Trans-SEC

Innovating pro-poor Strategies to safeguard Food Security using Technology and Knowledge Transfer

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Water resources situation in the Ngerengere river basin

Impact of land use change and water abstractions on the discharge of the Ngerengere river in Tanzania and its implications for agriculture and food security

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1. Introduction

Tanzania lies within a zone of strong hydrologic changes and reportedly high pressure from driving forces such as population growth, agricultural sector development, and climate change (Schäfer et al., 2016). In many cases, this leads to growing pressure on natural resources, and water demand in some places already exceeds water availability, thus limiting food production and agricultural development (Besada and Werner, 2015; Gunasekara et al., 2014). The Ngerengere river basin, which is located in the Wami/Ruvu catchment in South-Eastern Tanzania, is no exception to this case. Apart from climatic changes, the main underlying causes of these changes are attributed to water abstractions (WA) and land use/land cover change (LULCC) (Natkhin et al., 2015).

With regard to sustainable regional development and resource use, comprehensive knowledge on water resources and the processes affecting them on drainage basin scale is of great importance. The following report draws on data and insights from two multiannual research projects (ReACCT and Trans-SEC, 2008-2016) focusing on the historic and current state of water resources, observed changes in hydrological parameters, and the correlations with underlying main causes in the Ngerengere river basin.

The described research aims at a) an improved understanding of the relation between streamflow and LULC change, WA, and climate change in the Ngerengere river basin in Tanzania. The gained insight shall be applied to b) assess how future developments of the above pressures will affect discharge in the basin, thus c) providing an assessment of expected impacts on agricultural development and food security strategies. Findings will be specific for the Morogoro region, however, it is expected that some general statements can be derived and find application in similar regions.

The elaboration and results of the work are embedded in the Trans-SEC project, which aims at improving the food situation for the most vulnerable rural poor population in Tanzania through the identification and dissemination of successful upgrading strategies. All findings are shared with local authorities and the project consortium.

2. Overview of study area : Ngerengere river basin

The Ngerengere catchment is a sub-basin of the Wami-Ruvu river basin in Tanzania and approximately 2,780 km² large (Fig.1). It covers the extent of the 154km long Ngerengere river from its source in the Uluguru Mountains in the west to its junction with the Ruvu river near Mafisi village to the East (JICA, 2013c). From an elevation of up to 2,260masl in the Uluguru Mountains, the topography of the catchment changes considerably towards the plains at around 300masl in the East (Fig.2).

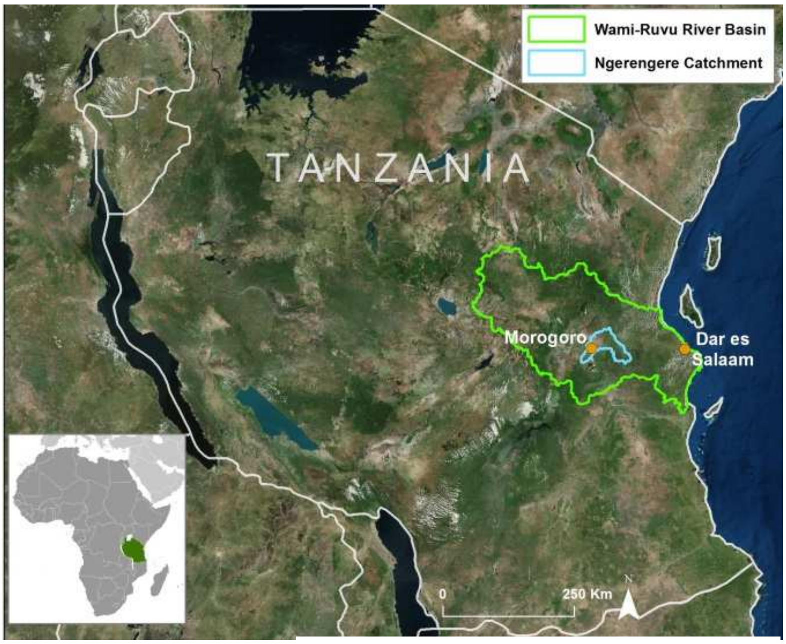


Figure 1: Location of case study site

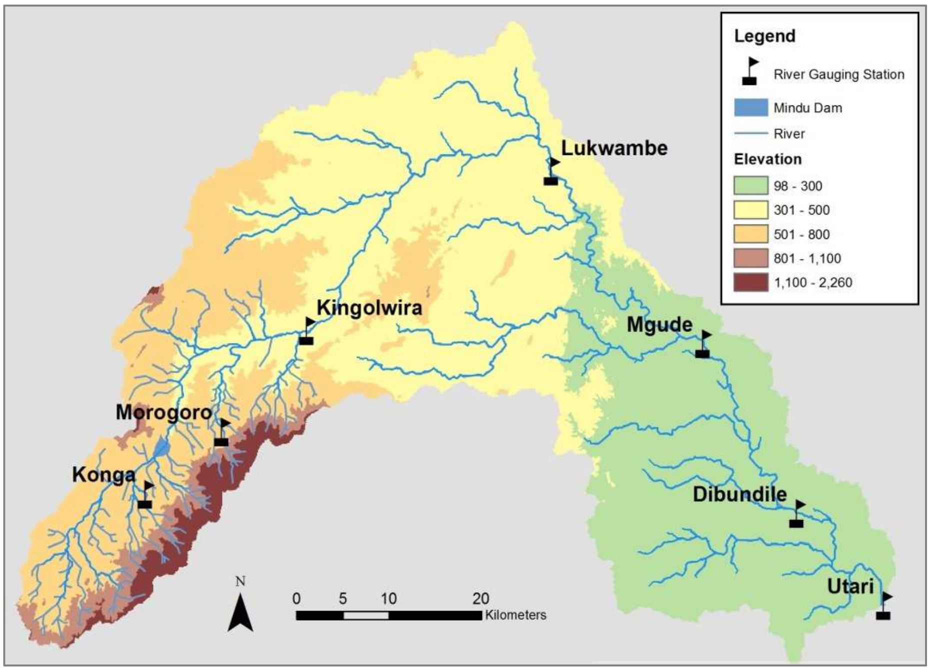


Figure 2: The Ngerengere river basin in Morogoro, Tanzania

The largest city in the catchment, Morogoro, is a centre of intense agricultural and industrial growth, and the region is exemplary for environmental changes induced by these developments. These include land use and land cover change, increased surface and groundwater withdrawal, the building of dams and reservoirs, and degradation of water quality due to erosion and pollutants.

