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# Water investment domains for sustainable agricultural development in the Blue Nile basin

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**Abstract:** In the Blue Nile basin, crop cultivation is predominantly rainfed and water availability is highly variable across both space and time. As a result, it often constitutes a limiting factor for reaching full agricultural potential in the region. While one third of the basin is estimated to have no soil moisture limitations, the remaining two thirds are crop water constrained in various ways. Analysis shows that across approximately 40% of the basin available soil moisture is utilized sub-optimally with smart management and crop water limitations can be alleviated. In contrast, across a further 25% of the basin, water deficits strongly limit plant growth. While rainfed agriculture is still possible in some of these areas, appropriate management is even more important. A great deal of variation also exists in terms of market access for agricultural inputs and produce. Travel time to markets in the basin can be up to 12 hours. One's distance to market centres influences the accessibility of farm inputs such as fertilizers, improved seeds and veterinary services. Inaccessibility vs. accessibility to population dense areas also determines the potential for agricultural production and the marketing of crops and livestock products, in particular for perishable produce. To capture the complexity and heterogeneity regarding both crop water limitations and agricultural market access, this study combines information on rainwater management potential and market proximity to map so-called water investment domains (WID). Context-specific recommendations for each of the domains are provided. In the short term, the results point to a need for agricultural produce strategies that are spatially differentiated and in the longer term for investment in infrastructure in order to enable full utilization of the agricultural potential across the entire basin. The results are intended to guide policymakers and other rural development actors in the identification of appropriate investment decisions and for improved planning of rural development strategies. Thus, the study aligns to the 'water-centred agricultural growth' strategy adopted by the Ethiopian Government, developed in response to the poverty and food security challenges faced in the country. The approach is widely applicable, easily replicable and can be used to inform decision-makers beyond the Blue Nile basin.

**Media grab:** Crop water limitations and proximity to markets vary widely across the Blue Nile basin. The combination of these two factors can be used to target investments and rainwater management interventions.

## Introduction

The Blue Nile basin is one of the major agricultural areas of Ethiopia. Compared with 25% of the national population, it has over 40% of cultivated land and 39% of the cattle stock. The landscape is dominated by rainfed mixed crop–livestock farming systems.

These span across arid into humid and subhumid zones, but are mostly found in the temperate areas of the basin. Most of the dry lowlands are managed by pastoralists or agropastoralists. Overall, livestock is a vital component of the local food systems.

The major part of the crop cultivation in the basin is purely rainfed and large areas are water limited. As proposed in the Ethiopian Government's 'water-centred agricultural growth' strategy, water should be seen as the entry point to raising agricultural productivity. Investments in rainwater management (RWM) practices are thus both an answer to actual water constraints which limit the success of many farmers and to aligning interventions with current policy priorities. With wide-spread land degradation and erosion across the basin, any rainwater management (RWM) intervention to improve agricultural development must also focus on sustainable land management (Merrey and Gebreselassie 2011).

Another factor impacting strongly on the agricultural development potential of a region is market access. Proximity often enhances market participation, with increased livelihood diversification options. It also increases the accessibility of farm inputs necessary for intensifying production. Remoteness, on the other hand, commonly increases transaction costs and is therefore an incentive for bulk sale of crops or livestock and hence specialist crop or pastoral production. The agricultural options in turn depend on the agricultural potential of the area.

The Blue Nile basin demonstrates a high degree of heterogeneity in terms of both bio-physical and socio-economic aspects and the way these factors interact influences both the applicability and impact of interventions. The objective of this study was to map water investment domains (WID). These capture the complexity and heterogeneity regarding both crop water limitations and agricultural market access across the Blue Nile basin. Context-specific recommendations for each of the domains are provided.

## Methods

### Rainwater management potential

A new approach is derived for mapping the potential for rainwater management (RWM) which takes into account rainfall seasonality and climatic moisture requirements, i.e. potential evapotranspiration. This is an improvement compared to earlier assessments which typically rely only on annual rainfall data (e.g. Chamberlain et al. 2006).

In principle, precipitation (P) and potential evapotranspiration (PET) data of suitable temporal resolution (daily or weekly) are sufficient to characterize the moisture regime of a given location. However, water limitation for plant growth depends on a range of additional site-specific characteristics such as soil properties and slope as well as on the phenological stage of the plants. To improve the robustness of the methodology, normalized difference vegetation index (NDVI) was used as a measure of actual plant growth. NDVI is used to compare sites with comparable moisture regimes in terms of their 'greenness'. Sites that appear less green than expected for their moisture regime use the available water sub-optimally and can therefore be upgraded by appropriate RWM interventions.

The analysis is based on normalized difference vegetation index (NDVI), potential evapotranspiration (PET) and precipitation (P) for the period 2000–2011. Determination of a representative growing period was done using a fixed length of 100 days, with the period of the highest average NDVI assumed to be representative. For each identified growing period, the overall P/PET ratio was determined and assigned as the average water availability to demand ratio for that period.

