of the characteristics separately without taking into account that many of these characteristics are correlated and that once this correlation is captured, for example, with a factor analysis, these sites are unexpectedly similar. Secondly, given the nature of the project focusing on action research, it might be that the availability of partners to work with is a criterion that has outweighed all the other criteria.

5.2 Targeting and out-scaling

Understanding the spatial heterogeneity of both biophysical and socio-economic dimensions is a first step towards targeting and out-scaling interventions. Indeed, a successful intervention in one location can be a best-bet intervention in a location with similar characteristics.

This similarity analysis includes a multitude of possible drivers for adoption of any water related intervention. It does not consider that some of the interventions might be driven by different processes and, therefore, not all the variables used in this study might be relevant. Therefore, two major further steps are needed to develop an efficient tool for identifying best-bet interventions: i. creating intervention/practice specific maps taking cross-scale dynamics into account, and ii. including a feedback loop with impact assessments and develop recommendation domain maps.

Firstly, the drivers of adoption and disadoption of rainwater management practices need to be understood. Feasibility maps that include socio-economic and institutional dimension indicate those locations where all drivers suggest a feasible location for adoption of a practice. Methods for aggregation of different drivers into a feasibility map include principal component analysis (PCA) and multi-criteria analysis (MCA).

Clearly, the previously discussed cross-scale dynamics suggests that crucial drivers influencing farmers' decision-making might not be captured at *woreda* level and consequently not be taken into account when feasibility maps are built based on the data used in this similarity analysis only. In this perspective, expert knowledge about drivers identified at lower scale and up-scaling of farm household surveys are promising techniques to take dynamics from lower scales into account.

Over the recent years, Ethiopia has been developing quickly, raising the issue whether data collected over the last decades is relevant for creating similarity maps for current analysis and targeting. Indeed new roads are being built and need to be remapped as soon as new road maps are finished. In addition, not only increasing urbanization creates new markets for agricultural products, also new export channels are developing. This suggests that market access should be redefined to reflect current economic situation and accessibility taking into account the different actors in the value chain. Consequently, the factor remoteness should be remapped and should be reviewed regularly. Due to the increasing opportunities due to urbanization, also the livelihoods of smallholders might have changed around the growing cities and the newly built roads. Therefore, the maps presented in this report still need to be validated and—where possible—updated with recent field data,¹ expert knowledge and action research. Only this will yield reliable maps indicating the current suitability.

1. The baseline from N2 could be used to validate at least some of the maps.

It would also be interesting to take a forward looking perspective. The inclusion of projections of population density, precipitation, food and feed demand, market access etc. could yield potential future feasibility maps. These would be of special interest for strategic long-term planning.

After the development of feasibility maps, a second remaining step involves taking into account of potential impacts. Based on the identification of suitable locations for specific interventions, a number of plausible scenarios can be built. These are in turn investigated in terms of their environmental and livelihoods impacts. The combination of biophysical suitability, socio-economic adoption potential and expected impact then yields the final recommendation domains. Methods for aggregating and synthesising these different components remain a challenge yet to be addressed, but could be along the lines of earlier work by Omamo et al. (2006), Peden et al. (2006), Freeman et al. (2008) and Notenbaert et al. (2011).

6 Conclusions

This report aimed at developing a methodology that allows identifying different dimensions in which locations within a landscape differ. It makes use of a time consistent factor analysis of spatial data at the scale of the smallest unit at which data is available (*woreda*). This approach has been applied to the Blue Nile Basin in the Ethiopian highlands. Factor analysis at *woreda* level identified four land based factors, namely, topography, access to education, remoteness and rainfall erosion potential and five non-land based factors, namely, agricultural dependency, demographical processes, institutions, household composition and off-farm income. Mapping these factors enables to identify spatial patterns that can be used for better targeting future research and interventions.

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