Climate and Landscape-related Vulnerability of Water Resources in the Mkindo River Catchment

Wami River Basin, Tanzania

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) Program

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Cover Photographs:

Front cover: Left-Right – Mkindo river waterfall; clouds condensing atop the Nguru Mountains, part of the Eastern Arc Mountain chain and the headwaters for the Mkindo River; girl fetching water for schoolhouse construction from stream in Kigugu village.

Back cover: Left-Right –Mkindo River Irrigation Intake; Riparian forest on the banks of Mkindo River, Hillslope agriculture in the Nguru Mountains

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Acknowledgements

This report composed by Amartya Saha and Valeria Perez Guida combines technical analysis, field visits and the knowledge on water resources gained from interacting with village communities in the Mkindo River Catchment. The interaction was done concurrently with another initiative, the Community Water Resources Monitoring (CWRM) Program over January – August 2013.

Heartfelt thanks are due to the numerous people and school teachers in the villages of the Mkindo River Catchment for the warm welcome to their communities and homes and their kind hospitality, their time, enthusiastic participation in CWRM meetings and for sharing their perspectives on issues related to water resources in the area.

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The climate change predictions for the Mkindo River Catchment and the Wami/Ruvu Basin were obtained via the excellent open source service provided by ClimateWizard in facilitating running Global Climate Models and generating maps. Maps of forest cover change over the period 2000-2012 for the Mkindo River Catchment have been obtained from the web-based map and data tool created by the partnership of Hansen *et al.* 2013 from the University of Maryland and Google Earth Engine, who have make available the results of their classification analysis of NASA Landsat images.

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Executive Summary

Villages in a river catchment are bound together by the water resources in the catchment that include streams, springs, and groundwater. Since the beginning of human settlements, village communities have managed local water resources. Today, however, the factors affecting water availability operate over much larger regions than those circumscribed to local communities. Examples are the rising human water demands basin-wide, deforestation, wetland loss, and climate change.

Assessing the vulnerability of local water resources at the catchment and community level is an important first step for a community in order to develop an adaptation strategy and thereby sustainably manage local water resources. The major environmental factors influencing water supply or availability in a catchment are climate (rainfall), forest cover, and wetland cover. A detailed understanding of how these factors affect water circulation enables predicting the effect of variations in climate and forest cover upon water resources. Subsequently, this understanding of water availability is combined with information on water demands, ie. the community's water needs along with the exposure and sensitivity of each water-related activity to variability in water availability (such as water shortage). This then paves the way for the third step, where adaptation and water resources management strategies are developed. Since water is central to life, it is not just the availability of water for human consumption that is a concern; water is required for agriculture and livestock as well as to maintain natural ecosystem function and biodiversity. Hence, the adaptation and management strategies are to be designed for all the water uses a community has. Furthermore, vulnerability assessment is not a one-time activity, but needs to be done periodically, since climatic, environmental, and socioeconomic conditions are always changing, as well as to learn from experiences and fine-tune adaptive strategies.

While the Government is usually entrusted with the task of water resources management at a regional (river basin) and national level, this is too spatially - intensive task for the Government alone. The active engagement of local communities and other water users in assessing local vulnerabilities can be considered along three dimensions:

(i) *information provision* for changing climatic/environmental/resource demand conditions/threats
(ii) *management* – protection of local catchment forests and undertaking soil and water conservation activities
(iii) *community empowerment* - supporting their capacity to improve their current situation by providing a sense of ownership of the proposed measures that increase their possibility of success.

This report presents information on climate and landscape factors that affect water availability and quality in the Mkindo River Catchment. It describes the present climate, climate change predictions, forest cover change, slope analysis to identify regions with steep slopes, and village water use information. The report then discusses the exposure and sensitivity of local water resources to climate and landscape factors. Finally this report suggests focal areas for adaptive strategy development for water resources management and monitoring by the stakeholders in the catchment.

Upcoming meetings to discuss and develop adaptation strategies are to be facilitated by the Mkindo Water Users Association, Mvomero District Officials, Wami/Ruvu Water Basin Office and the Tanzania iWASH Program. The development of specific adaptive solutions for different water uses by communities and other stakeholders in the Mkindo River Catchment would then complete the first round of the vulnerability assessment.

The major points arising from the current assessment can be summarized as follows:

1. *Forests, wetlands and hydrological services:* Forests and wetlands buffer communities and ecosystems from the vagaries of climate, including those arising from climate change. Existing primary forests (uncut old growth cloud forests) in the headwaters of the Mkindo River Catchment intercept moisture from clouds and rain, regulate water storage and ensure perennial springflow and baseflow. Wetlands in the lowlands adjacent to the foothills store huge amounts of water and promote both local agriculture as well as baseflow for the Wami river downstream. While most of the existing forests in the catchment are protected as Forest Reserves, agriculture, logging and illegal gold-mining have been extending right up to the borders of the forests. Hence maintaining primary forest cover is the single-most important way to maintain the flow of water in springs, streams, and rivers, to recharge groundwater, and to minimize soil erosion**.**

2. *Forests and cloud cover:* The cloud coverage in the higher slopes of the Eastern Arc Mountains (of which the Ngurus belong) depends upon the interaction between regional climate as well as the extent of primary forest cover; it is these clouds that feed the headwaters for the Wami and Ruvu rivers, including the Mkindo River. While climate change can decrease cloud cover in dry years and is out of any individual or instituitional scope to prevent, promoting the conservation of existing primary forest and reforestation activities constitute practical ways to maintain/retain cloud coverage and water supply as far as possible.

3. *Soil and water conservation:* Terraces, check dams and strip mulching are critical on steep slopes that have lost forest cover or have been dug up through mining activities. A mechanism needs to be set up to achieve effective soil and water conservation in the catchment, including identifying the participants in this labor-intensive activity. A GIS-based terrain analysis displays the steepest slopes in the Mkindo River Catchment.

4. *Adapting to uncertain rainfall:* Projections of rainfall patterns are very complex; however models and experience of the past decades indicates increasing uncertainty in the onset of rainfall and changes in rainfall patterns and distribution, with a possible increase in both extreme events and unseasonal rainfall. Communities need to develop strategies to adapt to the increasing uncertainty in rainfall; this is one of the intended outcomes of the community meetings for discussing adaptive strategies.

5. *Use and sector-specific adaptation strategies:* Water is used for domestic consumption, farming and livestock water needs. Each of these activities differs in their sensitivity to water shortage. Low rainfall years necessitate strategies that enhance water storage for domestic consumption and dryland farming/drip irrigation/higher water use efficiency crops in agriculture.

6. *Community programs:* The Community Water Monitoring Program facilitated by the Mkindo Water Users Association (MWUA) can serve as a springboard for village-level discussion of adaptation activities, .as well as to facilitate communication between communities. For instance, an early flood-warning system can be set up between upstream and downstream villages and other water users in the MWUA. Rainfall and springflow monitoring by village schools can help focus the connection between upland forests/wetlands and continued baseflow in local springs and streams.

1. Water resources vulnerability and management at the community level

Water resources vulnerability

Apart from direct human consumption, water underpins every economic activity. Ecosystems that ensure our survival also have water as their lifeline. The inadequate provision of freshwater threatens the health of ecological systems and human wellbeing. The amount of water available in a catchment at any point in time is determined by the interaction of various supply and demand factors. Water inputs in the form of precipitation are determined by climate and are thus subject to uncertainty from climate change. Forests and wetlands regulate water flow and storage; deforestation and wetland drainage in the humid tropics leads to higher river flows following rains with the rivers drying up earlier (eg. Bruijnzeel 2002, Yanda and Munishi 2007, Krishnaswamy *et al.* 2012). Furthermore, increasing domestic and industrial pollution, deforestation and the lack of soil conservation in catchments, can affect water quality. The changes in water availability go together with a growing human water demand following increasing water needs in the domestic, agriculture, industry, and power sectors accompanying increasing populations and economic development. There is also the necessity of maintaining the natural flow regime in rivers and estuaries (Poff *et al.* 1997) to preserve aquatic ecosystems and fisheries. Taken together, the net effect of these supply and demand changes affects the vulnerability of water resources (Gain, Giupponi, and Renaud 2012).

Vulnerability assessments

Given the complexity associated with water resources and their management, i.e. large numbers of possible alternatives usually characterized by high uncertainty arising from the numerous and often unknown interactions between a changing climate and the biophysical landscape, and conflicting interests of multiple stakeholders (Hyde, Maier and Colby 2004), water resources vulnerability assessment is a complicated endeavor. Furthermore, there is no universally accepted concept for vulnerability; this plurality in definitions leads to a diverse range of assessment frameworks and methodologies (Gain, Giupponi, and Renaud 2012).

Traditionally, vulnerability assessments under climate change scenarios were top-down scenario-driven approaches. These approaches go from global climate model scenarios derived from Global Climate Models, often in a scaled-down version or regional scenario form, to sectorial impact studies and then to the assessments of adaptation options. Some of the limitation of these type of approaches is that there is an array of significant local and microclimatic variables i.e. temperature variability and extremes, seasonality, rainfall distribution (Smit *et al.* 2000), that are not considered. A second drawback of this approach is its focus on an uncertain future; it tries to address how uncertain climate related impacts can be reduced by the process of adaptation under, often uncertain, future socioeconomic scenarios (Gain, Giupponi, and Renaud 2012).

Considering the limitations of an exclusively top-down approach, the present report considers an approach relevant to the local scale and works from the bottom-up. The Adaptation Policy Frameworks for Climate Change (APF) (UNDP 2005) recommends performing vulnerability assessment at local level, not just theoretical and future oriented, but empirical and based on actual observation of current climate risks and how communities cope with them. On the basis of this existing knowledge, the dimension of new risks (climate change, land use change, demographic and socio-economic processes) is introduced and assessed (van Aalst *et al.* 2008).

Figure 1 illustrates a heuristic model for the vulnerability assessment of water resources in the Mkindo catchment based upon the USAID framework of exposure, sensitivity and adaptation (USAID 2007). The main factors affecting water availability and water needs in the catchment are assessed. For water availability, climate determines the amount of precipitation while land cover regulates water storage and flow. Similarly, water needs are spread over an array of human activities and ecosystem water requirements to maintain structure and function. The intersection of water availability and water needs, both of which vary seasonally and inter-annually, determines the vulnerability of local water resources. An accurate understanding of this local vulnerability can then be used by communities to discuss and develop adaptation strategies for each water use (e.g. domestic, agriculture, livestock, and ecosystems).

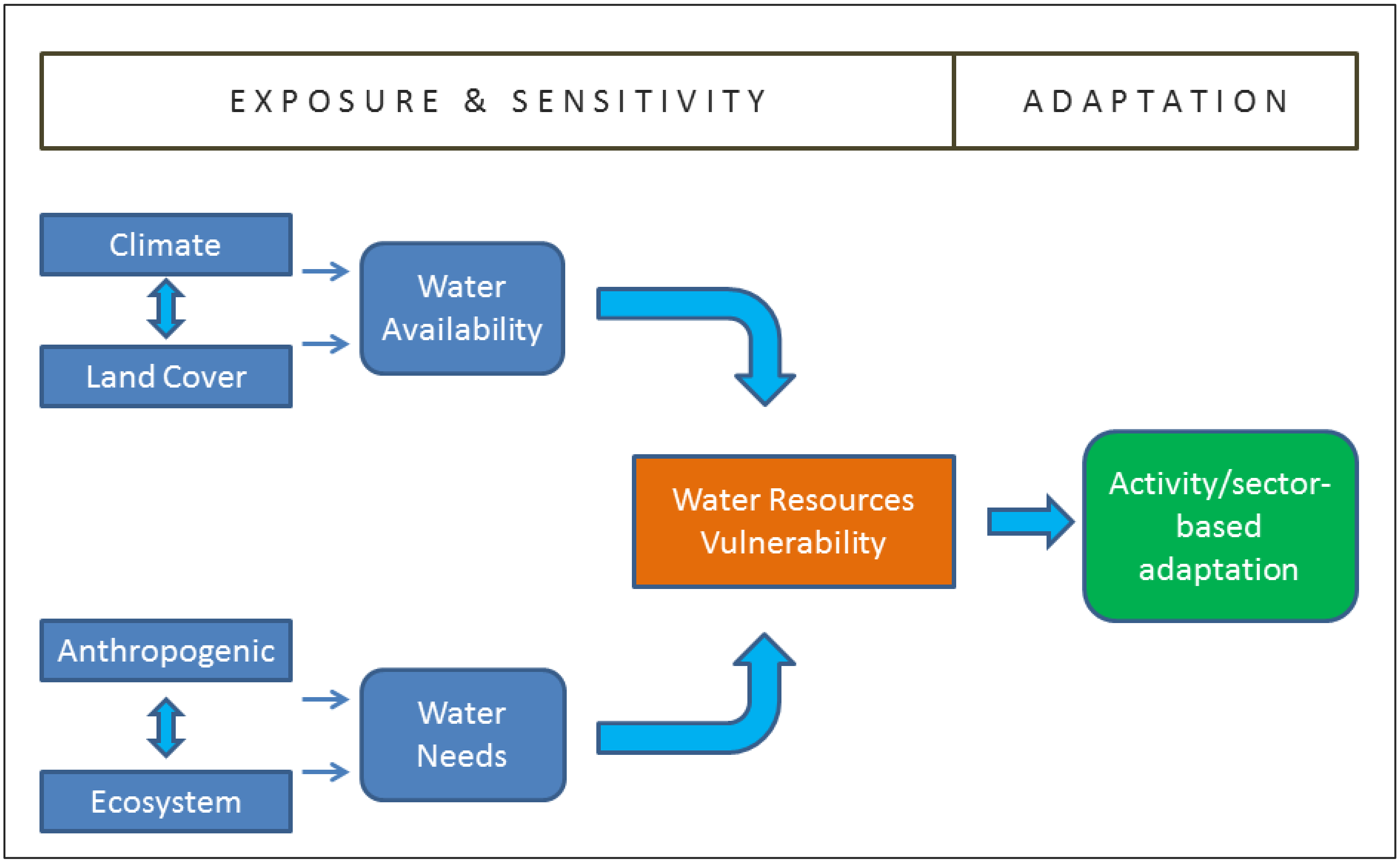

Figure 1: A comprehensive heuristic model of vulnerability assessment of water resources

Community engagement in local water resource management

While the Government is usually entrusted with the task of water resources management at a regional (river basin) and national level, the active engagement of local communities and other local water users, such as large farms and industries, in the management of water resources is essential for attaining the goal of sustainable and equitable water management at the local level (Warner 2006).

The involvement of local actors in assessing local vulnerabilities can be considered along three dimensions: information provision, management, and empowerment. Firstly, local actors are well placed to notice changes in water availability and demand at the catchment level, and in some cases provide information regarding the presumed causes underlying these changes. Additionally, existing knowledge within the community on water management and coping with water scarcity and other extreme events can contribute to developing locally-viable adaptation strategies. Secondly, typically a large extent of a river basin is rural and rural communities managed local water resources. Many of the processes governing water harvesting, infiltration/recharge/runoff and water quality occur in local catchments and are managed and influenced by local actors. Furthermore, it is the local people that need to adapt their management strategies to better deal with water related issues. Finally, involving communities in vulnerability assessment may catalyze a process that empowers the people in the community and supports their capacity to alter their own situation. Furthermore, activities that emerge will have the people's 'ownership' having more chance of success (van Aalst, Cannon, and Burton 2008).

Objective and Roadmap of this report

This report assesses the vulnerability of water resources to climate change and forest cover change in the Mkindo River Catchment. Through this assessment, areas for discussion with local communities in relation to the development of adaptation strategies at the community level in the Mkindo River Catchment are provided.

After this introduction, Chapter 2 introduces the physical landscape, the social and ecological setting of the Mkindo River Catchment. Chapter 3 and Chapter 4 analyze some of the main change occurring in the basin that could have an impact on water resources availability; climate change and forest cover change respectively. Climate change predictions are described together with their implications on rainfall, temperature and the water cycle. Forest cover change (loss/gain over 2000-2012) in the Mkindo River Catchment is examined at a 30 m resolution. A slope analysis of the catchment is done using GIS to identify and map areas with steep slopes that are likely most vulnerable to soil erosion and surface runoff if deforested. These steep-slope locations can be visited by field teams along with local communities to examine protection/restoration options, as part of developing adaptation solutions to maintain water quality by minimizing soil erosion and transport into streams, and to increase the water retention capacity of the landscape by targeted reforestation. Chapter 5 provides preliminary information on community water uses and users in the Mkindo River Catchment. This information was gathered at two workshops and subsequent village meetings in 8 villages that were held in 2013 (GLOWS-FIU, 2014b). The following chapter, Chapter 6, describes what could be main water quantity and quality issues in highland and lowland villages in the Mkindo River Catchment, and provides guidelines that could guide future discussion about adaptation measures in the Mkindo River Catchment. Following the APF recommendations, this stage was empirical oriented, based on actual observation of current climate risks, and later on introducing the dimension of new risks (climate change, land use change, demographic and socio-economic processes) are introduced. Finally, Chapter 7 closes with concluding remarks.