The Ngerengere basin has been the site of ongoing hydrologic research for several years because it is spatially diverse, comparatively well researched, and quite representative for developments and demographics found throughout Tanzania (see chapter 5 for further details).

3. Methodology

Data basis

Type of Data		**Record Length**	**Source**
Climatic Data (Precipitation, Temperature, Evaporation)	Measured	40 years (1970-2010)	Wami Ruvu Basin Water Office (WRBWO, 2014a); Tanzania Meteorological Agency (TMA, 2013)
	Re-Analysed	33 years (1979–2012)	The WFDEI Meteorological Forcing Data Set (Weedon et al., 2014)
	Projected	140 years (1960-2100)	The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al., 2014)
Measured discharge / streamflow		60 / 40 years (1950-2010)	WRBWO (WRBWO, 2014b)
Land use / land cover		1975, 1991, 1995, 2000, 2005	LANDSAT images (processed by SUA (Mbilinyi, 2014))
Soil type data		2003	SOTERSAF - Soil database for Southern Africa (Dijkshoorn, 2003)
Historical population figures		1967-2012	Census data (FAO, 2016; JICA, 2013b; NBS, 2006a; NBS, 2006c; NBS & OCGS, 2013; Regional Commissioner's Office Morogoro, 1997)
Projected population figures		2015-2035	Projection from census data (JICA, 2013b; NBS, 2006b; The World Bank, 2016)
Historical water abstraction figures		1995, 2010	WRBWO (WRBWO, 2014c)
Projected water abstraction figures		1975, 1991, 2000, 2005 2010-2035	Projection from WA data WRBWO / JICA (JICA, 2013b)
Literature			Major scientific citation databases (Web of Science, Scopus, Science Direct) and some renowned non-peer-reviewed hydrologic publication databases (International Water Management Institute, International Union for Conservation of Nature).

Terminology and categorization

Classification of landscape units

Due to the high spatial heterogeneity of the Ngerengere river basin, the terrain was sub-divided into four landscape units based on similar parameters regarding elevation, LULC pattern, population density, and number of river gauges with available data (Fig.3 & Table 1). These landscape units are the basis for all projections and interpretation of data and model results.

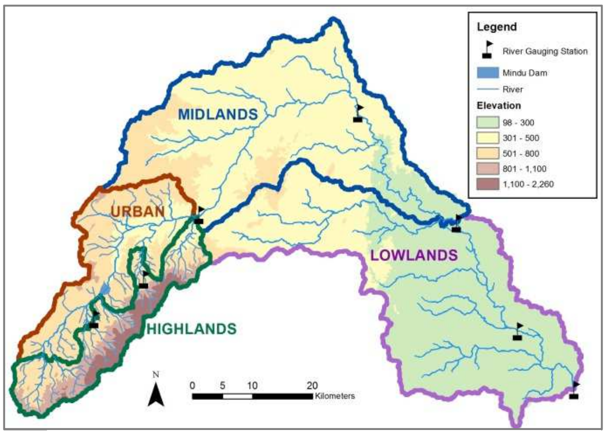


Figure 3: Ngerengere river basin landscape units

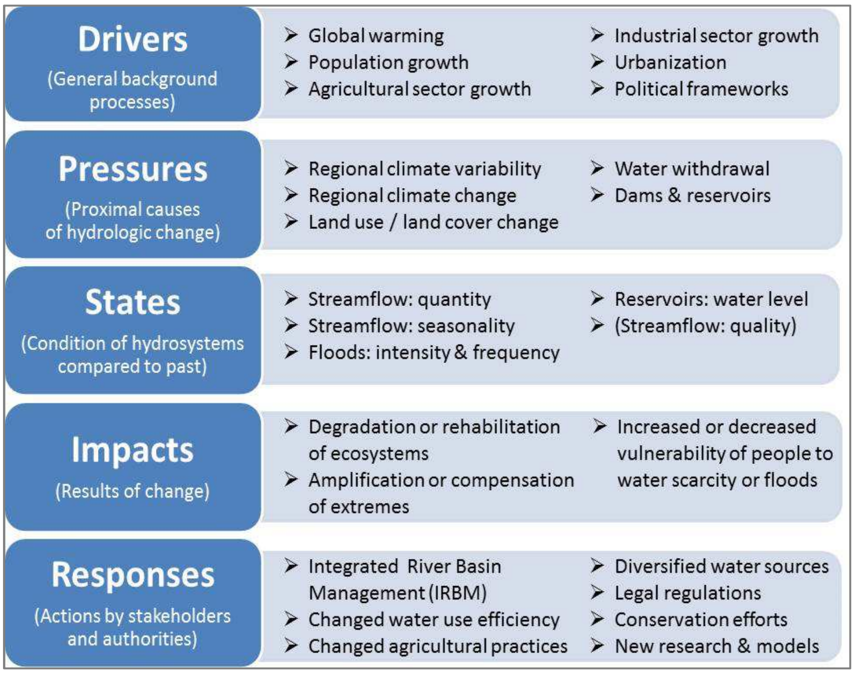
Table 1: Overview of landscape unit parameters

Landscape Unit	Extent (km²)	Dominant LULC (Year 2005)	Population/km² (Year 2012)	River gauges
Highlands	280	Cropland, Forest	300	Konga, Morogoro
Urban	362	Cropland, Built-Up Area	451	Mindu Dam, Kingolwira
Midlands	998	Bushland, Woodland	84	Lukwambe, Mgude
Lowlands	1093	Cropland, Bushland	23	Dibundile, Utari

DPSIR model

In order to provide a stringent and standardized frame for this research, a **modified DPSIR (Driving forces, Pressures, States, Impacts and Responses) model** was chosen to structure the causes, underlying drivers, impacts and possible responses regarding basin water resources.