Three classes of soil moisture availability determining crop growth in rainfed agriculture were defined in order to distinguish the need for RWM interventions (Table 1 and Figure 1).

Table 1. Selection criteria for the six identified water investment domains.

Soil moisture and crop growth	RWM need	Market access	Water Investment Domain (WID)
No Moisture Limitations, Full crop growth	No need	Close	NHL-CMA
		Remote	NHL-RMA
Sufficient Moisture Availability, optimal crop growth possible	RWM to reach optimal crop growth	Close	SMA-CMA
		Remote	SMA-RMA
Limited Moisture Availability, optimal crop growth not possible	RWM to optimize use of limited moisture	Close	LMA-CMA
		Remote	LMA-RMA

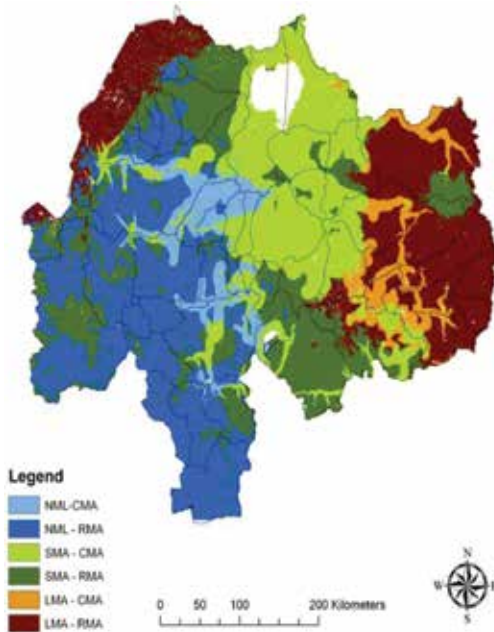


Figure 1. The Water investment domains (WDI) in the Blue Nile basin, derived from three classes of soil moisture availability and two classes of market accessibility.

#### Class 1. No moisture limited crop growth, no need for RWM

Two types of areas are included in this class: a) all areas with  $P/PET > 1.4$ , here optimal achievable NDVI values indicate that plant growth is not moisture limited; b) some of the areas with  $P/PET$  0.7–1.4, i.e. less soil moisture, but still showing optimal NDVI. In Class 1, there is no need for RWM

#### Class 2. Sufficient moisture, optimal crop growth possible, with RWM interventions

This class only includes the areas with a  $P/PET$  range of 0.7–1.4 showing sub-optimal NDVI values. Here, in contrast to areas in the same  $P/PET$  range in Class 1, available soil moisture is not utilized in the best possible way. Thus, with smart RWM practices available moisture can be sufficient for optimal plant growth.

#### Class 3. Limited moisture, optimal crop growth not possible, RWM to optimize sub-optimal water availability

This class comprises areas with a  $P/PET$  ratio less than 0.7. Here soil water deficits clearly limit plant growth. Rainfed agriculture is still possible, but optimal yields are not achievable. However, the results show a considerable NDVI range, indicating that by meticulously applying RWM practices crop growth can be considerably improved, i.e. to reach optimal growth within existent local soil moisture constraints.

### Water investment domains

Agricultural development options are strongly influenced by market proximity. A combination of the newly created dataset on rainwater management potentials with spatially-explicit data on travel time to markets, i.e. closeness and remoteness, yields geographically defined zones where these interactions play out. These zones are named Water Investment Domains (WID) and are defined as geographical units in which similar water-related agricultural development problems or opportunities are likely to occur.

Through combination of three soil moisture categories and two accessibility classes, the differences in agricultural potential from a water resources availability perspective and access to rapidly growing urban markets is spatially shown in the six WIDs (**Table. 1**). The domains are described according to a number of bio-physical and socio-economic traits, with summary statistics given per domain. Total area covered, the human and livestock population, the share of the area under different land cover classes and erosion potential were tabulated for all WIDs (Table 2).

Table 2. Characteristics of the six water investments domains, WIDs, in the Blue Nile basin.

Water Investment Domain (WID)	Population		Livestock		Area (km <sup>2</sup> )				Agricultural system	
	People	Share total	TLU*	Share total	Total area	Share total	Cropland mosaic	Share WID	Only livestock	Mix livestock & crops
NML-CMA	1 048 000	8%	428 554	8%	11 505	8%	7 298	85%	12%	85%
NML-RMA	2 745 750	15%	1 078 888	15%	51 255	28%	20 152	39%	51%	88%
SMA-CMA	8 494 880	54%	2 081 871	29%	41 108	21%	27 054	88%	4%	95%
SMA-RMA	5 094 520	18%	1 522 025	21%	42 875	22%	19 570	49%	21%	79%
LMA-CMA	1 551 040	7%	478 488	7%	9 204	5%	5 081	55%	1%	98%
LMA-RMA	5 924 140	21%	1 575 552	22%	58 984	20%	12 520	52%	24%	78%
	18 906 110	100%	7 140 915	100%	194 885	100%	91 383	47%	12%	79%