This study attempts to be an initial step towards a water resources vulnerability assessment and adaptation strategy in Mkindo River Catchment. Following steps in assessing the vulnerability of water resources in the Mkindo River Catchment could be holding workshops with local communities and other water users in the catchment to discuss the sources of vulnerability as presented in this report, identify other possible sources of vulnerability, and then develop adaptive strategies and solutions for each water use.

This report presents maps detailing the topography, climate, forest cover, and slope of the Mkindo River Catchment. It is hoped that the maps in this report will serve as a useful reference to the Mkindo Water Users Association (MWUA) and other institutions for managing water resources in the catchment. High resolution versions of these maps will be available at http://glows.fiu.edu

2. The Mkindo River Catchment: Physical, Ecological and Sociological setting

Physical setting

The Mkindo River Catchment is situated within the Wami River Basin in Tanzania. The Mkindo River headwaters lie in the forested upper slopes on the southern flanks of the Nguru Mountains (forest belt 1200-2200 m; latitude 6o 12’ – 6o 16’S and longitude 37 28’ – 37o 34’ E) that are part of the biodiversity-rich Eastern Arc Mountains (EAMCEF 2014). The Mkindo River joins the Diwale and eventually the Wami River in the marshy lowlands just south of the Ngurus The catchment has varied topography, from the headwaters around 1500 m right down to the lowlands around 300 m elevation (Figure 2).

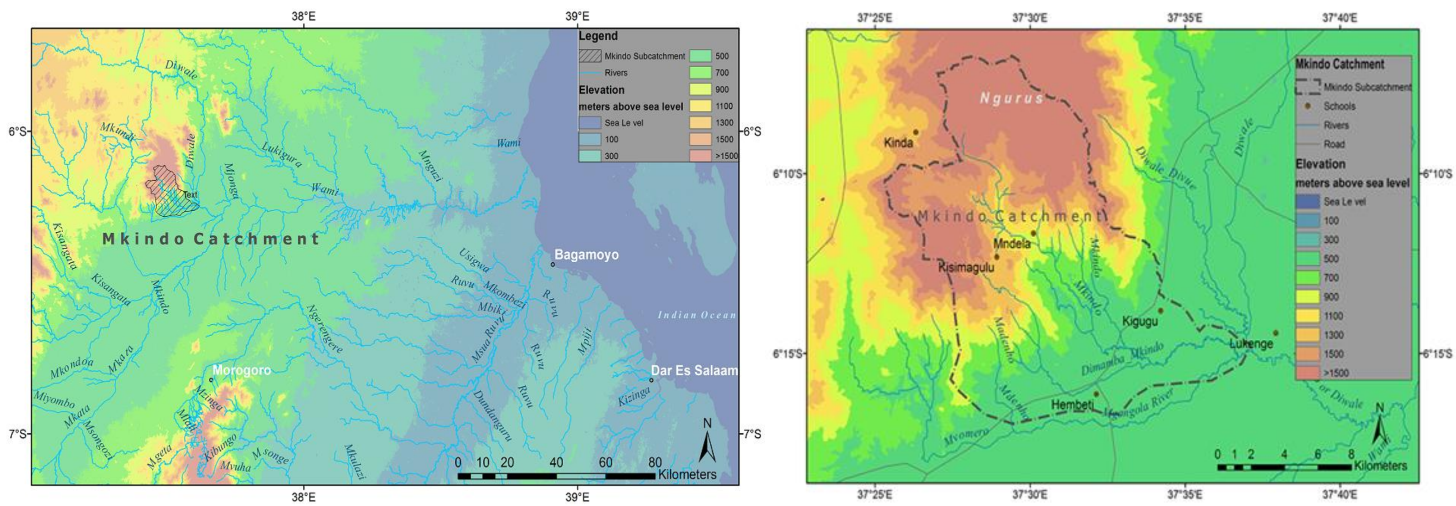

Figure 2: (Left) Location of the Mkindo River Catchment (dotted line) in the Wami River Basin, Tanzania. (Right) Close up of the Mkindo River Catchment showing elevation and main water courses based on the ASTER 30 DEM [Data Source: NASA and JSRO]

Land cover in the mountainous part of the catchment (highland) includes gazette forest reserves (primary old growth evergreen tropical forests) stretching across the upper slopes greater than 1000-1200 m. Below 1200 m exists a mosaic of forest patches, rainfed farming, pasture, and plantations. The lower slopes (600 m and lower) have deciduous *miombo* (*Brachystegia*) woodlands. At the foot of the mountains, where the Mkindo River meets the plains, there are extensive wetlands, part of which have been converted to irrigated rice and sugarcane farms (Figure 3); also see Chapter 4.

Ecological setting

The South Nguru Mountains contain exceptionally high biodiversity amongst the Eastern Arcs Mountains (Menegon *et al.,* 2008) which are an isolated chain of 30 million year old mountains having some of the highest levels of endemism and biodiversity in the world (Myers *et al.* 2000, Burgess *et al.* 2007). Most of the ecosystems in the Ngurus have not been systematically studied (but see Owen *et al.* 2007), and as a result species lists are far from complete. For instance, a recent 2013 expedition to catalogue amphibian, reptile and fish diversity by scientists from the University of Dar es Salaam, University of Dodoma, and the Tanzania iWASH Program recorded several amphibian species that are absent in species lists from the area. Not much published information is available on the wetland ecosystems of Mkindo catchment.

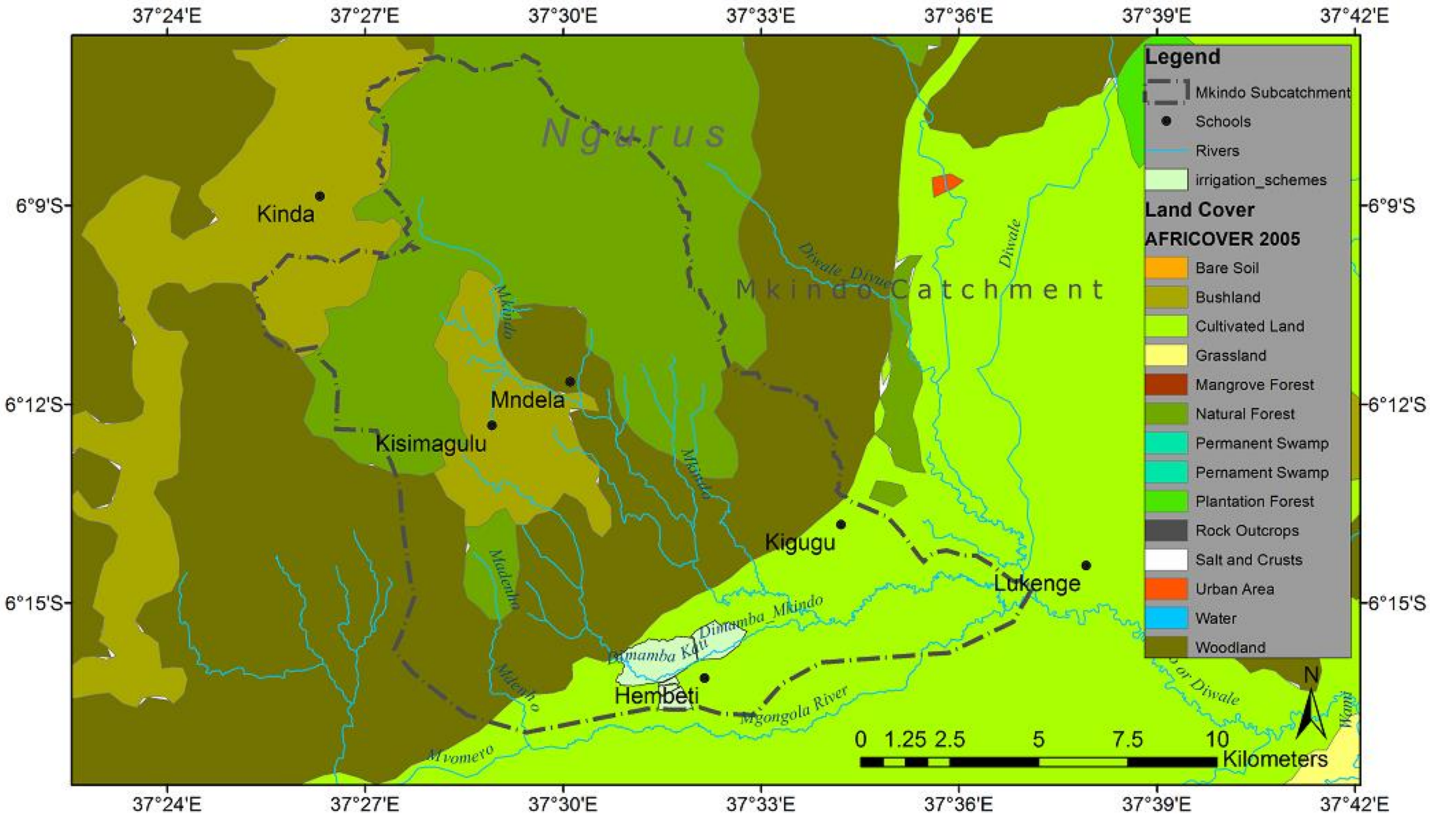

Figure 3: Land cover in the Mkindo River Catchment. The brown boundary line indicates the hydrologically-delineated catchment boundary. [Data Source: AFRICOVER 2005]

The Forest Reserves

The Mkindo River Catchment holds two contiguous National Protection Forest Reserves (FR)[1] - the South Ngurus FR and the Mkindo FR (Figure 4), both situated in the Eastern Arc Mountains. The South Ngurus FR has an extension of 18,792 ha with an elevation between 760-2300 masl, and the Mkindo FR has an extension of 9086 ha with and elevation between 380-1000 masl (Doggart and Loserian 2007). The South Ngurus FR has tropical montane evergreen cloud forests with very high levels of biodiversity and endemism (Owen *et al*. 2007). While the Mkindo FR does not have such a rich biodiversity and species endemism like the South Ngurus FR, it has a major role in relation to the water catchment value for several rivers feeding the Wami River (Bracebridge 2006).

National Protection Forest Reserves are reserved 'for the purposes of protection of water sheds, soil conservation and the protection of wild plants' (Government of Tanzania, 2002). Nguru South FR is managed directly by the Morogoro Regional Catchment Forest Office while Mkindo is managed jointly by the four surrounding communities and the Morogoro Regional Catchment Forest Office; even though, it is intended that all forest reserves will have a management plan only Mkindo FR has one at present. However, despite the legal protection afforded by the Forest Act of 2002 enforcement is weak and sporadic (Menegon, Doggart, and Owen 2008).

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[1] Forest Reserves (FR) fall under the legal authority of central government (National Forest Reserves), local government (Local Authority Forest Reserves), or village government (Village Land Forest Reserves and Community Forest Reserves) and are either designated for production (managed for timber and other productive uses) or protection (managed for water catchment or biodiversity conservation functions). Both, the South Ngurus FR and the Mkindo FR, are Central Government FR (Doggart and Loserian 2007) and are under the category of Catchment Forest Reserves

According to Doggart and Loserian (2007) the following types of threats were recorded within Nguru South and/or Mkindo Forest Reserves: agricultural encroachment including cardamom, banana and yam cultivation in the forest understory and forest clearance for bean and cocoa cultivation; timber harvesting; livestock grazing; pole cutting; firewood collection; hunting for duiker, bush pig, primates, hyrax and other mammals; wild bird and insect collection for trade; gold mining; fire and charcoal production.

Figure 4: (Top) Montane evergreen primary forest in the South Ngurus Forest Reserve. (Bottom) Deciduous woodlands in the lower foothills of the Mkindo River Catchment, part of the Mkindo Forest Reserve.

Social setting

Eight major villages lie in this catchment. Kinda, Kisimagulu and Mndela are located in the highlands (700-1200 masl); Hembeti, Dihombo, Mkindo, Kigugu and Lukenge are located in the lowlands (300 and 500 masl) with Lukenge lying at the confluence of the Mkindo and Diwale rivers (Figure 3). The lowland villages are well connected to Turiani and Mvomero by road. In comparison, the highland villages are more remote: only Kinda can be reached by a four wheel drive vehicle from the northwestern side of the Nguru Mountains via Semwali. Access to the villages of Kisimagulu and Mndela is by foot only. Mobile phones are swiftly providing connectivity to the outside world. Table 1 presents some information on these villages including their conformation (number of sub-villages), population, dominant ethnic group and religion as well as the main public facilities available in these villages, specifically water facilities, schools and health care centers.

These villages are members of the Mkindo Water User Association (WUA) that has been formed recently with support from the iWASH Program and the Wami Ruvu Basin Water Office (WRBWO), to facilitate sustainable water resource management at both community and catchment levels. About 80% of the population farm on small holdings with men mainly producing paddy rice and rainfed maize while women focus more on growing vegetables on small irrigated lots (de Bruin *et al.* 2012). Most of the agriculture is rain-fed while some farmers have access to a gravity-fed small irrigation scheme. Livestock rearing is an important occupation in the lower part of the Mkindo River Catchment. Another large water user in the Mkindo catchment, the Dzungu Sugarcane Farm is also part of the WUA.

Table 1: Major villages in the Mkindo River Catchment, Wami Basin, Tanzania.

Village name	Number of sub-villages	Population	Dominant ethnic groups	Dominant Religion	Water facilities (borehole, taps)	Schools	Health care centers
Mndela	2 (Mndela and Bohelo)	785	Wanguu	Christians	None	1	None
Kisimagulu	4 (Mneke, Kwechiwe, Kisimagulu and Mondo)	3010	Wanguu	Christians & some Muslims	None	1	None
Kinda	5 (Dibuti, Manguwe, Unyasi, Lugombe A and Lugombe B)	1505	Wanguu	Christians	None	1	None
Mkindo	10 (Kitga, Mwedongo, Minazini, Sauduwa, Mtakuja, Bungoma, Kilangawageni, Gulioni, Matola and Kisazile)	6050	Wanguu, Waluguru	Both Christians & Muslims	27	4	1
Hembeti	8 (Mbuyuni, Matenko, Miembekumi, Mkuyuni, Mvuleni, Mpapa, Ndimamba and Rahamati)	4443	Wanguu, waluguru	Both Christians & Muslims	26	4	1
Dihombo	5 (Kwa begi, Mji mpya, Ofisi ya Kijiji, Kigulukilo and Shuleni)	4193	Wanguu, waluguru	Both Christians & Muslims	5	3	None
Kigugu	9 (Mvereni, Barabarani Msene, Chazi, Bogolwa, Shuleni, Misajini, Ndizungu and Kiungwi)	3059	Wanguu, Waluguru	Both Christians & Muslims	5	2	None
Lukenge	3 (Kitongojii A, Kitongoji B and Songambele)	2962	Wanguu, Waluguru	Both Christians & Muslims	12	2	1

3. Climate of the Mkindo River Catchment region

The following chapter presents the current climate of the Mkindo River Catchment. Specifically, temperature and precipitation data is provided, as well as the role of the Eastern Arc Mountains, and other regional phenomena (the El Nino Southern Oscillation and the Indian Ocean Dipole) in determining these patterns. A second section discusses climate projections in terms of precipitation and temperature for the Mkindo River Catchment.

3.1. Current climate

The location of the Mkindo River Catchment in the tropics leads to a uniform day length over the year, but with pronounced rainy and dry seasons. The temperature regime in the humid lowlands is fairly constant throughout the year, with the diurnal temperature variation exceeding the seasonal variation, as seen in Figure 5 for Turiani, the closest town to Mkindo catchment. However, the Nguru Mountains experience a range of temperature regimes, depending on the elevation and aspect (direction). Thus, evening and night temperatures in the highland villages can 10 °C lower than lowland villages just a few kilometers away but 500 or more meters below. Villages in the higher reaches, such as Kinda (altitude ~1200 masl) also face windy conditions during the day that also adds to wind chill.