The structure and attributed terms relevant for this review are summarized in Fig. 4.



Drivers
(General background processes)

- Global warming
- Population growth
- Agricultural sector growth
- Industrial sector growth
- Urbanization
- Political frameworks

Pressures
(Proximal causes of hydrologic change)

- Regional climate variability
- Regional climate change
- Land use / land cover change
- Water withdrawal
- Dams & reservoirs

States
(Condition of hydrosystems compared to past)

- Streamflow: quantity
- Streamflow: seasonality
- Floods: intensity & frequency
- Reservoirs: water level
- (Streamflow: quality)

Impacts
(Results of change)

- Degradation or rehabilitation of ecosystems
- Amplification or compensation of extremes
- Increased or decreased vulnerability of people to water scarcity or floods

Responses
(Actions by stakeholders and authorities)

- Integrated River Basin Management (IRBM)
- Changed water use efficiency
- Changed agricultural practices
- Diversified water sources
- Legal regulations
- Conservation efforts
- New research & models

Figure 4: Hydrologic changes at drainage basin scale structured in terms of a modified DPSIR model (own rendering, adapted from Schulze (2004), supporting data from Arthurton et al. (2008)).

The DPSIR concept was developed by the OECD (Organization for Economic Co-operation and Development) in the 1990s and has since been applied in several studies assessing drainage basin changes (Arthurton et al., 2008; Schulze, 2004). In addition to the structured evaluation of causes and linkages, the strength of the DPSIR concept lies in its strong emphasis on the appropriate management and policy responses of stakeholders and authorities at the local scale and beyond. With the identification of linkages between pressures and states/impacts, respective remedial actions can be defined to achieve more beneficial state changes in the future.

Scenario approach

For the assessment of future developments, scenarios are employed which consider changed land use/land cover (LULC), WA, and climatic conditions for two time slices (2025&2035).

This baseline scenario assumes a continuation of LULC and WA trends based on the development within the past 40 years. As the analysis of historic data has shown, there is a strong correlation between phases of massive changes in LULC respective WA and population growth in the Ngerengere river basin. To take this important linkage into account, an approach was developed to also factor in district level population development figures to these future extrapolations of LULC and WA. For WA, extrapolations were also employed backwards to derive at approximate figures for WA in 1975, 1991, 2000 and 2005. The approach was tested against available data, and suggests the general suitability of the concept for data scarce regions. The same

Climatic projections for the baseline scenario are based on data from the ISI-MIP project, which assessed a set of possible future scenarios based on increasing solar radiation until 2100. This change in solar radiation is translated into regional precipitation and temperature signals by using global circulation models (GCMs). Our calculations are oriented towards the RCP8.5 SSP2 scenario, which assumes “business-as-usual” greenhouse gas forcings and a “middle of the road” socio-economic/population development for the coming decades (Warszawski et al., 2014). However, the spatial resolution of the models is rather coarse (0.5°x0.5°), while the climate in the Ngerengere river basin is highly heterogeneous and small-scale, resulting in considerable deviations regarding concrete data. It was therefore decided to apply the trend from four CGM model runs (based on ISI-MIP RCP8.5 scenario) to the projection of observed climatic data in the Ngerengere basin by derived adjustment factors.

The resulting concrete attributes for LULC, WA, temperature, precipitation and evaporation for the time slices were computed and included in a SWAT model. To distinguish the effects of different pressures, the model was run several times while changing one input parameter at a time, resulting in a multitude of runs or scenarios in total. The differences in discharge between the scenarios will indicate the relevance of each pressure for streamflow. Comparison of results will be done by analysis of average values for 30-year-timespans (1976-2005, 2006-2035) and 5-year timespans for each time slice (i.e. 1975 = 1973-77; 1995 = 1993-97, 2005 = 2003-07; 2025 = 2023-27; 2035 = 2033-37). The results are discussed under consideration of findings from the literature, partnering expert institutions, and local authorities.

SWAT model

To assess the effects of climate, soil, land use and land management on the water balance of the Ngerengere river basin, the Soil and Water Assessment Tool (SWAT) was utilized. This physically based hydrological model is commonly used for the simulation of hydrological processes in tropical river basins (Baker and Miller, 2013; Lubini, 2013; Ndomba et al., 2008). The model sub-divides the catchment into hydrological response units (HRUs) based on topography, soil type, and land use/land cover. HRUs are consolidated into sub-basins, each of which features a corresponding intermediate outlet (i.e. virtual river gauge, Fig.5). This allows for the analysis and attribution of very small-scale changes.