\* TLU = Cattle equivalent units

## Results and discussion

The spatial distribution of the six domains is shown in Figure 1. About one-third of the basin is estimated to have no soil moisture limitations. These domains, NML-CMA and NML-RMA, are found in the southwestern part of the basin. The further we move to the west, the greater the distance to markets. The remaining two-thirds of the basin is crop water constrained in different ways. In areas with sufficient moisture availability, SMA, constitute about 40% of the basin's area and are mainly found in the central parts of the basin. Half of this domain class is relatively easily accessible; the other half, however, is more remote. In the remaining 25% of the basin, water deficits strongly limit plant growth. These areas with limited moisture availability, LMA, are found in the eastern and northwestern parts of the basin. Most of them have the added challenge of remoteness to the markets. As expected, the domains with close market access, CMA, are found in the more urban central parts of the basin and along the major roads, while the RMA domains dominate in the western, southern and eastern parts of the basin.

The six water investment domains differ in many aspects, as shown in Table 2. One of the most important characteristics in relation to soil moisture availability for crop growth is the agricultural intensity in each domain. In landscapes dominated by fragmented mixed land uses, such as the smallholder dominated Blue Nile basin, it is very difficult to use remote sensing to spatially differentiate crop and pasture lands. However, the category 'cropland mosaic' in Table 2, extracted from Globcover 2009, gives a clear indication of the spatial distribution of cropland. According to this dataset, almost half of the basin is cultivated, i.e. about 50% of the 'share WID' is cropland mosaic. Furthermore, the domains SMA-CMA and NML-CMA are the two most agriculturally intensive areas, with approximately two thirds of each of the area cultivated. Comparing accessible with remote areas, higher shares of cropland mosaic are found in the more accessible WIDs. This confirms the influence of market accessibility on agricultural intensification in the landscapes. Highest numbers and highest densities of people and livestock are found in the SMA-CMA domain. In general, a higher population density (human and animal) can be found in the accessible areas as compared to the remote areas.

The 'mixed livestock and crop' agricultural system clearly dominates the area, with an average of 79% for the entire basin. In contrast, 'only livestock' systems are practised in about one fifth of the basin only. When comparing agricultural systems for RMA and CMA across all six domains, it is clear that the highest shares of 'mixed livestock and crop' systems are found close to markets (85–98%). In contrast, 'only livestock' systems are found in higher shares in the remote areas (21–31%). In total more than 90% of the areas with only livestock systems are under the remote RMA domains.

## Conclusions and recommendations

With three quarters of its area having enough soil moisture to reach full crop growth potential, the Blue Nile basin clearly has great agricultural potential. About one-third of this high potential area is already exhibiting optimal plant growth. This provides very good opportunities for high-value perishable crop and livestock products, such as horticulture and possibly dairy production. In the other one third of the high potential area, there is a need for more well-targeted RWM interventions. Most of the area with good potential under appropriate RWM is cultivated under a mixed crop–livestock system. This means that there is a high potential for using the livestock component to increase

the resilience of the overall system and optimization of both crop and livestock. Highlighting potential synergies will thus be important. In a considerable portion of the areas with no or limited soil moisture limitations, there is a need to invest in infrastructure. NML–RMA is, for example, five times the size of NML–CMA. Currently about one third of the remote NML–RMA domain is exploited in a livestock-only system. Despite the lack of investments in roads and market infrastructure, good potential for non-perishable crops exists. It would thereby be very important to look at the larger-scale impacts on the livestock production.

Only 25% of the Blue Nile basin's area is experiencing severe soil moisture limitations. In these areas it is very important to put appropriate RWM in place and by doing so to increase the resilience of the systems. Technologies such as drought-resistance crops, feed purchasing systems, water harvesting, including storage structures and soil water management and diversification in order to deal with variable circumstances should be supported by the extension services.

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## References

- Arino, O., Perez, J., Kalogirou, V., Defourny, P. and Achard, P. 2009. Globcover2009. [http://due.esrin.esa.int/globcover/LandCover2009/GLOBCOVER2009\\_Validation\\_Report\\_2.2.pdf](http://due.esrin.esa.int/globcover/LandCover2009/GLOBCOVER2009_Validation_Report_2.2.pdf)
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25:1965–1978.
- Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu, G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker, E.F. and Wolff, D.B. 2007. The TRMM multi-satellite precipitation analysis: Quasi-global, multi-year, combined-sensor precipitation estimates at fine scale. *Journal of Hydrometeorology* 8(1):38–55.
- Merrey, D.J. and Gebreselassie, T. 2011. Promoting improved rainwater and land management in the Blue Nile (Abay) basin of Ethiopia. NBDC Technical Report 1. Nairobi, Kenya: ILRI.
- Mu, Q., Zhao, M. and Running, S.W. 2011. Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment* 115:1781–1800.