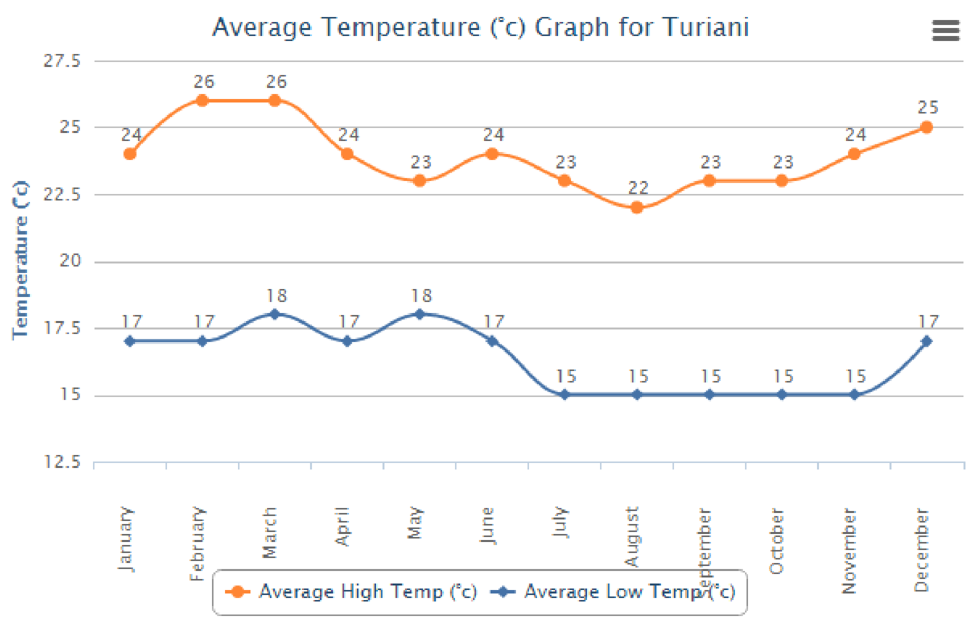


Figure 5: average temperature in Turiani. [Source: World Weather Online]

Precipitation regime

The upper reaches (900 ~ 1500 masl and possibly higher) on the windward side (eastern side) of the Nguru Mountains are visited by clouds almost all throughout the year (Figure 6). These clouds are formed by the adiabatic cooling of moisture-laden winds, coming from the Indian Ocean and intercepted by the mountains. There still exists a significant amount of primary forest on these cloud-shrouded slopes (ISCN 2010); the forest canopy intercepts a large amount of moisture from clouds and rainfall, as do tropical montane forests worldwide (Bruijnzeel 2001). The upper slopes of the Ngurus receive the highest rainfall in the Mkindo River Catchment, as the entire Catchment lies on the windward side of the Ngurus. The South Ngurus FR was awarded a protected status as it is considered to be one of the major watersheds of the Wami River supplying water to the Chalinze water treatment plant, the Mtibwa sugar farm, and other localities (Menegon, Doggart, and Owen 2008).

Figure 6: Clouds shroud the upper reaches of the Nguru Mountains.

Annual average rainfall in the catchment region is spatially displayed in Figure 7, while Figure 8 shows long-term monthly rainfall averaged over the period 1950-2011[2]. As shown in both figures, the Nguru Mountains receive much higher rainfall than the lowlands. This trend is commonly observed in the Eastern Arc Mountains (e.g. Munishi and Shear 2005), which are thought to have experienced moist conditions for millions of years due to proximity with the Indian Ocean while much of the surrounding region (and most of sub-Saharan Africa) has undergone several drying regimes over these epochs (e.g. WWF 2014). At lower altitudes (< 800 masl) the annual rainfall decreases, much of it falling between March-May (*masika* rains), with some in December-February (*vuli* rains). June to September is the dry season. The leeward side of the Ngurus receives much less precipitation, as mentioned by locals from Kinda village that straddles the catchment divide (personal communication).

These precipitation patterns influence the natural vegetation of the area; moist evergreen forests occupy regions with the highest rainfall (east-facing slopes) while areas with lower rainfall, such as the lower elevations and the leeward (western) faces of the Ngurus, have deciduous forests ranging from moist deciduous forest to thorny acacia woodlands near Pemba (ISCN 2010, personal obs.).

Influence of regional climate on precipitation

Rainfall in the Mkindo River Catchment is generated from the moisture-laden trade winds blowing in from the Indian Ocean. These winds result from differences in atmospheric pressure influenced by sea surface temperatures and ocean currents that in turn have an inter-decadal variation in intensity and direction. The ENSO (El Nino Southern Oscillation) and the IOD (Indian Ocean Dipole) are the climate teleconnection patterns with the greatest influence on Tanzania's rainfall (Liu *et al.* 2011). These teleconnection patterns result in periods of higher than usual rainfall alternating with low rainfall years every 7-15 years (GLOWS-FIU 2014a) as noted over the latter half of the 20th century. The frequency of this variability is becoming more uncertain. This has been associated with increasing concentration of greenhouse gases in the atmosphere. These effects add to other sources of uncertainty in regards to rainfall predictions.

[2] Note that there is just one rainfall station in the Ngurus at Mhonda and there are no rainfall stations within the Mkindo River Catchment. The rainfall averages were obtained using data of surrounding areas.

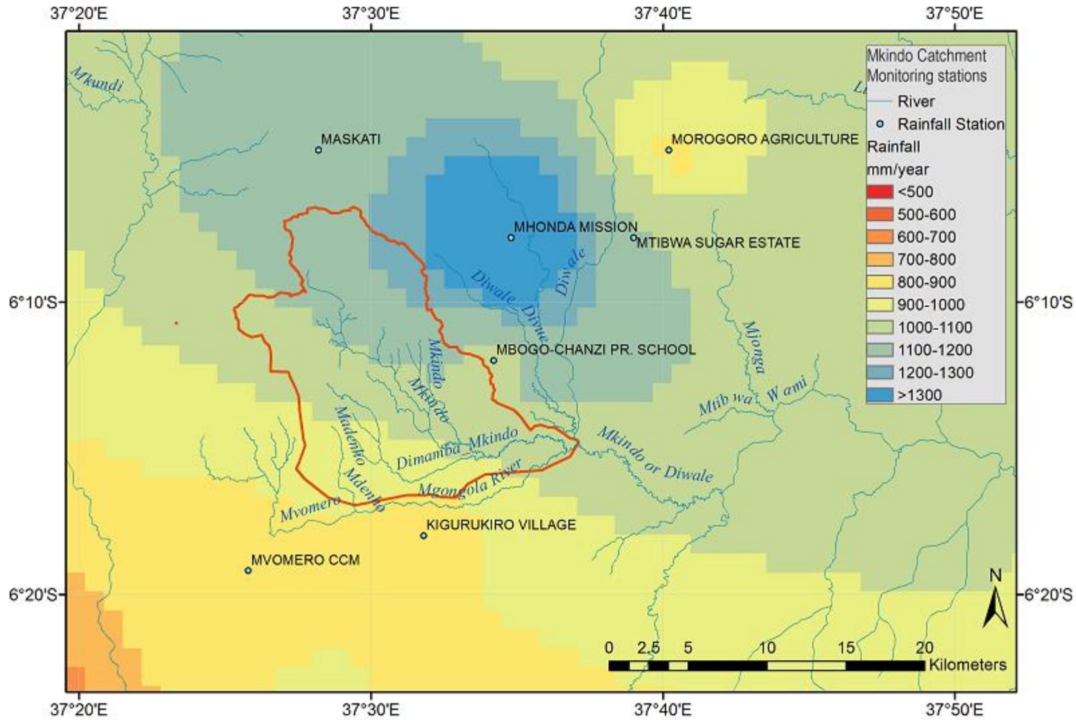


Figure 7: Annual rainfall isohyets averaged over the period 1950-2010 and rainfall stations in the region of the Mkindo River Catchment (boundary shown in orange) that are operated by the Wami/Ruvu Basin Water Office. [Data Source: WRBWO]

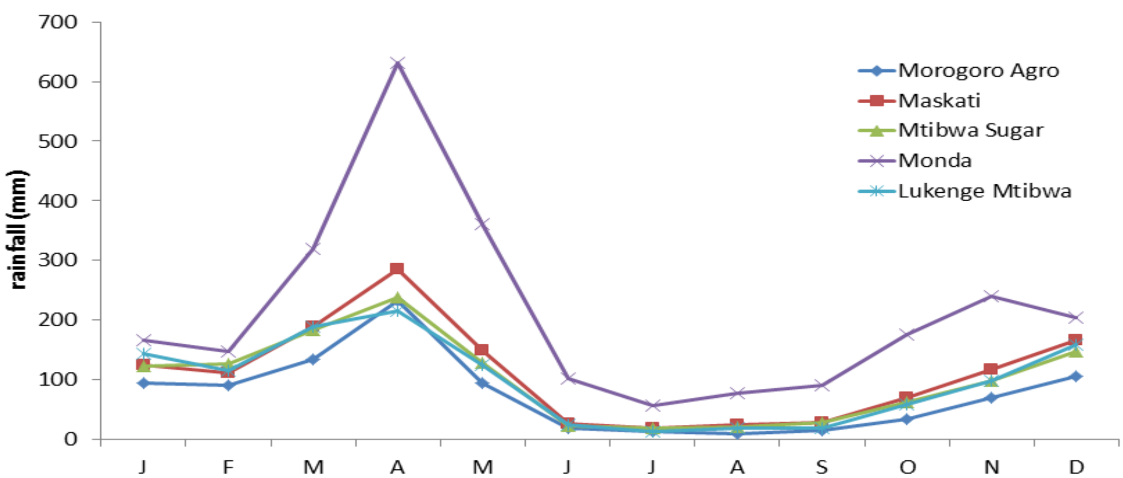


Figure 8: Monthly rainfall averaged over the period 1950-2010 in 5 stations around the Mkindo River Catchment region. [Data Source: WRBWO]

3.2. Climate projections

The increasing concentration of greenhouse gases in the atmosphere has been changing the atmosphere-biosphere energy balance with resulting cascading effects on temperature, pressure and ocean/wind currents affecting local climatic patterns (IPCC 2007). Predictions for the Wami/Ruvu Basin include an increase in temperature by 2-4°C over the 21st century (GLOWS 2014a), and an increase in the uncertainty of rainfall – both the timing of rainfall onset and rainfall distribution over the season. Box 1 briefly describes the process used for generating these predictions.

Precipitation projections - uncertainty

Figure 9 shows that the existing pattern of higher annual rainfall in the Eastern Arc Mountains, as compared to the surrounding lowlands, is likely to continue over this century. However, the sheer complexity of the interconnections between different pressure systems, energy storages/transfers and physical topography imparts a great deal of uncertainty in rainfall predictions[3]. The dependence on rainfall upon climatic factors, as discussed earlier, can result in greater uncertainty and inter-annual variability on the onset of the rainy season and rainfall amount. This has large implications for planting crops, as well as production rates in the case of rain-fed agriculture. Rainfall may also become less evenly distributed with a few intense events coupled with longer dry spells in between. Intense rain events can cause flash floods and bank erosion.

Box 1: Methodology for climate projections

General Circulation Models (GCMs), also called Global Climate Models, constitute the foundation of climate prediction (Jack 2010). These models divide the earth's surface into a grid, typically at 2.5 degree latitude by 2.5 degree longitude. For each grid cell, models perform an energy balance by considering net solar radiation, wind speed, relative humidity, temperature, and different greenhouse gas concentrations that trap heat. This allows forecasting climate (temperature, precipitation, ET) under different greenhouse gas emission scenarios (IPCC 2000). These results are uniform over the grid cell, a large area (typically 300 by 300 km), and actually work better at larger scales such as 500-1000 km (Jack 2010). However, such a large area can have big differences in climate. Therefore, in order to capture climate variability within such a large area, the model outputs have to be scaled down to include local factors that affect climate, including topography and land cover, by a process termed downscaling. Most human activities such as agriculture and water resources management occur at scales far smaller than a 300 km grid. Hence, downscaled climate predictions, even at a 50 km resolution, must be looked at as an average for a 2500 sq km area that glosses over local (topography-related) differences in climate that may exist (USAID 2007). Downscaling further to 10-15 km grids requires local met and hydrological data for calibration; this is often unavailable.

For this study precipitation and temperature projections were obtained using 16 GCMs under the A2 greenhouse gas emission scenario downscaled to 50 km resolution from the native 300*300 resolution of GCM using Climate Wizard (GLOWS-FIU 2014a).

In general, the Mkindo River Catchment is very fortunate to have a perennial source of water, in terms of the clouds that condense on the mountaintops, feeding streams, springs, and rivers year-round, as well as the presence of wetlands at the base of the Nguru Mountains that store water. However, there can be years with low rainfall in association with ENSO and IOD, especially if these two major climate teleconnection patterns happen to occur in tandem. Furthermore, as it will be discussed, there is potential of cloud coverage decrease caused by both global climate change as well as regional climate change as a consequence of extensive deforestation.

[3] A higher annual rainfall in the Eastern Arc Mountains was forecasted by the model. This forecast can be partly an artifact of the models' calibration and downscaling routines that use past weather data and orographic condensation processes. However, the scale of predictions at the 50 km grid is too coarse to describe rainfall predictions for the Mkindo River Catchment, which has a much smaller area. Indeed, the predictions do not display the high rainfall that occurs in the eastern Ngurus. It is to be borne in mind that there is an extremely high uncertainty in rainfall prediction, given the sheer complexity of coupled regional weather systems.

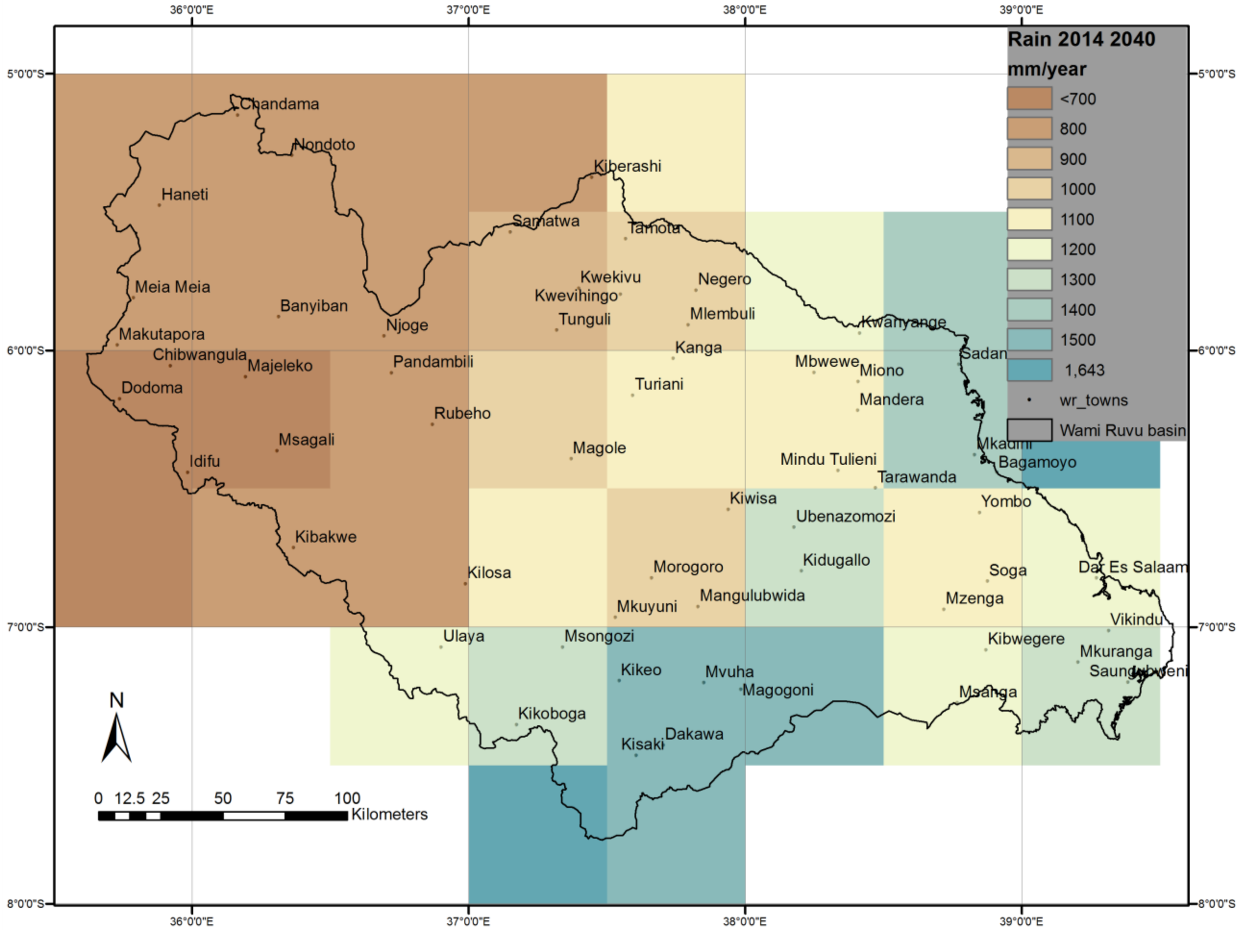


Figure 9: Precipitation projections for Wami/Ruvu Basin (2014-2040) at a 50 km grid. [Data Source: ClimateWizard]

Temperature

Almost all GCMs predict a rise in average annual temperature of 2-4°C over the present century (Figure 10, GLOWS-FIU 2014a). Apart from causing changes in weather patterns at various scales from global to local, changes in the average temperature regime also alters the ecosystem structure (species shifts) and function (production, decomposition, and biogeochemical cycling), and has been associated with pest and disease outbreaks, fires and increased severity of droughts. As an example, the spread of mosquito-borne illnesses to higher elevations that were previously free of such diseases has been recorded (e.g. Siraj *et al.* 2014) in tropical highlands on several continents. The higher elevations of the Mkindo River Catchment are currently malaria-free.