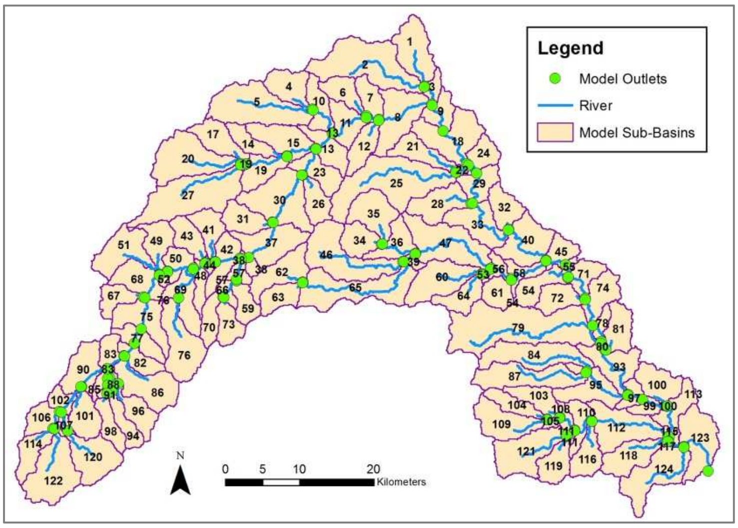


Figure 5: Ngerengere river basin SWAT model sub-basins and outlets

The employed SWAT model is an updated version of the model established by M.Natkhin for a previous research project in the Ngerengere river basin (for a full description of model parameters, please refer to Natkhin et al. (2015)). The validated basis model consists of 124 topography-driven sub-basins and is divided into 425 hydrological response units based on 8 land use classes, 5 soil types, and three slope classes. The model was calibrated/validated with data from 14 precipitation stations, 4 river gauges (Konga, Morogoro, Mgude, Utari), water abstraction data from 1995, and remotely sensed land use/land cover shapefiles from 1995. Vegetation parameters were adapted for rainy respective dry season conditions.

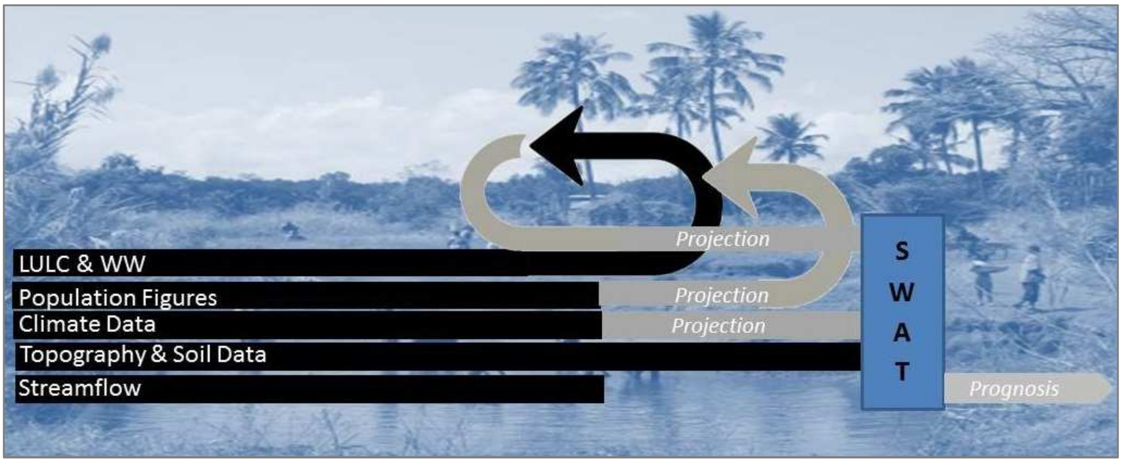


Figure 6: Input and analysis parameters of SWAT model

4. Current status of streamflow in the Ngerengere river

The flow of the Ngerengere river and its tributaries is linked to the rainfall pattern in the basin. Streamflow is generally highest at the end of the long rainy season in May, and lowest in October. Most tributaries in the upper part of the basin are small perennial streams, with high flows during periods of heavy rainfall, but mere rivulets in the dry season. In the downstream part, the river has a very gentle slope and forms ox-bow bends (JICA, 2013c).

The annual specific discharge at the basin outlet gauge, Utari, is 39,477 m^3/year/km^2 in a normal year, and 25,203 m^3/year/km^2 in a dry year (JICA, 2013b). In dry years, prolonged cessation of river flow is increasingly common – especially with increasing distance to the Uluguru mountains, and below the Mindu dam. The largest dam in the basin was built in 1983, has a surface of ca. 500ha, and a capacity of 13 million m^3. The Ngerengere river is the only outflow of the dam. There have been recurring disputes about the prioritization of urban and industrial water supply from the dam to the detriment of downstream users (IUCN, 2010; Yanda and Munishi, 2007).

Natkhin et al. (2015) describe how mean discharge in the Ngerengere river basin has decreased between 1956 to 2010. Findings indicate, however, that changes are varied and even opposed at different sub-basin gauges. While mean discharge has remained relatively stable at around 0.7 – 0.8m^3/s at the upstream Morogoro gauge, it has decreased drastically from 9.2m^3/s to 5.7m^3/s at the further downstream Mgude gauge. Furthermore, both stations recorded an increase in the span of low-flow and no-flow days (i.e., days with very little or no streamflow), but the same period saw an increase of high-flow events (i.e., floods) only in Morogoro, not Mgude. The divergences are attributed to the different importance that relevant pressures play at each sub-basin level: the general decrease of discharge and increase of low-flow duration is linked to a basin-wide increase in the length of dry periods (but not annual or monthly precipitation – no significant trend could be established in this respect). The transformation of natural areas into agriculturally used land lead to a quickened surface runoff and thereof increase in the magnitude of floods. It seems that the impact of this process was higher in Morogoro than in the less LULCC affected Mgude sub-basin (Natkhin et al., 2015). This research's aim to enhance small-scale analysis of changes and causes by working with pre-defined landscape units based on topography, climate and LULC was mainly based on the findings.

5. Main pressures affecting streamflow in the Ngerengere river basin

Climate

The largest part of the Ngerengere river basin can be classified as a tropical savanna climate, but the western part with its steep slopes of the Uluguru mountains comprises a much more humid region (Peel et al., 2007). Annual rainfall varies accordingly from 800-1,000mm in most parts of the catchment to over 1,500mm in the mountainous areas. Precipitation mainly occurs during the two rainy seasons from March-May (long rains, called Masika) and from October-December (short rains, called Vuli). Rainfall is characterized by a high spatial and temporal variability. The daily temperature ranges between 22° in July-August and 33°C in December-January (GLOWS-FIU, 2014b; Gomani et al., 2010). Throughout most of the basin, annual rainfall is clearly exceeded by annual potential evapotranspiration (Fig.7).