Models simulating a doubling of greenhouse gases have shown that a 1°C rise in annual temperature can considerably decrease the cloud base in tropical cloud forests. Giambelluca and Gerhard (2011) review evidence of shrinking cloud bases (area in the mountains that is usually covered in cloud) in tropical montane forests in various parts of the world. According to this review, the lower boundary of cloud forests (Lower Condensation Limit - LCL) is shifting higher up due to regional warming, while the upper boundary of the condensation zone (the upper boundary of cloud forests) is shifting down by the lowering of the Trade-Wind Inversion (TWI) which defines the upper limit of orographic condensation. This shrinking of the condensation zone results in lesser moisture available to cloud forests with attendant negative effects on hydrology and species diversity. Bruinjzeel (2001) reviews a large number of studies observing reduced dry season flows due to reduction in tropical montane forest cover in the Neotropics and Southeast Asia. For instance, the LCL has been seen to shift upwards in Costa Rican tropical montane cloud forests as a consequence of the local climate effects of regional deforestation in Central America (Lawton 2001).

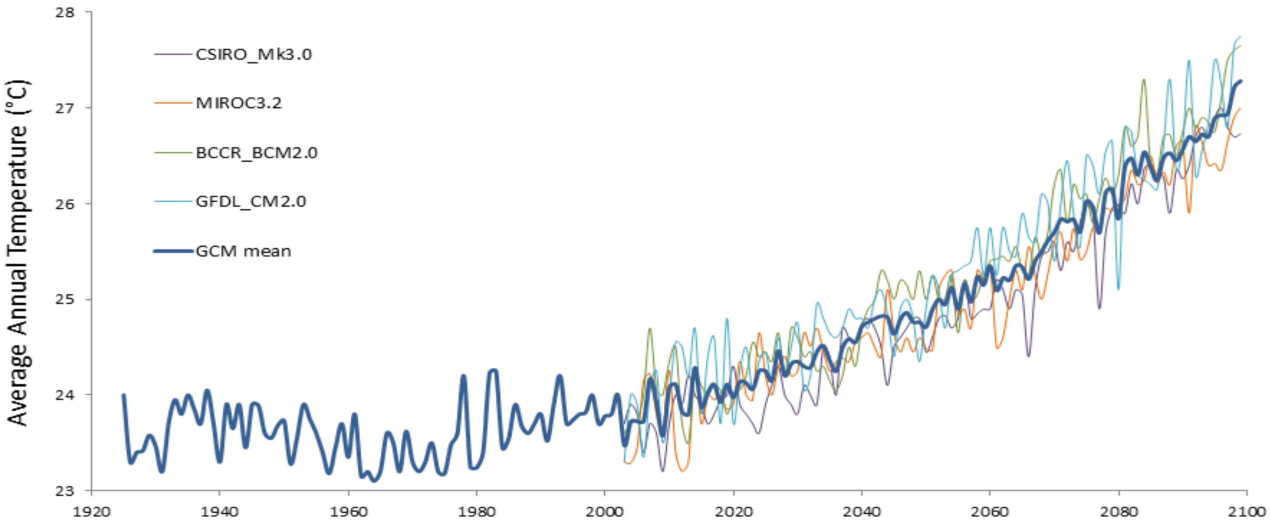


Figure 10: Past and projected annual mean temperature for the Wami/Ruvu basin by 4 GCMS. [Data Source: ClimateWizard]

4. Land cover change in the Mkindo River Catchment (2000-2012)

4.1. Forest cover, soil erosion, and water harvesting

The availability of water in a watershed not only depends upon incident rainfall but also on the presence of forest cover. Native tropical evergreen cloud forest that occurs typically above 1100 m in the Ngurus has a thick interwoven canopy with moss, lichen and epiphyte-covered branches that trap moisture from clouds present year-round (eg. Bruijnzeel and Hamilton 2000). Rainfall is similarly stored; the canopy and thick leaf litter layer on the ground intercept and store a large fraction of rainwater which then infiltrates through the soil and recharges the groundwater. Groundwater is the source for springs and streams. The canopy and litter layer also protect the soil from erosion. Removal of forest cover has been thus linked to greater runoff during rains and earlier drying up of springs and streams in the dry season (Bruinjzeel 2001). The foothills in the Mkindo River Catchment have deciduous woodlands (Figure 4 bottom), part of which is a gazetted forest reserve (Mkindo Forest Reserve). While these forests lie below the cloud base, these forests also promote groundwater recharge by interception and infiltration as well as maintain water quality by minimizing soil loss from the region.

Another factor influencing water availability and quality is soil erosion. Soil has an important role in regulating the drainage, flow and storage of water and organic and inorganic compounds (i.e. nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water) (USDA-NRCS nd). Soil erosion increases water runoff, thus decrease water infiltration and the water storage capacity of the soil; furthermore, during the erosion process organic matter and nutrients are removed from the soil ending up in water courses increasing their turbidity, therefore affecting not only water quality but also land productivity (Pimentel 2006). Furthermore, the soil washed off enters streams and the heavier fractions settle down on the streambed, covering rocks and the gaps between rocks that are the habitat for aquatic macroinvertebrates (insect larvae) that form the prey base for fish as well as breakdown organic litter in streams. Sedimentation of the river bottom also decreases the channel depth that increases the risk of the river breaching its banks and constituting a flood hazard (USDA-NRCS nd). Surfaces with steep slopes are the parts of a catchment that are the most vulnerable to soil erosion, especially following the loss of the forest cover. In this sense, considering the geography of the Mkindo River Catchment and the current situation in relation to deforestation, it is pertinent to assess the areas that possess higher risk for soil erosion in the catchment.

Keeping in mind these factors that can be affecting water quality and quantity at the Mkindo River Catchment , this chapter looks at the changes in forest cover in the Mkindo River Catchment area over the period 2000-2012, maps are presented indicating forest cover loss and forest cover gain in the Catchment and surrounding areas. Additionally, a slope analysis of the catchment is performed in order to identify those areas in the catchment that are more susceptible to soil erosion.

4.2. Forest cover change in the Mkindo River Catchment and surrounding region

Figure 11 indicates the extent of forest cover in the Mkindo River Catchment in the year 2000. Most of the intact forests are part of the South Nguru Forest Reserve in the upper slopes (tropical montane cloud forest) and the Mkindo Forest Reserve in the lower slopes between the villages of Mndela and Mkindo (lowland montane and moist deciduous forests). In addition, riparian gallery forests adjoining rivers can be seen on this map. Anecdotal information from village elders indicates that a greater area in the surrounding hills was under forest cover than currently. A lot of the forest that does not have protection of being a forest reserve has been cleared for hill agriculture over the latter quarter of the 20^{th} century; this has been the case overall the Eastern Arc Mountains (Forestry and Beekeeping Report 2006). In this section maps that show forest cover loss and forest cover gain in the Mkindo River Catchment and surrounding areas are presented. Box 2 presents the methodology used to obtain these maps.

Box 2: Methodology used to develop the forest cover maps

The maps have been made from a supervised classification of Landsat images and time series analysis over the period 2000-2012 (Hansen *et al.* 2013). The analysis defined trees as all vegetation taller than 5m in height. Vegetation cover is expressed as a percentage per output grid cell as '2000 Percent Tree Cover', categorized as 25-50, 50-75 and >75 %. Each 30m * 30m pixel that has lost most of its forest cover is shown in red while forest cover gains are shown in blue. 'Forest Loss' is defined as a stand-replacement disturbance, or a change from a forest to non-forest state. 'Forest Gain' is defined as the inverse of loss, or a non-forest to forest change entirely within the study period. The graphic result are discussed using information gathered during the fieldwork, including informal talks with local actors as well as visual registration (photos) to better illustrate the processes that are occurring.

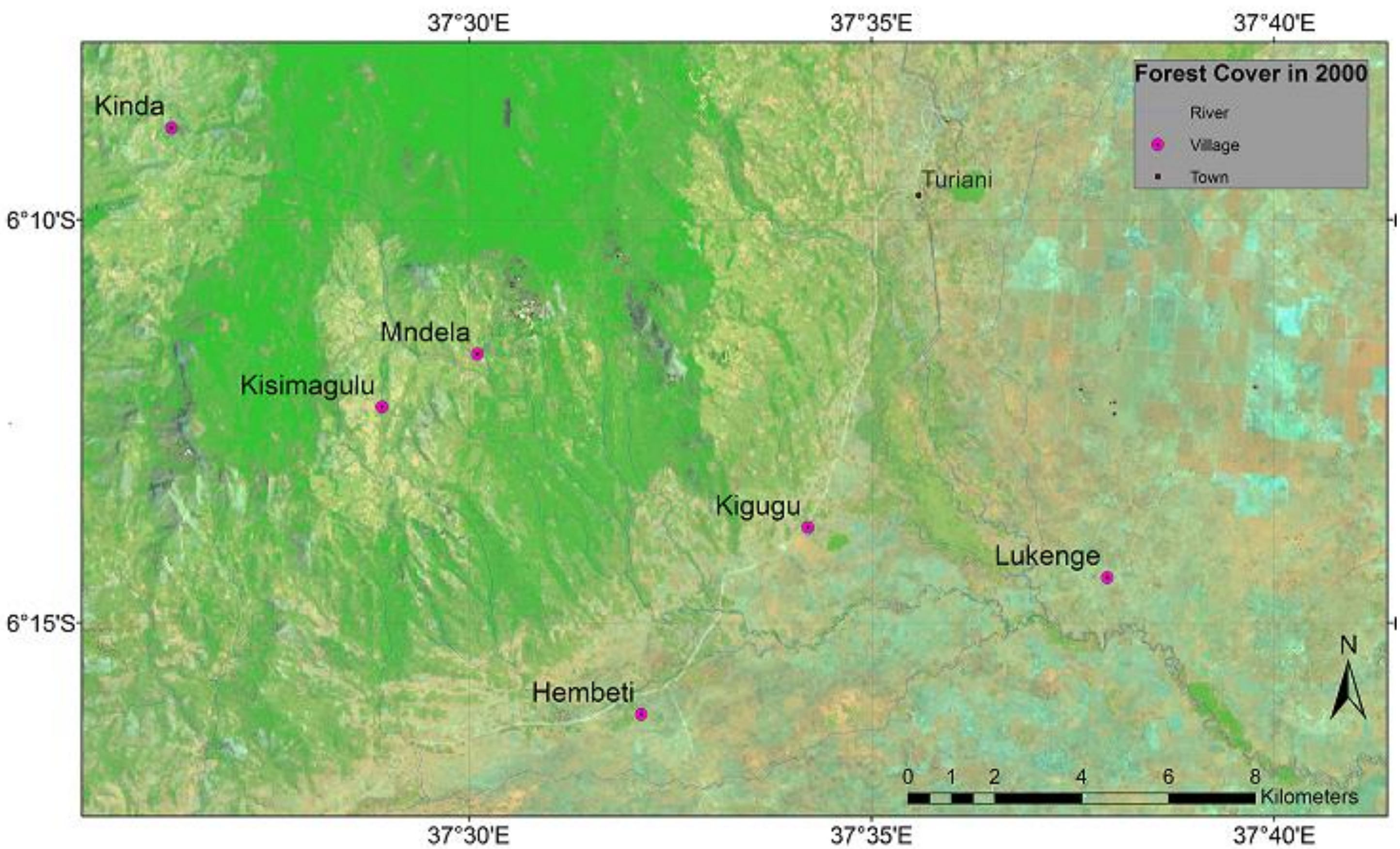


Figure 11: Forest cover in the year 2000 in the Mkindo River Catchment shown in green against a Landsat image (Bands 4, 5 and 7). [Data Source: Hansen *et al.* 2013]

The maps for land cover loss and gain have geographical coordinates added to enable geo-referencing these locations. These locations can then be visited by field teams developing adaptation strategies for verification, investigation of the possible causes, and finally to devise possible ways to restore and safeguard these forests for water and soil harvesting.

Forest lost in the Catchment and surrounding areas

Figure 12 indicates forest cover loss (2000-2012) for the Mkindo River Catchment and surrounding region including Mtibwa Sugarcane Estate. The largest amount of deforestation in the region has occurred in the lowlands east of the Ngurus and the Mkindo River Catchment. The natural vegetation in this area is mainly *miombo* (*Brachystega*) woodlands that have been witnessing widespread branch and tree cutting for charcoal manufacture and export to urban regions. In comparison with the lowlands, the Mkindo River Catchment has experienced lower forest loss over the past decade. This is on account of the protected forest reserve status of a large extent of the forests in the Mkindo River Catchment and Nguru Mountains which provides some impediment to random forest clearance. However, illegal tree-felling also occurs inside forest reserves (Forestry and Beekeeping Report 2006, Braceridge 2006, personal observation).

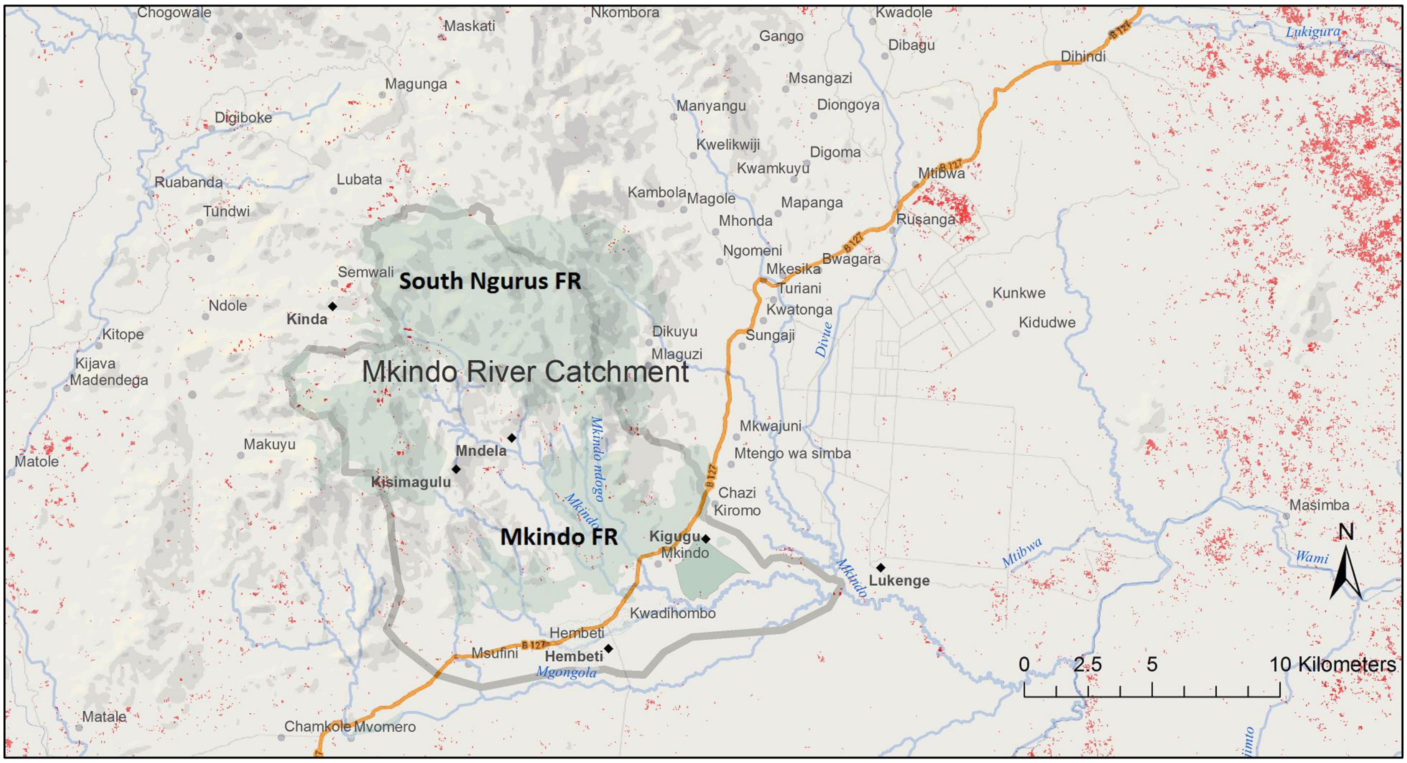


Figure 12: Forest cover loss over 2000-2012 in the Mkindo River Catchment and surrounding region shown in red at a 30m resolution, the green shaded area indicates the forest reserves. [Data Source: Hansen *et al.* 2013]

Figure 13 shows the deforestation in the upper and lower Mkindo River Catchment. As seen by the red dots in the map, deforestation has occurred outside the forest reserves areas and, in some places, inside the Forests Reserve.