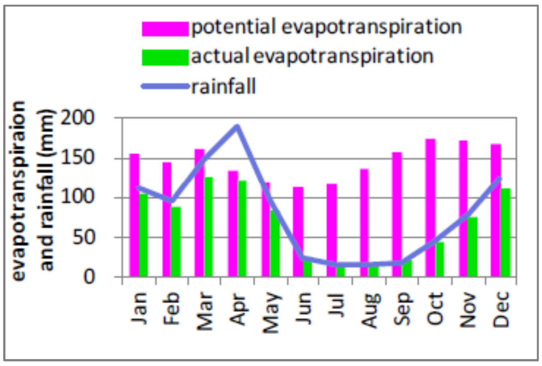


Figure 7: Monthly mean potential and actual evapotranspiration and rainfall in the Wami/Ruvu Basin (p..233 / 8-13, JICA 2013b)

The analysis of data from rainfall stations in the Ngerengere basin has not yielded a significant trend regarding precipitation between 1956 and 2010. The only signifcant change observed is an increase in the length of dry periods, i.e. the number of weeks per year with less than 15mm rainfall (Natkhin et al., 2015). Reviews of larger data sets e.g. for the Wami/Ruvu basin have arrived at similar inconclusive results, with observed but not statistically significant slight declines of rainfall since the late 1990s. The only climatic parameter corroborated by almost every source is a clear increase in air temperature since the 1950s. For the Wami/Ruvu basin, this increase ranges from 0.014 to 0.026°C/year (JICA, 2013c). Since temperature has an important effect on evapotranspiration, it is quite conceivable that this parameter affects hydrological processes just as strongly as a direct change in precipitation would.

Land use and land cover change (LULCC)

LULC is an integral part of hydrological processes because it directly affects climate and soil parameters, and also reflects on the degree of human activity in a given region. The previous research highlighted the role of LULC and the importance of respective data with good spatial and temporal resolution. The LULC dataset for the current research was commissioned for this very purpose. It originates from remotely sensed imagery (Landsat), which was processed, classified and ground truthed by our local project partner Prof. Mbilinyi from the Sokoine University of Agriculture in Morogoro. In total, the period from 1975-2005 is covered in 5 individual time steps (unfortunately, no recent images could be obtained due to band issues and cloud cover).

The provided LULC dataset distinguishes between 8 land use classes: built-up area, bushland, cropland, forest, grassland, swamp, water, and woodland. Swamp and water both account for a relatively small proportion and remain steady over the course of time, therefore they are not included in the following descriptions.

Figure 8 shows the development of each land use class across the analysed time slices for the entire Ngerengere river basin. Particularly striking is the increase of built-up area (+754%, comparing 2005 to 1975) and cropland (+39%), mainly at the cost of woodland (-28%), grassland (-10%) and bushland (-6%). The marginal reduction of forest extent (-1.9%) can be explained by the fact that as of the 1970s, remaining forest patches in the Uluguru mountains had been placed under strict protection.

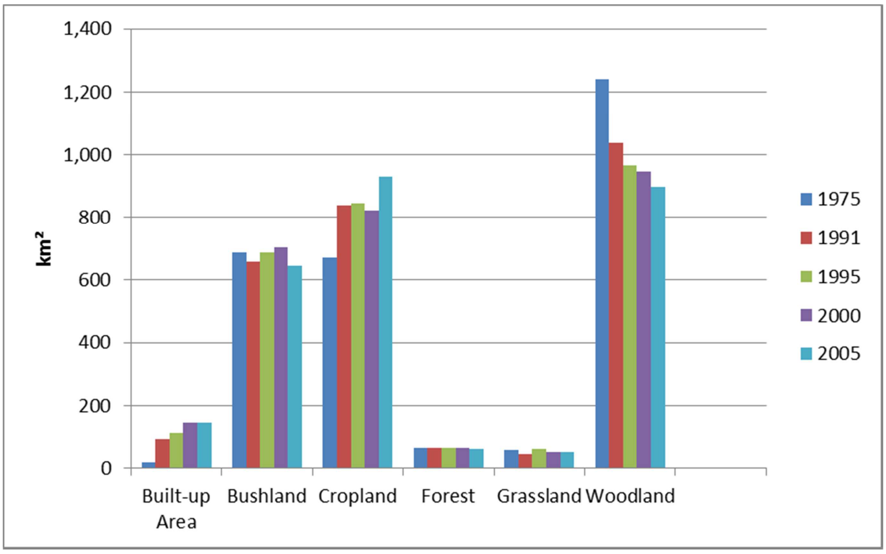


Figure 8: Development of extent of LULC classes in the Ngerengere river basin over time

A look at the expansion of individual LULC classes per landscape units reveals the spatial diversity of developments within the basin (Fig.9).