While the highest reaches and steep slopes in the Mkindo River Catchment still have forest cover, the middle elevations (600-1200 masl) currently have a mosaic of cleared forest for agriculture, forest patches and abandoned land where the soil has eroded away (Figure 14 and Figure 15). Land cleared for agriculture is typically farmed for less than 10 years (personal communication), during which time soil is eroded away on account of lack of effective soil conservation. Thereafter it is abandoned. In some cases, vegetation succession occurs leading to secondary forest usually within 20-30 years. However, not much soil remains following farming on steep slopes (slope > 45 degrees), precluding forest re-establishment.

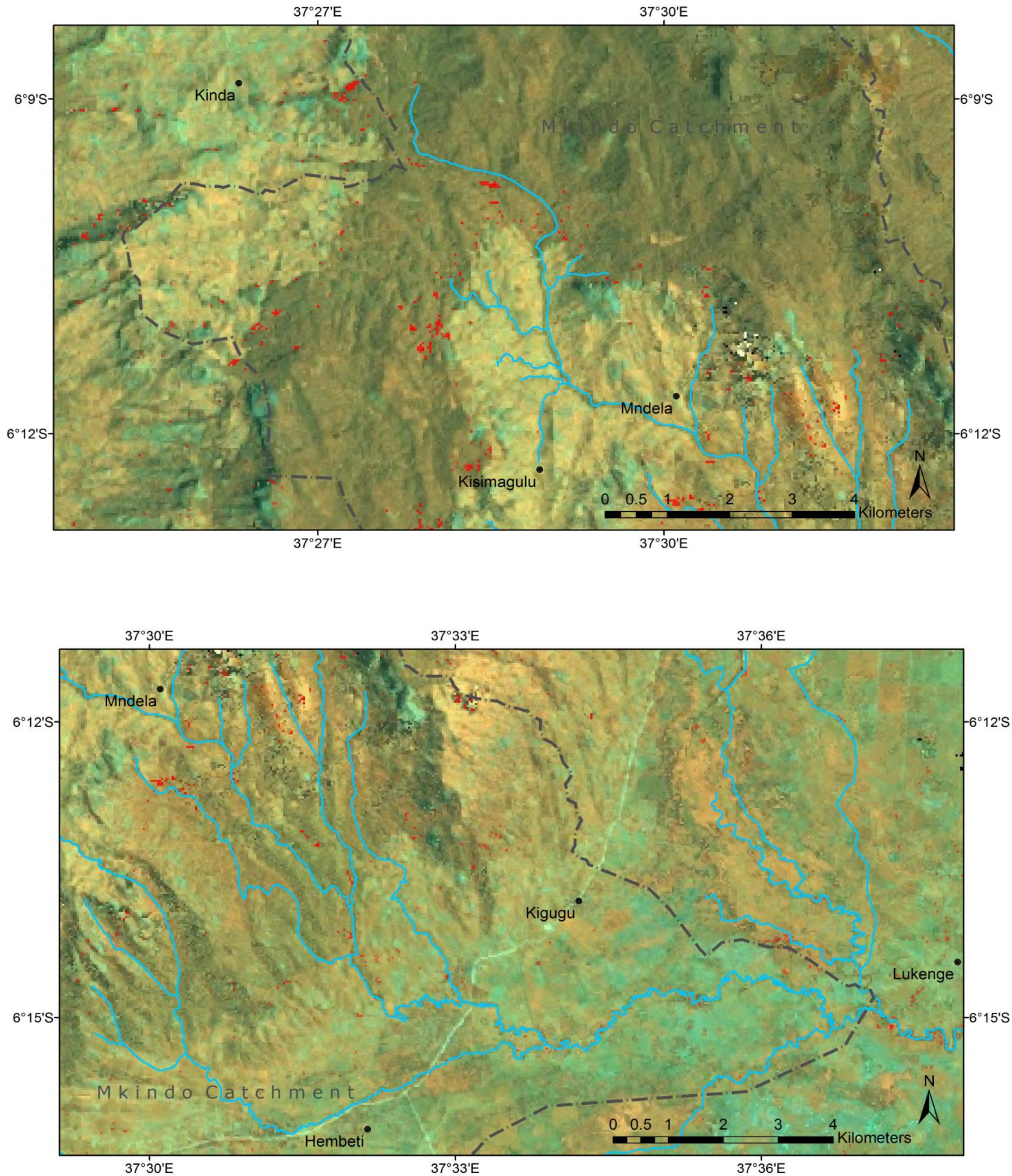


Figure 13: Shown in red forest loss in the Upper Mkindo River Catchment (Top) and Lower Mkindo River Catchment (Bottom). Each pixel represents an area of 30 m * 30 m on the ground. [Data Source: Hansen *et al.* 2013]

Figure 14: (Top) A mosaic of primary forest, cleared land, maize farm (right foreground) and abandoned farm (left with weeds) in the Ngurus ~ 1200 masl. (Bottom left) Deforestation up to the edge of the Forest Reserve with stands of primary tropical montane cloud. (Bottom right) charcoal bags ready for pickup by local transport at the side of the road.

Deforestation has occurred right up to the margins of forest reserves in many parts of the Ngurus mainly for agriculture (Figure 14 bottom left). The lack of terraces or any other soil conservation mechanism is causing severe soil erosion. Figure 14 (top) shows secondary forest on the left, cornfields in the center and abandoned farms on the right with the presence of furrows and gullies, signs of advanced soil erosion.

Charcoal manufacture is another major activity underpinning deforestation, greatly accelerated by urban growth and continued dependence on forest products (Ahrends *et al.* 2010). Figure 14 (bottom right) shows charcoal bags ready for pickup by local transport, an increasingly common sight. While charcoal provides an affordable source of fuel and income to village communities, there is a real danger of forest degradation and with it, loss of essential water harvesting ecosystem services, valuable topsoil, biodiversity and future fuel reserves.

Clear-cutting primary montane forest for agriculture results in heavy soil erosion accompanying torrential rainfall characteristic of these mountains (Figure 15). Anecdotal evidence suggests that once a forest is cleared, the soil is washed away within a decade and the farm is then abandoned. Figure 15 (bottom left) shows a silt-laden stream in a deforested catchment (about 1250 masl). Mud deposits on the stream bottom choke and cover stones, thereby wiping out habitat for the larvae of aquatic insects that maintain water quality and also constitute prey for fish and other organisms. In a forested catchment, the stream would be expected to have a rocky bottom without the layer of deposited sediment.

Figure 15: (Top) Deforestation for agriculture on steep slopes of the Nguru Mountains near Pemba with subsequent soil erosion and formation of furrows visible on the right side of the photograph. (Bottom left) Silt-laden stream in the Ngurus Mountains characteristic of widespread deforestation. (Bottom right) Mud deposited on the riverbed (Note the footprint on the left bank).

Illegal gold mining

Gold mining usually involves diverting a mountain stream and intensely excavating the streambed using diesel-powered pumps to wash away the sediment (personal obs - Figure 16). This completely destroys the stream ecosystem as well as the adjacent riparian ecosystem and disrupts downstream hydrology and water quality, not just with excess sedimentation but also with toxic compounds such as mercury used to amalgamate the gold fines. Miners depart leaving behind pits 2-3 m deep, that fill up with stagnant water that can give rise to a host of public health issues, such as providing sites for mosquitoes to breed that otherwise are not common in hill environments. While miners are often armed and hence direct confrontation is not desirable, a reporting system between villages and government authorities can spur enforcement action. In addition, the rehabilitation of abandoned pits and streamcourses is very necessary to restablish hydrology and recover water quality and the ecosystem in an accelerated manner.

Figure 16: Excavation for gold mining on a streambed in the Nguru Mountains whose flow was diverted upstream. A gold miner's temporary hut can be seen in the background.

4.3. Forest gain in the Catchment and surrounding areas

While forest loss has been the dominant trend over the past decade in the Wami River Basin (GLOWS-FIU 2014a), an increase in forest cover is seen in the Ngurus (blue pixels in Figure 17). These blue areas can indicate reforestation projects as the one near the Kisimagulu village. It should be noted that, while reforestation projects (Figure 18) provide renewable fuel/fodder/timber resources and income sources to village communities and resist soil erosion to an extent, their effect upon the hydrological cycle differs from primary native forests (eg. Krishnaswamy *et al.* 2012). Primary forests have a greater amount of rainfall interception, infiltration and soil retention than monoculture plantations on account of their thicker, multilayer canopies, and well-developed organic soil horizons. Still, reforestation provides a degree of protection against soil erosion, and builds up a soil organic horizon over time.

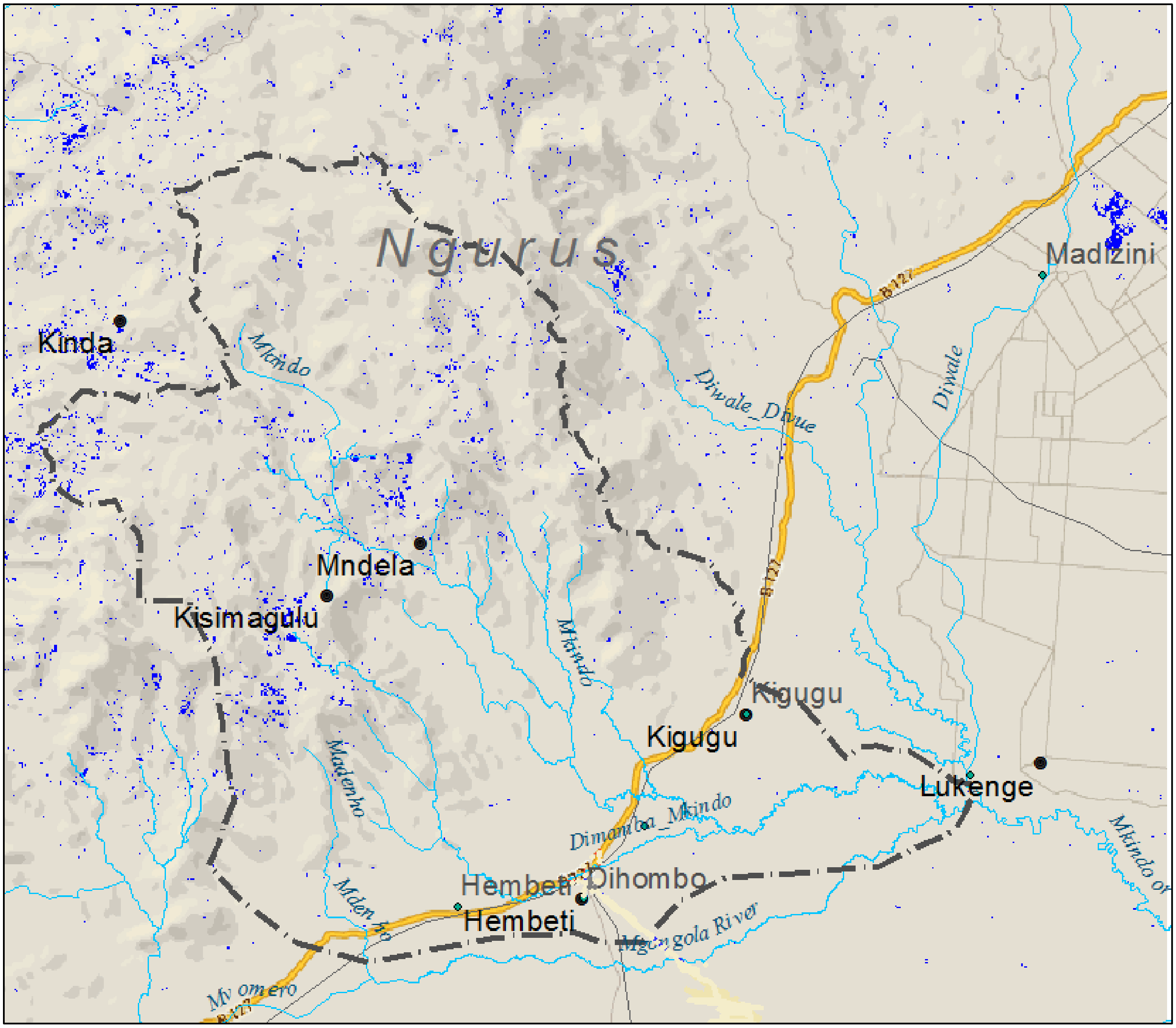


Figure 17: Forest gain (blue) in the Mkindo River Catchment, 2000-2012. [Data Source: Hansen *et al.* 2013]

Figure 18: Reforestation in the Ngurus Mountains with fast growing single-species plantation.

4.4. Soil erosion and slope analysis in the Mkindo River Catchment

Soil erosion has an array of negative consequences on natural resources, human livelihoods, ecosystem function and natural disasters (Pimentel 2006). Soils on hillslopes are typically thin and easily lost following the removal of vegetative cover. The lack of soil conservation measures such as terraces and contour bunds leads to soil being lost from the watershed that in turn leads to the abandonment of cultivation. Forest regeneration on surfaces stripped off soil can take centuries.

Box 3: Methodology for the slope analysis

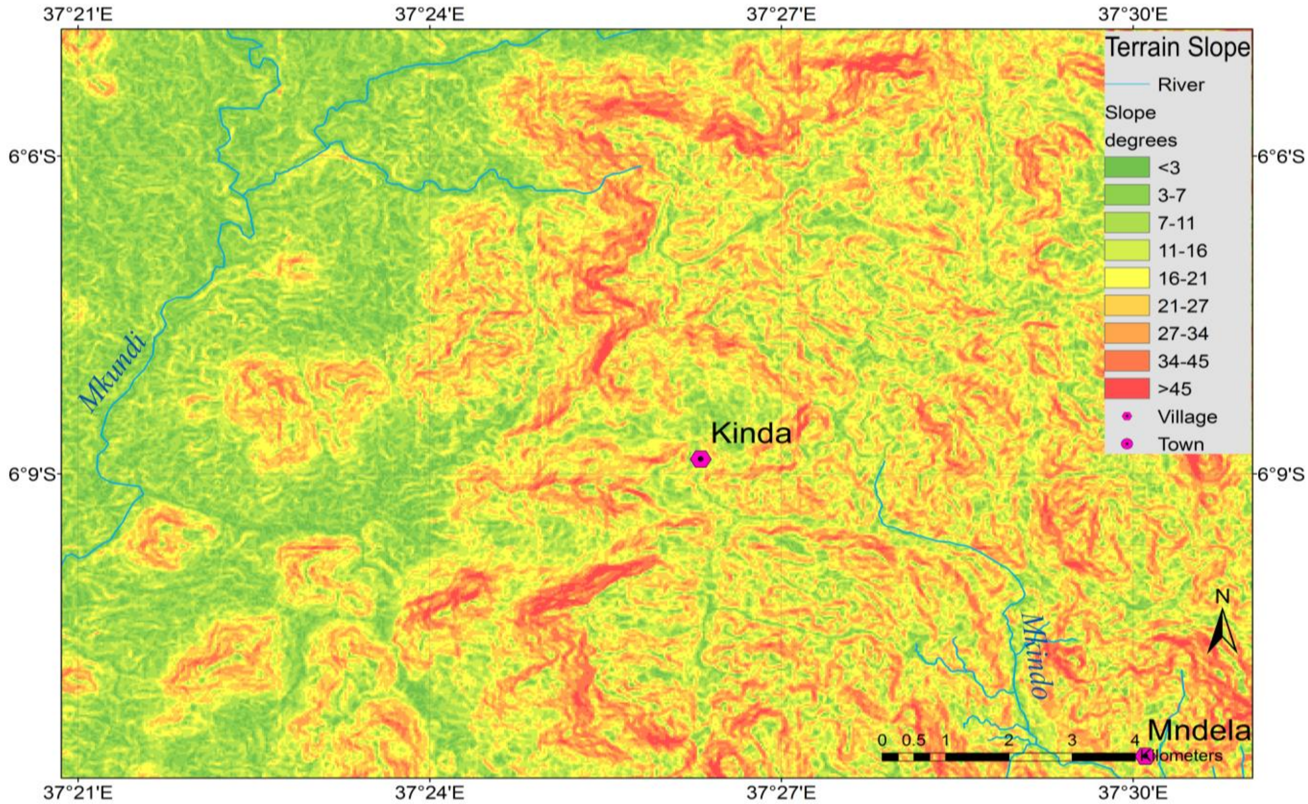
This section presents maps created by performing topographic slope analysis. The maps depict the slope of each location, and thus indicate the zones with the steepest slopes. A value of 1 referred to 45 degrees slope, with higher values for higher slopes until a slope of vertical or 90 degrees results in an infinite value. Maps are created with slope value for each pixel (as opposed to elevation in the case of an elevation map). In addition, the analysis creates a .tif image of the entire catchment which can be loaded in ArcMAP and zoomed in to obtain geospatial coordinates (lat-long or UTM) of specific areas that can then be used by field personnel equipped with a handheld GPS to locate these areas in the field.