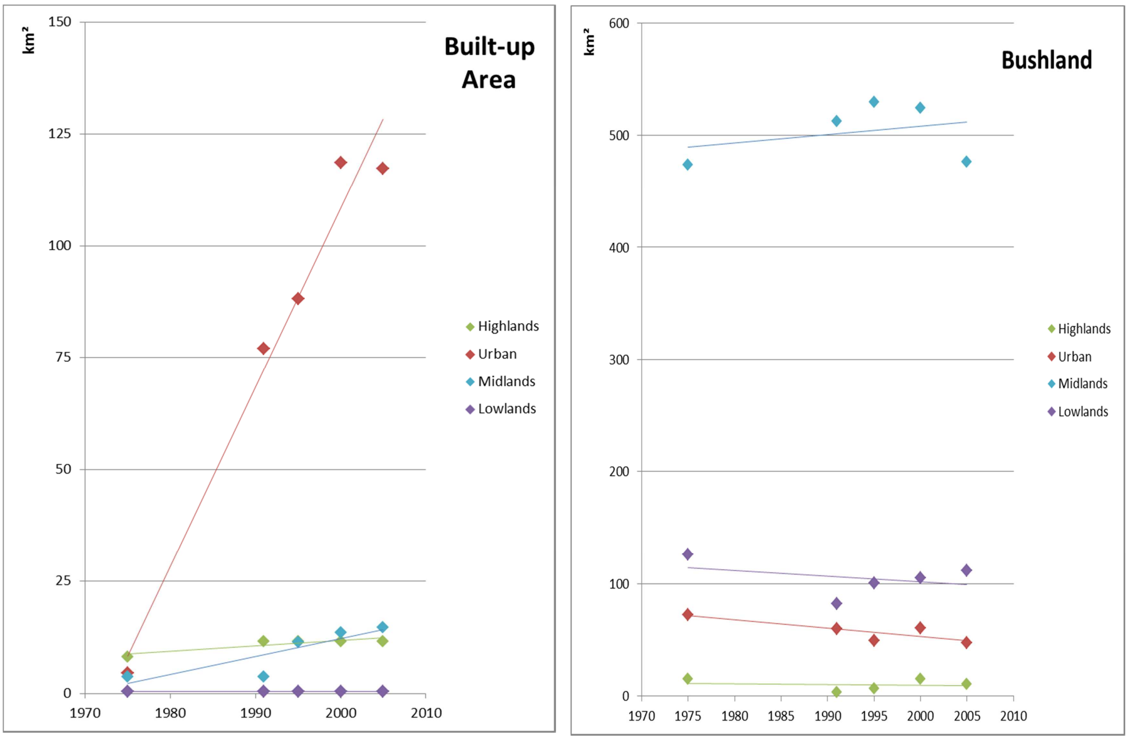


Figure 9: Development of individual LULC classes per NB landscape unit over time

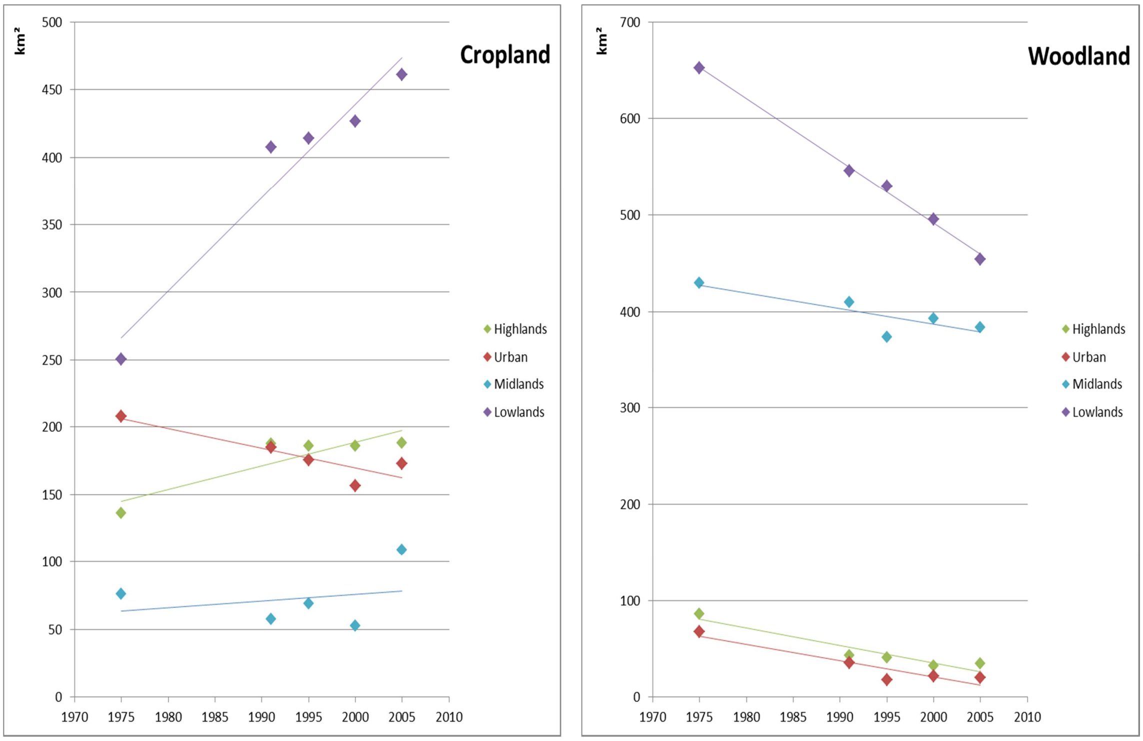


Figure 9 continued: Development of individual LULC classes per NB landscape unit over time

The general increase of crop area at the expense of natural vegetation is in line with descriptions from many other catchments in the region (Kashaigili, 2008; Mtalo et al., 2005; Yanda and Munishi, 2007). Between the 1970s and 2000s, for example cultivated area – that is, land used for annual and perennial crops – has increased by 39% in the basin and by 45% in overall Tanzania (Fig.10). Although different in scale and initial position, the trend is rather similar. The figures also show that a notable increase has occurred in the mid-2000s, hinting at accelerated developments in the current decade.

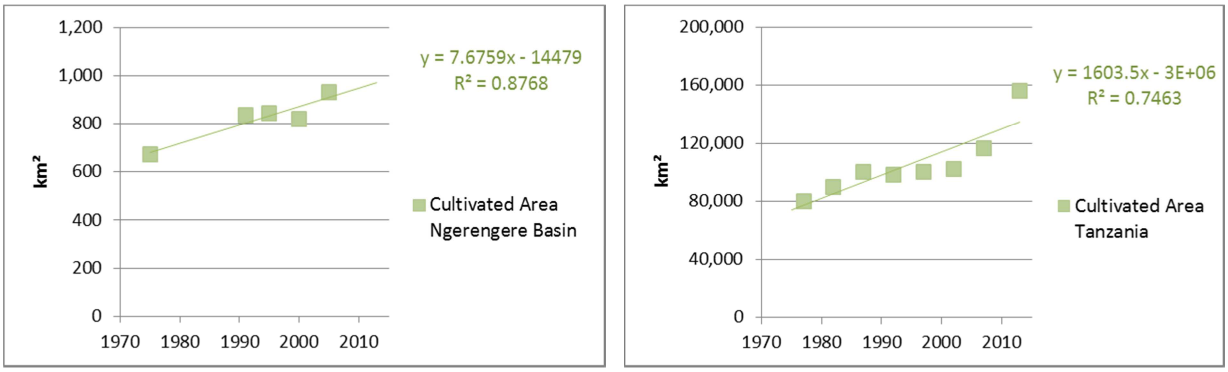


Figure 10: Comparison of extent of cultivated area in Ngerengere Basin (2,780km^2) and Tanzania (947,300km^2) from 1975-2013. Own rendering. Source: (FAO, 2016; Mbilinyi, 2014; NBS, 2006c; NBS & OCGS, 2012a; Regional Commissioner's Office Morogoro, 1997)

Water abstractions (WA)

Water abstractions constitute a major intervention for any catchment water balance. In the case of the Ngerengere river basin, single abstraction amounts are not as high as to have a marked input on flow parameters yet, but the sum of small withdrawals needs to be considered to properly assess climate and LULCC impacts.

Especially in countries with limited hydrological monitoring coverage such as Tanzania, WA data is difficult to obtain. One basic approach is to use population figures and calculate a certain amount of daily water use per head. This is commonly done (e.g. JICA report) and yields quick results, however, total values tend to be overestimated and are not be spatially refined.

For this research, data on registered water abstraction permits for 1995 and 2010 was obtained from the Wami Ruvu Basin Water Office (WRBWO). The acquired database contains information on exact abstraction amounts and locations, as well as the main purpose of the permit holder (i.e. irrigation or domestic/industrial – levels for the latter were too low to place them in separate categories). The downside of this approach is that total values are most likely underestimated, since they only include officially registered abstraction permits and recent investigations show that there is a large share of illegal abstractions.

However, both approaches allow an approximation and arrive at similar insights about the relative development of WA. Figure 11 illustrates how rapidly WA has picked up in the Ngerengere basin over the course of the past decade: with an increase of 166%, total WA has more than doubled between 1995 and 2010. Still more markedly is the increased share of irrigation water abstractions – the last years have seen a rise by 325%, or four times the 1995 value. Even accounting for a possible increase of the share of registered permits vs. actual increased abstraction, the trend is obvious.

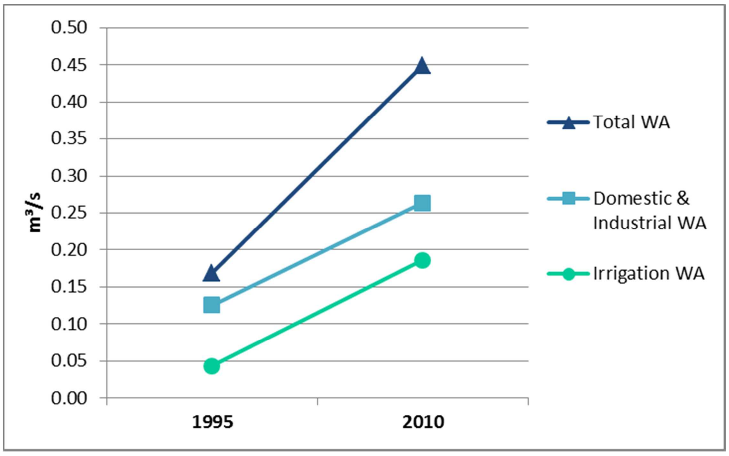


Figure 11: Water abstraction per main use in the Ngerengere basin over time

It is interesting that a differentiation at landscape unit level once more yields distinct differences (Fig.12). The nearly exclusive development in the urban and highland areas may be attributed to general urbanization processes, including the establishment of industries, as well as high-quality grocery production in the vicinity of urban agglomerations. The negative growth in the midland areas is due to the expiration of several permits whose holders had not reapplied as of 2010.

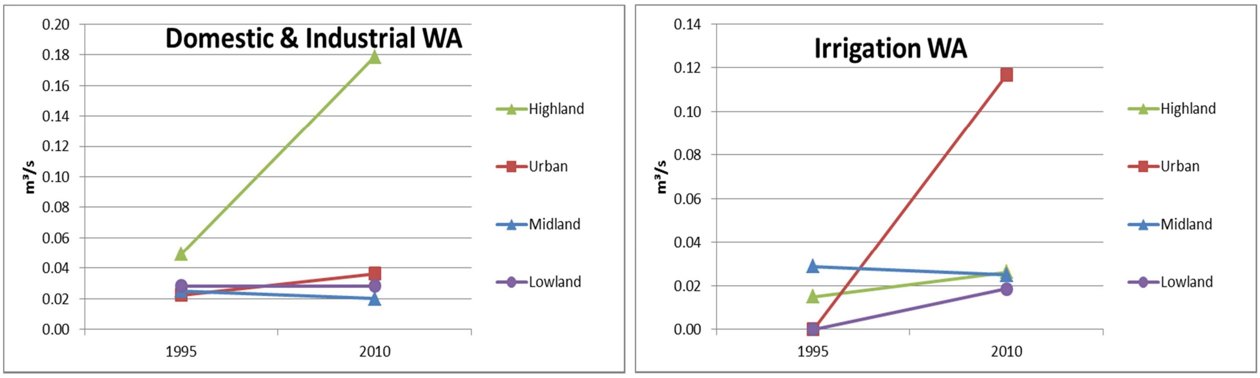


Figure 12: Development of WA per main use for different NB landscape units over time

As with LULCC, WA progression can be compared to the overall development. Over the course of forty years from 1970 to 2010, the total amount of abstracted water has quadrupled in the Ngerengere Basin, and increased sevenfold in overall Tanzania (Fig.13). Although the dimension of abstraction differs, the trend is assimilable. Once again, marked rises occur from the 2000s onwards, and water abstractions are projected to further increase in the coming decades.