Terrain analysis was performed using the SLOPE function included in the Surface toolset of the Spatial Analyst Toolbox (ArcGIS 10.2, ESRI, Redlands, California, USA), following the method of the determination of the steepest slope for each pixel in the Digital Elevation Model (ASTER DEM 30m) from the 8 neighboring pixels (Burrough and McDonnell 1990). Slope was calculated in terms of the tangent of the degree (rise over run), with values ranging from zero (level terrain) to infinity (vertical).

Usually, the steepest slopes are the last to be cleared for farming on account of being rocky and not having adequate soil for cultivation, for the difficulty of access, and the rapid instantaneous drainage of water. Most of the steeper slopes in the Ngurus are thus still forested, and in the upper reaches of the valley, have been protected as forest reserves for water harvesting. However, and as observed during the field visit, the pressures of a growing population are resulting in the extension of farming right up to the borders of reserve forests.

In this analysis, slope maps were produced that can be used to identify the areas with steep slopes. Box 3 gives an overview of the methodology used. Usually 45 degrees is considered as a bottom cut-off for a slope to be considered steep, although the erosion potential depends upon other variables such as forest cover, rainfall, and geographic orientation. These maps can be used in field visits along with village communities, to identify the slopes and areas, assess the forest cover and signs for soil erosion and discuss the threats and issues that may have led to degeneration of an area. Options can then be discussed with the community as how to safeguard these areas for protection of tree cover, reforestation, soil and water conservation measures.

Figure 19 shows the slope map of the headwater and the lower mountainous part of the Mkindo River Catchment. Steep slopes (> 45 degrees) are shown in red. These maps can be used as an aid to the identification of the steep slopes in the vicinity of each village included in this study. Annex 1 shows the map for the entire Mkindo River Catchment, showing the Ngurus and the flat lowlands. In addition to the maps presented in this report, the slope map of the Wami/Ruvu Basin is available as a high resolution .png file that can be opened in any picture viewer, zoomed in and printed. The map is also available as a .tif file that can be loaded into ArcGIS or the Digital Atlas of the Wami/Ruvu Basin (http://glows/fiu.edu) and zoomed in as desired to create new maps or to obtain geospatial coordinates for any particular area.



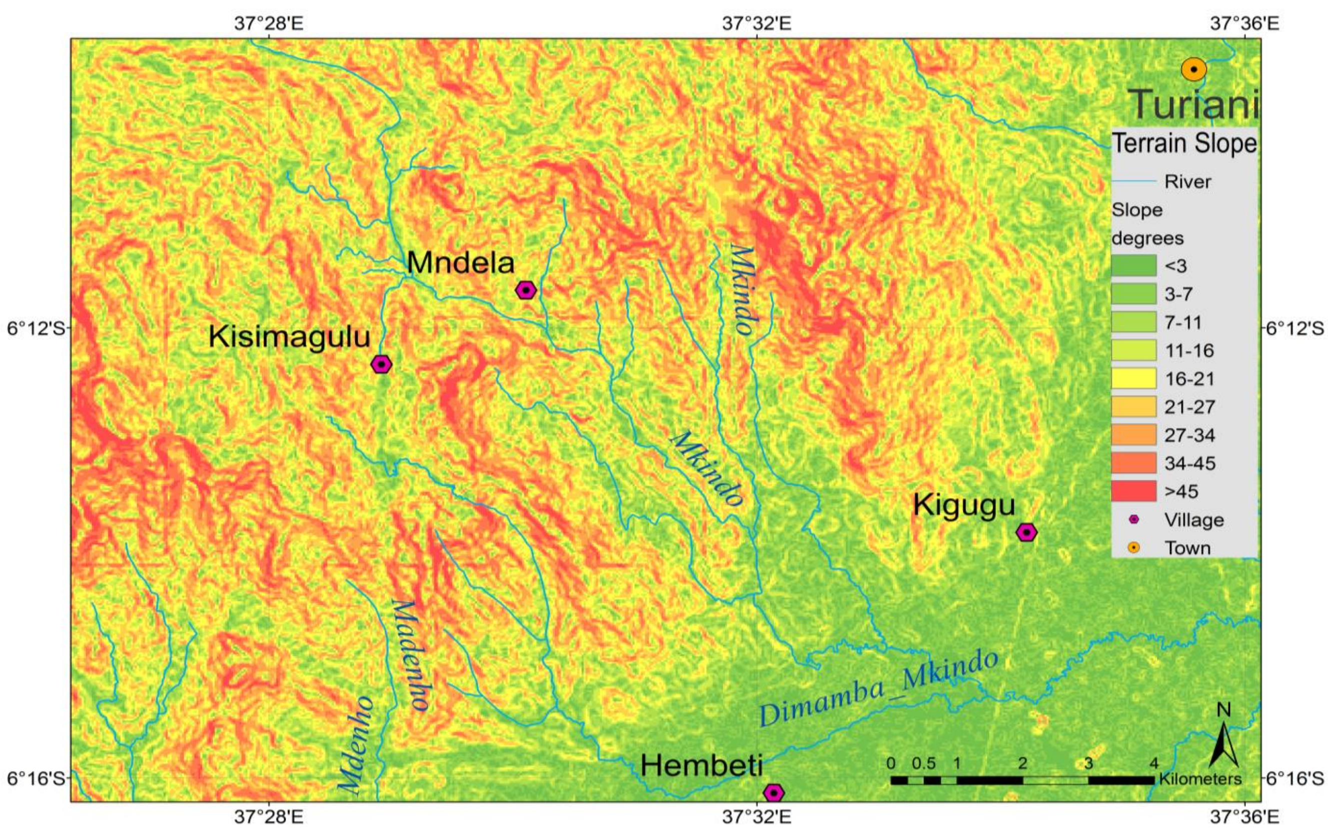


Figure 19: (Top) Slope map of the headwater mountainous part of the Mkindo River Catchment. (Bottom) Slope map of the lower mountainous part of the Mkindo River Catchment. For both maps steep slopes (> 45 degrees) are shown in red

4.5. Wetlands in the Mkindo River Catchment

Wetlands play an important role in regulating water flow in catchments, flood control, groundwater recharge, retaining excess sediments and nutrients and other organic and inorganic compounds, thereby cleaning the water. They also constitute highly productive ecosystems by providing habitat for flora and fauna and accelerating biogeochemical cycling (eg. Mitsch and Gosselink 1993). Lowland areas in the Mkindo catchment have extensive wetlands arising from a combination of soil type and the large amounts of water harvested by the Ngurus that flows down perennially in streams and as baseflow. These wetlands are hydrologically connected to other riverine, lacustrine, and palustrine wetlands in the broader region, such as the Wami Dakawa wetlands (Kamakula and Crafter 1993, Ngana *et al.* 2010). Even though it is known that wetlands contribute to the water flow in the Wami river downstream through the dry season, the specific dynamics of flow are unknown (Gritzner and Jemison 2009).

Paddy farming has been a traditional activity in wetlands (Figure 21), there are also extensive sugarcane farms both in the catchment (eg. Dzungu Farm - Figure 20) as well as in the region (Mtibwa Sugar Estate). In a 2009 assessment of wetlands in the Wami River Basin, including wetlands in the Mkindo, Diwale and Divue catchments, Gritzner and Jemison (2009) list adverse effects of agriculture upon wetland function, with land conversion, water abstraction and sediment/agrochemical pollution being the leading threats.

Crops are often grown right up to the banks of stream channels and in or adjacent to wetlands to take advantage of sediment-rich floodbanks and high water table in the dry season. The removal of riparian vegetation can lead to bank erosion and sediment influx into streams, followed by river widening and channel migration, which in turn leads to further loss of riparian land (Gritzner and Summerlin 2007). Bank erosion is very likely in wetlands on account of the organic and alluvial soil deposits that cover bedrock on streambanks. Hence the protection of riparian zones is of critical importance in wetlands. Riparian zones can also be negatively impacted by high frequency trampling by livestock as well as by poorly managed grazing. High volume water abstractions for proposed expansion of industrial agriculture in the region can pose another threat to wetlands in the Mkindo catchment, with lowered water tables and the attendant loss of wetland ecosystem services of water cleaning. The ongoing construction of the new Dakawa-Turiani road is also generating a lot of loose sediment that is settling down in the adjacent wetlands (personal observation). Wetland ecosystems are also subject to toxic poisons that are used by some people to kill fish; the impoverishment of fish and invertebrates from wetland ecosystems can lead to the proliferation of mosquito larvae with attendant increases in the risk of malaria (Gritzner and Jemison 2009). The report by Gritzner and Jemison (2009) lists recommendations specific to wetlands in the Wami Basin attending to all these threats, with emphasis on the requirements for coordinated action amongst numerous stakeholders.

Figure 20: Irrigated sugarcane farm in the Mkindo catchment lowlands.

Figure 21: paddy fields in the lowlands with the Ngurus in the background

Figure 22: A lacustrine wetland in the Mkindo catchment region

5. Water resource users and uses in the Mkindo River Catchment

Overall, the Mkindo River Catchment is rich in renewable water resources stemming from the high rainfall and year-round cloud cover on the upper slopes of the Ngurus. In the mountains, springs are the main water source while streams, rivers, and small ponds along with groundwater constitute the water sources in the lowlands. The present chapter describes what are the main water users and uses in the catchment, specifically for the case of agriculture and fisheries, considering their main role in the wellbeing of the catchment villages. It also discusses some of the threats to water resources under current and projected conditions, particularly those arising from the socio-economic spheres (complementing those linked to climate and land cover change discussed in Chapters 3 and 4). The information provided in this Chapter was gathered mainly during field visits to the villages and surrounding areas, as well as several community workshops. Box 4 describes these activities.

Box 4: Methodology for qualitative data gathering

The workshop held for the Mkindo River Catchment Community Water Monitoring Program (GLOWS-FIU, 2014) in January-February 2013 and the village meetings in June-August 2013 (Figure 23) provided opportunities to discuss with communities on their various uses of water as well as their perceptions of issues and threats affecting local water resources. The results of these discussions provide preliminary data of the communities' uses of water for their various needs. These communities came from villages situated both in the higher reaches of the catchment (900-1200 masl elevation, grouped as 'highland villages') as well as from the plains (300 masl elevation, grouped as 'lowland villages') which greatly differed in their local climate, ecosystem and the exposure to goods and services. These topographic location differences were reflected in the water sources the communities used as well as in the manner water was used.

As part of the vulnerability survey, workshop participants were grouped as per their villages and asked to respond to a set of questions (Annex 2); this same set of questions was discused in the village meetings subsequently. The response to the posed questions is summarized in Table 1. This exercise serves as an initial survey, noting the fact that it is difficult for people to estimate quantities of water consumed for different activities without being provided an occasion to measure them. Hence the answers are treated as rough estimates. To obtain more accurate estimates, the survey questionnaire can be distributed to the communities and then a group meeting held in a few weeks, so as to provide an opportunity for the community to quantitatively measure and record their water usage in different activities.

Water needs for agriculture

Being a predominantly rural catchment, the major uses of water are domestic use, agriculture and livestock (Table 2). Within these use categories, there are a variety of uses. For instance, both rain-fed farming and irrigated agriculture exist. In the highland villages, most springs are perennial and hence support domestic water use. In addition, channels dug from springs transport water to small farms that otherwise depend upon rain. There are some pastoral communities in the highlands, but not in the villages visited or part of the MWUA. In the lowlands, domestic use relies partly on surface water from the various tributaries of the Mkindo and Diwale rivers, and partly on community-managed borewells. While many farms are rain-fed, some farmers have access to water from the Mkindo river irrigation project that has an intake to divert part of the flow from the Mkindo and brought to fields below via a concrete channel and a network of smaller channels with gates to control flow into fields. A survey of some other villages in the Mkindo River Catchment is described by de Bruin *et al.* (2012) who found that farmers benefitting from the Mkindo Irrigation Project are better off than farmers that solely depend on rainfall, who in turn are generally better off than livestock herders. Hence de Bruin *et al.* caution against the adoption of only high technology solutions for water management (i.e. irrigation schemes) because such schemes benefit a limited number of farmers, thereby further marginalizing other communities.

Figure 23: Clockwise from top left: community meeting at Mkindo village; CWRM workshop at Turiani; meeting at Lukenge; school meeting at Kisimagulu.

In addition to small farms, there are a couple large sugarcane plantations that supplement rain with irrigation from rivers. Sugarcane requires an ample supply of water (1200-1500 mm per annum – Tarimo and Takamura 1998). Even though annual rainfall might be adequate, much of that falls between March and May, necessitating additional irrigation (Tarimo and Takamura 1998). There is an interest in using groundwater reserves to further increase irrigated agriculture in the Wami Dakawa region, which as mentioned before is hydrologically connected to the Mkindo floodplain wetlands and aquifer. Groundwater monitoring would be necessary to indicate conditions of over extraction exceeding natural recharge that can lower water tables, leading to a host of problems, such as borewells running dry, to land subsidence and the salinization of surface soil, if salts are present in lower layers.

Water needs for freshwater fish communities

Fish constitute a major protein source for local communities. On the other hand fishes are dependent on adequate water quality and, for many fish, adequate flow. Therefore, the water needs for sustaining freshwater fishes communities is an issue to consider. Most fish are caught in large streams and rivers, while communities that have access to ponds and flooded paddy fields have an additional source of fish. Much of the fish caught is consumed locally. Table 2 indicates the variety of fish caught in villages in the Mkindo catchment.

Communities mention that fish catches in rivers are declining, forcing them to retain smaller fishes that they would previously release. Large fishes (> 1 m standard length) are rarely seen, except for an occasional large catfish. Catfish was mentioned as one of the more common fishes now; they are air breathers and hence able to survive in both muddy low oxygen environments such as ponds as well as dry conditions by burying in the moist mud (eg. Beadle 1974, Lowe-McConnell 1975). This suggests the possibility of a shift of fish communities towards a dominance of obligate air breathers over free swimming stream fishes. Reasons for this possible shift can include the reduction of dissolved oxygen in aqueous environments through the reduction of streamflow, increasing sedimentation, excess nutrients entering lowland ponds and overfishing. Related to this, Tamatamah (2007) mentions that the composition of aquatic invertebrates in lowland streams is dominated by moderate to high pollution tolerant taxa, thereby indicating problems with sedimentation and agrochemicals.

There is a variety of native catfishes in the region, however locals mentioned that some of the hill stream catfishes are no longer seen in streams below Mndela village (500-600 masl elevation). Pond dwelling fish such as catfish, cyprinids (carp) and cichlids (such as Tilapia) are successfully reared in ponds and floodplain wetlands owing to their tolerance of lower oxygen waters. Such aquaculture initiatives can be stepped up in the catchment as a way to buffer decreases in wild fish populations in streams from a local fishery resource perspective. As far back as the 1990s, Bwathondi and Mwamsojo (1993) mention the importance of wetlands in supplying fish to urban centers such as Morogoro in this region.

Figure 24: Riparian forest along the Mkindo River minimizes sedimentation, keeps water temperature cool and provides energy and nutrients to aquatic communities.

Table 2: Water uses, availability and extreme events in 8 villages in the Mkindo River Catchment, Tanzania

Village [4] (pop)	Water sources	Water use per household per day[5]	Rainfall	Agriculture	Water scarcity & floods	Fishing
Kinda (1505)	Springs, streams	Drinking, cooking, washing	Twice a year (March-May and Sep.-Dec.)	Maize, beans, bananas, cassava, yams, tobacco. Only tobacco is sold outside, all other locally consumed	No floods, no droughts	No fish
Kisimagulu (3010)	Springs; streams	Cooking and washing: 6 buckets	Twice a year	Rainfed, no irrigation; beans, groundnuts, cassava, maize; no change in crop pattern	Plenty of water during heavy rains	No fish
Dihombo (4193)	Mabana river and water scheme	Drinking: 1 bucket Cooking and washing: 2 buckets Livestock: 1 bucket	Twice a year; heavy and short rains	Maize, rice. Sell for cash. Some people rotate or change crops if low rain.	Water shortages in October	*Kambale* (catfish), decreasing number of fish
Hembeti (4443)	River, water supply tap	Drinking, cooking and washing: 5 buckets	Twice a year; heavy and short rains	Rice, *simisim*, maize, cassava, peas, sesame tomato; crop pattern change if less rain; some produce sold.	Floods during heavy rains in April	*Sulusulu, pelage, kambale*
Kigugu (3059)	Chazi river, borehole	Drinking: 20 liters Cooking: 30 liters Washing: 100 liters	Twice a year; heavy and short rains	Rainfed and irrigation; rice, maize, cassava, sugarcane; no change in crops, half crop sold	Floods have occurred in the past	*Pelage, ngogo, kambale, ningu;* decreasing fish catch
Lukenge (2962)	Mkindo River	Drinking: 1 bucket Washing: 3 buckets Cooking: 1 bucket Livestock: 1 small bucket	Twice a year	Rainfed, no irrigation; maize, rice, sugar cane, *mbaazi,* sesame	No floods	*Pelage, kurufi, bembe, catfish, pugi* in the Mkindo River ; decreasing fish
Mkindo (6050)	Mkindo River	Drinking: 15 liters Washing: 40 liters Cooking: 20 liters Livestock: 50 liters	April highest rain	Rainfed and irrigation scheme; crops: rice and maize, surplus sold	Floods during heavy rain	*Catfish, pelage, sulusu, kange, kurufi.* Lot of fish during heavy rains; fish numbers decreasing

[4] Kinda and Kisimagulu are located in the highland while the other villages in the lowlands. There is one highland village, Mndela, which is not included in the table.
[5] One bucket holds approximately 15 liters

6. Vulnerability of water resources at the community level

Based on the previous sections and fieldwork data this section discusses the vulnerability of these water sources to climate change and deforestation in highland and lowland villages in the Mkindo River Catchment. Factors affecting water quality are also considered. The highland and lowland villages are considered as two separate groups as their water resource availability and use scenarios are different.

6.1. Water resources vulnerabilities in highland villages (Kinda, Kisimagulu, Mndela)

Springs (locally known as '*chemchem*') provide almost all of the water for village domestic consumption year-round. In addition, channels are dug from spring outlets to irrigate farms downslope. Locals report that rarely they face any water shortage. However springs dry up earlier in certain locations over others. Water quality is generally good, with low temperatures and very low turbidity. Chances of bacterial pollution are generally low because most of the spring water has its origins as percolated rainwater/cloud moisture in uninhabited forested catchment areas at elevations above the villages. However, there can be possible bacterial groundwater contamination from surface runoff seeping into the groundwater in village areas, to resurface downslope as a spring outlet (Figure 25). In addition, there can also be point sources of fecal bacterial contamination from the farms just below the forests in the watershed.

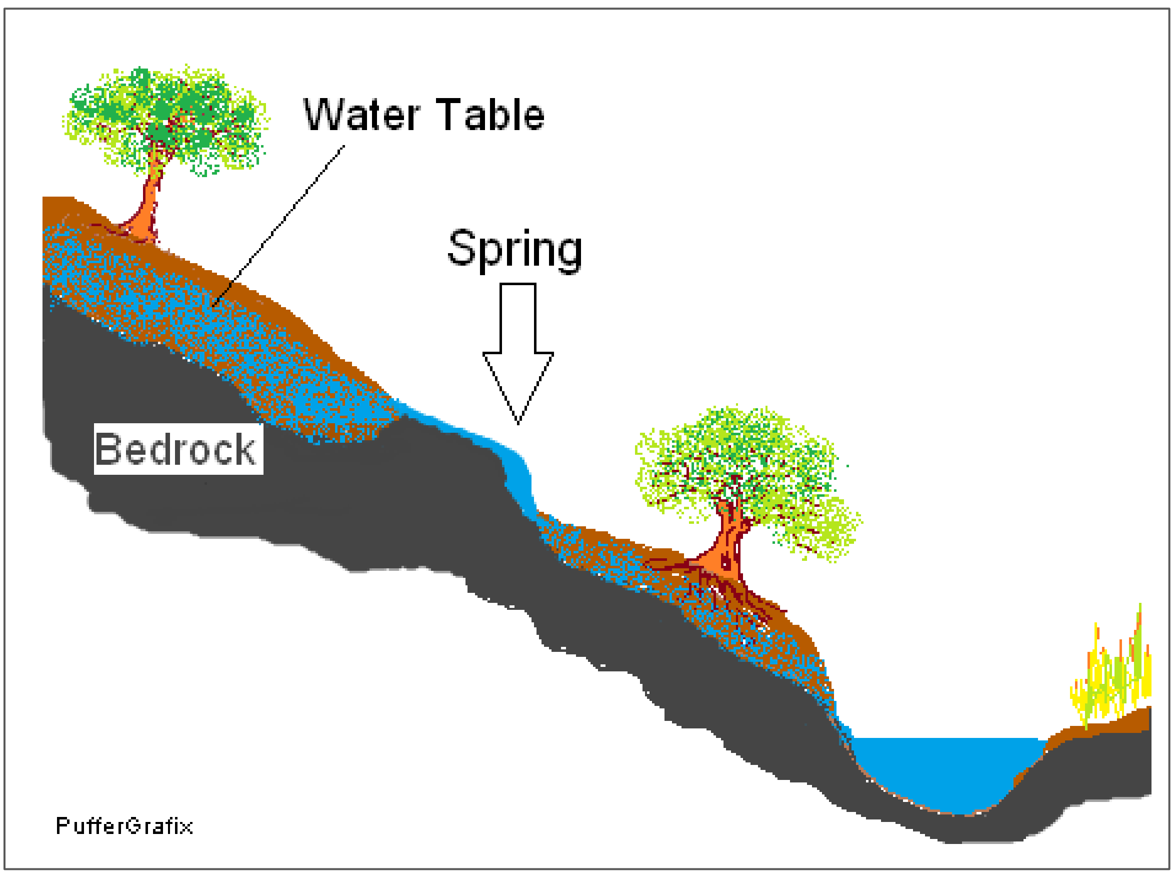


Figure 25: Schematic showing a spring emerging where the water table meets the surface.

Influence of climate/catchment forest cover on highland water sources

The magnitude and duration of water flow in springs depends upon the extent of forest cover in upstream catchment, the type of forest (whether primary or single-species plantation) and the amount of rainfall and cloud cover.

Forest cover has an immediate effect on the streamflow regime. Continuous primary forest cover results in a larger fraction of incident rainfall infiltrating and recharging groundwater, while removal of forest cover results in higher instantaneous surface runoff. Forests, especially primary montane forests, also intercept significant amounts of moisture from clouds (that are present almost year-round). While specific studies are required to estimate the fraction of springflow that is provided by cloud moisture interception, the existence of photosynthesis and growth in the non-rainy season by evergreen trees together with the presence of dew condensation on leaves, trunks and litter layer suggests moisture inputs to the catchment ecosystem from clouds (Bruijnzeel and Hamilton 2000). Deforestation shifts the partitioning of rainfall towards surface runoff because of lesser infiltration and lower transpiration, resulting in higher streamflows after rain events. However, eventually the springs and streams dry up earlier in the year owing to the lower groundwater recharge in deforested terrain. The upper slopes of the Ngurus (>1200 masl) within the Mkindo River Catchment still have a large amount of primary montane forests, although the lower regions (900-1200 masl) are witnessing fragmentation of forest cover (observation during field visit) as evident from the mosaic of forests, bare land, and small farms.

Rainfall and cloud cover – vulnerability to climate change

Rainfall is the major source of water for the springs. Hence any decrease in rainfall in a certain year arising from climate tele-connection patterns, related to the ENSO and IOD (Chapter 2) , will lead to decreased spring-flow and earlier drying up of springs and streams in the ensuing dry season. Atmospheric warming has also been seen to shrink cloud bases by decreasing the zone of condensation or cloud formation in tropical mountains as described in Chapter 2. This warming is a combination of greenhouse gas-caused heat storage and local deforestation-caused soil and air temperature increases. There is a very real possibility that the extent of cloud cover can decrease in future. Protecting primary forests and reforestation programs have the potential to partially buffer the negative effects of global warming upon cloud formation. However there can be years with low rainfall and/or cloud cover that will decrease water availability despite forest cover. This requires the community to think along the lines of water storage, conservation and low-water use strategies in farming.

Water quality: Bacterial contamination is possible from surface runoff downstream of settlements. Sediment pollution results from deforestation, illegal gold mining, road building and the lack of adequate soil conservation measures. Sedimentation in streams causes excess turbidity and wipes out aquatic invertebrate communities from streambottoms which are instrumental in decomposing organic matter and thus naturally maintaining water quality.

6.2. Water resources vulnerabilities in lowland villages (Dihombo, Hembeti, Kigugu, Lukenge, Mkindo)

Surface water (streams, river, ponds, etc.) and groundwater, either from open well or borewell constitute the main water sources in these lowland villages. The water table in this region is high (shallow) as this region lies at the base of the mountainous Mkindo River watershed and thus has extensive natural wetlands, many of which have been converted to agriculture in the recent past. Today, agriculture in this region is rain-fed as well as irrigated (de Bruin *et al.* 2012) via the irrigation intake in the Mindu Forest Reserve (Figure 26), or pumped from rivers. The irrigation intake has a small reservoir constructed adjacent to the Mkindo River that has a concrete sluice to transport water to the rice fields below. Surface waters are prone to contamination with fecal bacteria, domestic/industrial waste, agrochemicals, oils and grease. In the Mkindo River Catchment, bacterial contamination is a real danger, as are dust, oil and grease from the increasing vehicular traffic on B-127 and the washing of vehicles. Road extension/construction is also releasing large amounts of soil into the rivers locally. In addition, increasing irrigated high-input agriculture can load fertilizers and pesticides into to the Mkindo, Diwale, Divue and their tributaries.

Groundwater in comparison to surface water is held to be safer on account of lower direct exposure to contamination. However, there is the danger of bacterial contamination from septic tanks and open wells, contamination with organic chemicals from leaching of motor oils and agrochemicals.

Figure 26: The Mkindo River irrigation intake

Influence of climate/catchment forest cover on lowland water sources

Rivers: The flow in lowland rivers (Mkindo, tributaries of Mkindo, Komtonga and Diwale) depends upon:

- Rainfall in the catchment (subject to inter-annual variation and at risk from changing patterns / uncertainty due to climate change). Climate change-induced uncertainty in rainfall and cloud base as described for highland villages.
- Upstream abstractions/diversions for irrigated agriculture.
- Forest cover change – removal of forest cover can lead to higher flows immediately following rainfall events (rainfall partitioning in favor of surface runoff) and then a decrease in flow (even drying up) earlier in the dry season in comparison to historical flow trends. Reforestation can regulate the flow peaks, with lower discharges following rain events, and flow occurring longer in the dry season.
- Wetland drainage – wetlands serve the function of water storage on the landscape. Their functioning is analogous to capacitors in electronic circuits: they recharge during rainy season and discharge to downstream rivers in the dry season. The clearing and drainage of wetlands for agriculture decreases the water storage capacity. Wetlands also improve downstream water quality by holding on to sediments and some fraction of nutrients (agrochemicals) and other organic chemicals.

Groundwater: Currently, the water table in the Mkindo River Catchment lowlands is shallow (high). Borewells are few and have been recently installed. However, with greater groundwater use expected in the future, in particular, due to new groundwater-dependent irrigation schemes for large farms, there are chances that the water table can drop if extraction exceeds natural recharge. Hence, groundwater monitoring wells are necessary. In addition, new borewells should feature a monitoring port.

Water quality: Bacterial contamination is possible from surface runoff, leaching pit latrines and defecation/washing on riverbanks. Nonpoint pollution results from surface runoff of sediments, agrochemicals, oils, grease and trash (plastic bags, bottles, domestic garbage)

6.3. Guidelines for Adaptation

After considering the exposure and sensitivity of local water resources to climate change and land cover change, as described earlier in this report, the following section provides guidelines for improving and/or ensuring water availability in order to better deal with the water availability uncertainty. A first set of recommendations looks at protecting the source of water including the protection and sustainable management of springs and rivers, as well as the entire catchment. A second set of recommendations are related with improving/ensuring water availability through water supply infrastructure related measures.

These recommendations could guide the discussions in subsequent meetings with local stakeholders and the MWUA for jointly assessing the vulnerability of local water resources, developing adaptation strategies, and incorporating them into water resource management plans at the community level. Following the planning and strategy development phase, communities should also become involved in the implementation stage, as well as monitoring and subsequent evaluation. As mentioned in the introductory section, the involvement of local actors can be considered along three dimensions: information provision, management, and empowerment.

Water sources management and protection

Catchment protection

The following are some of the actions that are recommended to improve the conservation of the catchment:

- Creating a monitoring process/mechanism to report any large tree-cutting, illegal gold-mining and forest clearing activities to the Water Users Association who can then inform the Water Basin Office, who in turn can then alert the appropriate agencies.
- Recharging catchment groundwater recharge by using soil and water conservation methods such as terraces, strip mulching, contour bunds and check dams.
- Protecting mountain slopes using some of the techniques mentioned above (i.e. terrace, contour bunds, reforestation, other). Slope maps such as the ones presented in Chapter 4 can be utilized to identify areas of the catchment that are more vulnerable to soil erosion and landslides. These areas can then be prioritized for conservation action.
- Maintaining riparian vegetation buffers along rivers in the entire catchment. Prevent the cutting of old-growth trees, and promote the formation of a gallery forest with minimum width of 10 meters. The protection of riparian vegetation in wetlands is also important, as discussed earlier.
- The legal figure of Forest Reserves offers a policy tool to protect catchment areas from deforestation and forest degradation. At the same time local communities depend on FR for some natural resources and therefore sustain their livelihood. Understand and manage the tension between these real or/and potential conflicting interests should be pursued in order to assist in conservation management and poverty alleviation.
- Water quality - Periodic monitoring of local spring water using the simple field Hydrogen Sulfide test for detecting bacterial contamination in water (GLOWS-FIU 2014b) can indicate how safe the local water is for direct consumption. Implementation of water treatment methods such as boiling and filtration in the rainy season are to be considered when chances of bacterial contamination are high, keeping in mind the challenges in obtaining fuelwood for boiling and financial resources for ceramic filters.
- Education - Awareness generation can be carried out in local schools of the role of forests in maintaining spring flow. This can be included as part of the activities implemented by the Community Water Monitoring Program whose rainfall measuring component is undertaken by school students with their teachers (Figure

27). Visual aids such as posters are also very useful for generating awareness within the school and the village community.

Figure 27: Rainfall measurement exercise by a student at the Kisimagulu Primary School. Schools offer an apt platform for involvement of the community in monitoring their local watershed.

Springs (particularly for highland villages)

- Spring inventory and survey – Assessing local water resources starts with listing the springs used, the number of users or approximate amount of water drawn from each spring along with noting the condition of each of the spring outlets in terms of slope stability and pollution potential.
- Springflow monitoring – monitoring the flow periodically and keeping records to know when and for how long do the springs run low or even dry up. Over years this data is valuable in assessing the dependability of springs as a water source, especially when combined with rainfall measurements by the local primary school carried under the CWRM (Community Water Resources Monitoring) Program. Springflow can also be related to loss of forest cover. One method of measuring spring flow is to note the time taken for a 1 liter bottle to get full; as the flow decreases over the dry season, the time taken to fill the bottle gets longer. This is a relative simple technique, and the community is encouraged to come up with other measurement methods as well.
- Maintenance of area around the spring – while springwater is held as being of good quality by local communities, primarily because of the lack of turbidity, it should be ensured that there is no waste disposal or defecation in the area near the spring outlet which could contaminate the groundwater. Also, spring water should be tested for natural contaminants (e.g. arsenic, other)
- Regional hydrogeology mapping – this is to attempt to locate the recharge zones of the springs as well as recognize the type of water transport involved. It is important to determine whether springs are fracture springs (faults in rocks that serve as conduits for groundwater) or seepage spring (that are slower flowing).

This understanding can aid in maintaining and repairing springs in the event of landslides that can block water flow and thus change the course of springs (India Water Portal 2014).

River flow (of special relevance to lowland villages)

- Water level is commonly monitored and used to obtain river discharge measurements from a site-specific rating curve. However, staff gage installation for the measurement of water level is challenging in the Mkindo and other tropical rivers, owing to sudden increases in flows in the wet season that can wash away simple staff gages. The existence of steep incised channels (4 m high at Lukenge) and local accounts of where the water reaches in the wet season both indicate high flows. To withstand these high flows, staff gages need to have concrete bases and steel anchoring rods. An easier alternative to constructing staff gages is to look for locations with permanent structures on rivers, such as bridge pilings and paint staff gage markings on them. Examples of such locations are the irrigation intake at Lukenge (Figure 28) and the intake for the Mkindo farm irrigation

Figure 28: (Top) Irrigation intake at Lukenge, where water level marks can be painted on the wall for monitoring water level (Bottom) The Mkindo River in the dry season at Lukenge. The river rises 4 m higher in the wet season as evident from the incised channel and from local anecdotes

Water supply infrastructure

Water storage

This can be done at the household level by acquiring large containers and a rooftop rainwater harvesting system. This can also save time and effort in going to the spring during rainy months when the dangers of bacterial contamination are greater. However, household water storage containers should be maintained clean, kept free of contamination and covered to prevent mosquito breeding.

Another solution is a community water storage tank – however this requires capital to build and community maintenance thereafter. While a large community tank can store rainwater longer through dry months that is especially useful in a year with an extended dry season, the community would need to figure out the issues of funding the construction of a tank, community cooperation in maintenance and how to ensure equitable water sharing and mechanism for conflict resolution should they arise.

Borewell installation

Borewells are for use in dry season or if springs dry up due to low rainfall. Note that while borewells may extend the time of water yield, they also can run dry because the groundwater storage on hillslopes is typically much lower than in the lowlands, given that water is always flowing downhill. There are also issues of funding construction of a borewell, community pricing/monitoring as well as borewell parts maintenance.

Piped water supply (water point)

This is a possibility for villages with the availability of more reliable (longer flowing) water sources upstream that can be piped to the village and made available as a community-maintained water point. Just as with community water storage tanks, the community would need to work out a participatory pricing and maintenance program.

7. Concluding remarks

This report has described the major factors affecting water availability and water use in the Mkindo River Catchment. This information can add to the background understanding of local water resources necessary by stakeholders in order to develop adaptive strategies under various scenarios of water availability and demand.

Rainfall is the ultimate source of all water in the Catchment, and rainfall itself varies from year to year. Climate change is likely to add to this variability; increasing temperatures can change regional climate systems that bring rainfall to the catchment, changing the onset and the frequency of rain events, often in unpredictable ways. Regional climate systems can also reduce the cloud cover, another source of moisture, in the high areas of the catchment. This effect can be exacerbated by the reduction of primary forest cover associated with deforestation.

Preliminary information on the various water uses and water sources in the village communities has been included here. Highland villages are almost wholly reliant on perennial springs, while lowland villages rely upon a mix of surface water and, increasingly, groundwater through borewells. There is the possibility of increased groundwater extraction for large agriculture projects. Water quality impairment from excessive sedimentation associated with deforestation and non –point pollution sources is another possibility.

Even though the global scale of some of the changes occurring at the catchment influencing water resources availability, there are several measures that can be implemented at community level in order to better manage the water uncertainty associated with climate change and other regional changes. The present reports focused on those measures. A main measure is to maintain ecosystem services provided by forests and wetlands. Forests and wetlands regulate the water supply, provide flood control and ensure good quality well into the dry season. Maintaining these ecosystem services include protecting existing primary forests, promoting agroforestry in cleared lands, and maintaining natural vegetation along stream courses in both uplands and wetlands. Incorporating these activities into village common lands and community joint forest management should be explored. Other measures to be implemented at the community level, and by the local communities include individual/community water storage, developing programs to monitor local water sources for quality and quantity, and agriculture/livestock adaptations to droughts and floods. The role of village communities in ensuring equitable water distribution and fair conflict resolution remains essential. Communities are also uniquely placed to notice both short and long term environmental changes; WUAs provide a means of communication between communities bound by a common catchment, i.e. early warning of floods or reporting illegal activities such as logging, mining and fish kills.

Considering that these activities are to be done at the catchment level and by the community that inhabits the catchment, identifying, planning, implementing and evaluating these activities should be considered to be done together with the local actors, such as village communities and Water User Associations. The involvement of local actors can be considered along three dimensions: information provision, management, and empowerment.

It is the sincere hope of the authors that this report can help in forming ecologically sustainable solutions that seek to ensure the health and prosperity of the people of the Mkindo River Catchment over the long run.

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Annex 1: Map Plates

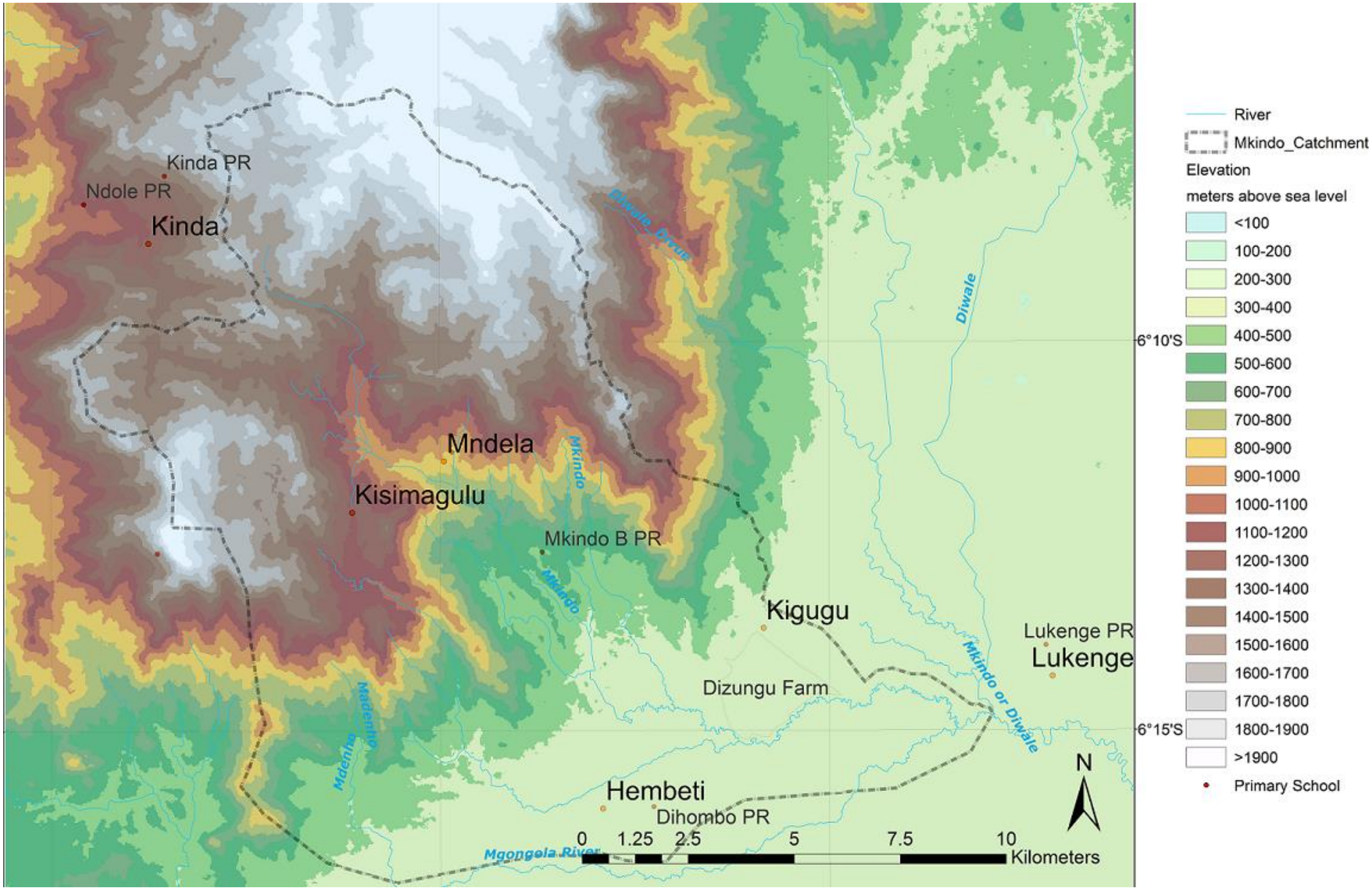

Figure 29: High-resolution topographic elevation map of Mkindo River Catchment derived from the ASTER 30m Digital Elevation Model. [Data Source: NASA/JSRO 2013].

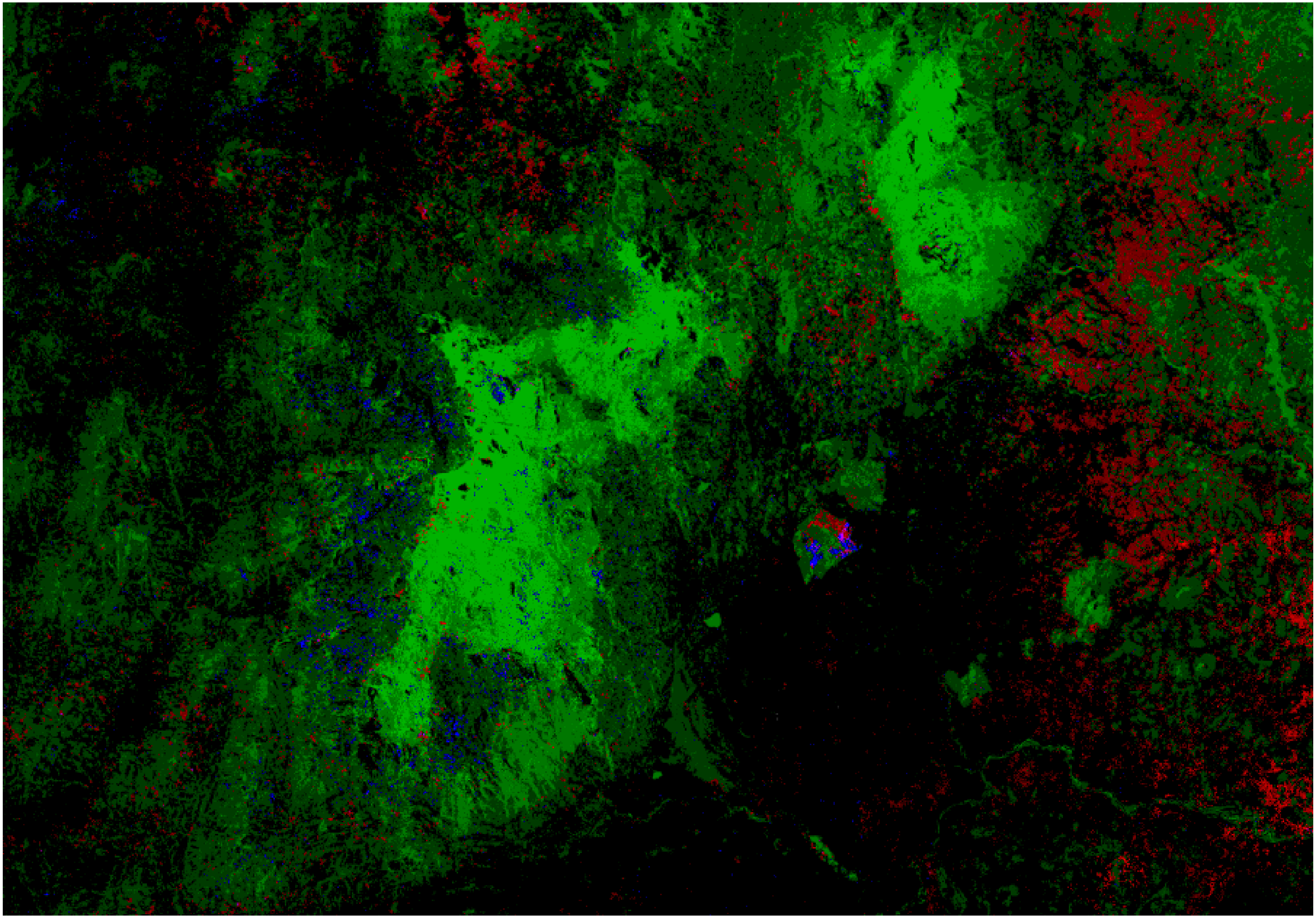

Figure 30: Forest cover (2000) in green, forest loss in red and forest gain in blue for Mkindo River Catchment and surrounding region. [Data Source: Hansen *et al.* 2013]

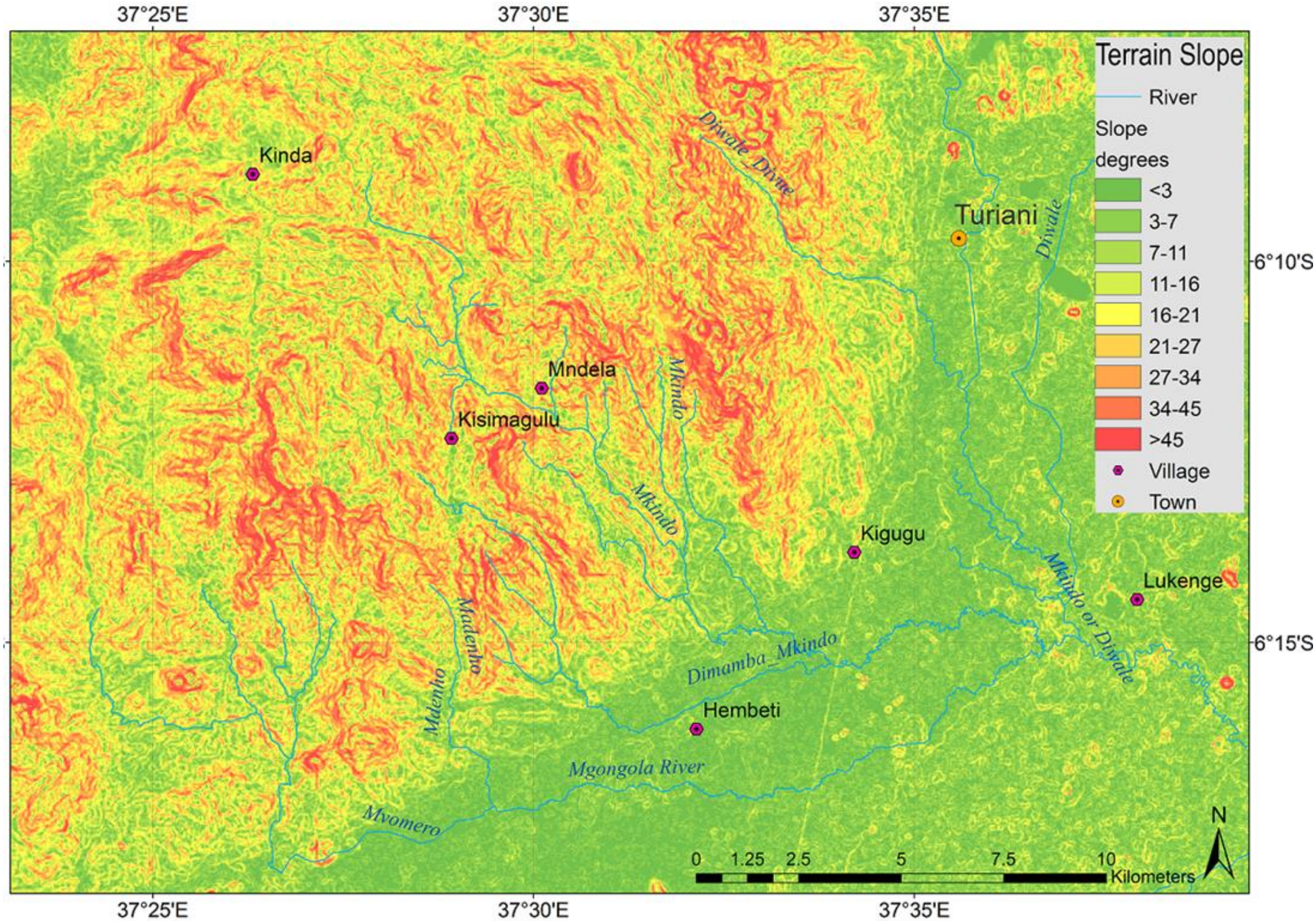

Figure 31: Slope map of the Mkindo River Catchment. Steep slopes (45> degrees) shown in red

Annex 2: Community Water Use and Resources Survey

Domestic use:

- How much water is used in your family for drinking, cooking, washing clothes/utensils/cleaning house, kitchen garden and small livestock?

Water shortages

- Are there water shortages in the dry season? If so, where and how do you get water from?
- How do you manage that water? Are there any activities that you stop? Are there any activities that you do differently?
- In your recollections, have there been any years with very low rain or with water shortages?

Agriculture

- Do you irrigate your farms, or do you just rely on rain? What crops do you grow and how many seasons? Are there crops that you switch to in dry spells? Are there any issues with pests and fires? Do you sell some of your produce? Where?

Livestock:

- Do you have chickens, goats, sheep, cattle? If you have cattle, how do you provide them with drinking water?

Fisheries

- Where do you catch fish?
- How many kinds of fish are there in the river and/or pond?
- Do numbers and types of fish change with water level and season?
- What do these fish eat?
- Have there been fish kills? If so, do you know why?

Notes

Notes

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