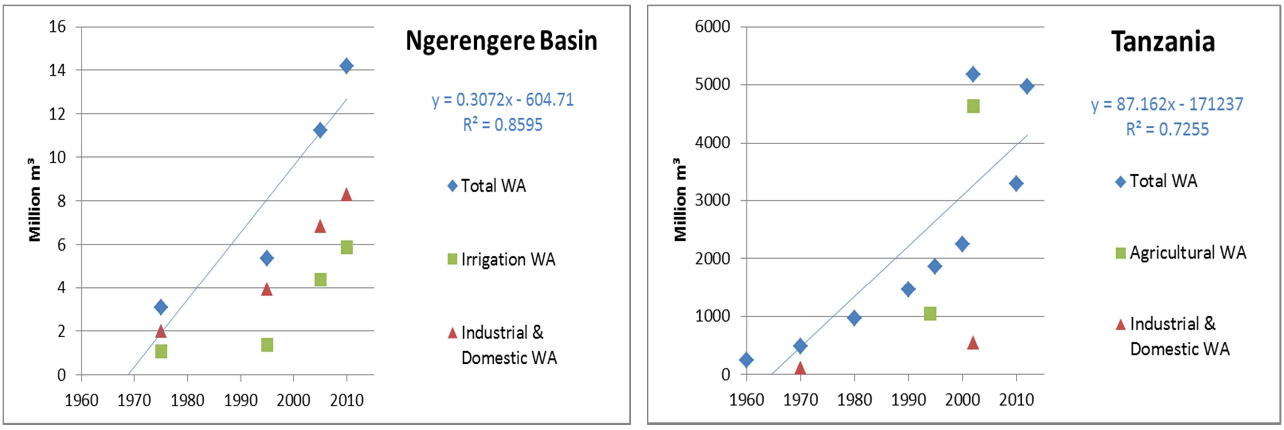


Figure 13: Comparison of water abstraction (WA) in Ngerengere Basin and Tanzania from 1960-2012. Own rendering. Source: (FAO, 2013b; FAO, 2016; SHI & UNESCO, 1999; WRBWO, 2014c)

6. Main driver of pressures in the Ngerengere river basin: population growth

In frames of the DPSIR model, the described proximal causes of hydrologic and environmental change (i.e. pressures) are shaped by general background processes (i.e. drivers). The most important of these drivers in the Ngerengere Basin is population growth.

As in most of Eastern and Southern Africa, increase of agricultural land at the cost of natural vegetation is primarily driven by a growing share of small-holder subsistence farmers, with only about one tenth being attributed to large-scale commercial farming (FAO, 2014). Deforestation is strongly related to an increasing population because firewood and charcoal are still the predominant sources of energy even in semi-urban areas (Mtalo et al., 2005). Water abstractions, too, are mainly linked to an increase of semi-urban population and irrigation water requirement by smallholders (WRBWO, 2008). The need for increased and reliable domestic water supply was also the main reason for the construction of the Mindu dam and reservoir in the upper part of the Ngerengere river (IUCN, 2010; Natkhin et al., 2015).

In 2012, approximately 350,000 people were living in the Ngerengere Basin with an average household size of 4.4[a]. The population density is extremely variable, ranging from 300 in the highlands and 451 in the urban region, to 84 in the midlands and down to 23 in the lowlands (source – see caption Fig.14).

Between 1970 and 2012, the population in the Ngerengere Basin has increased by a factor of 4, which is significantly more than the 2.8 national growth rate during the same period (Fig.14). The relative and total increase of population in the Ngerengere Basin is not only due to natural increase, but also to strong inward migration, which somewhat decouples the regional from the national trend. Due to its accessible location, good connection with transport infrastructure, and favourable climatic conditions, Morogoro town has developed into a prosperous regional capital which steadily attracts agricultural and industrial investments. The current regional growth rate of 2.2% is projected to slightly decrease over the next decades, assuming a post-2020 growth of 1.95%. This means an additional 159,000 people living in the Ngerengere Basin by 2035.

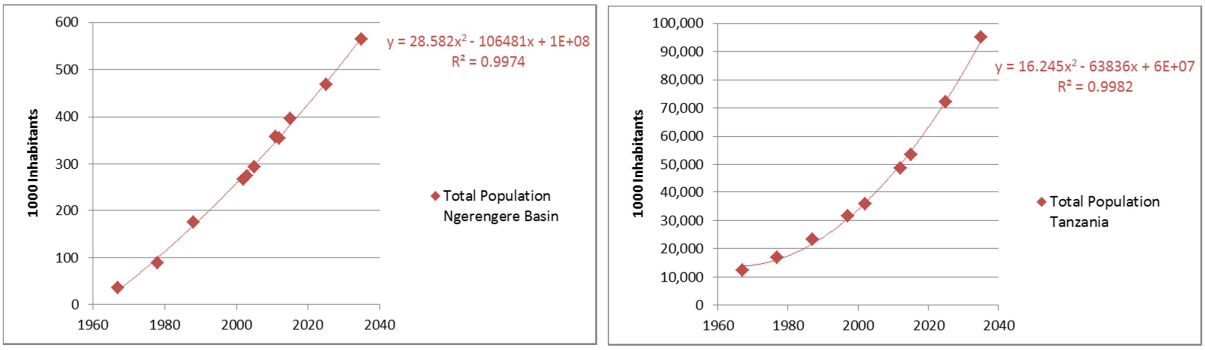


Figure 14: Comparison of population growth in Ngerengere Basin and Tanzania from 1960-2035. Own rendering. Data past 2012 are projections. Source: (FAO, 2016; JICA, 2013b; NBS, 2006a; NBS, 2006b; NBS & OCGS, 2013; Regional Commissioner's Office Morogoro, 1997; The World Bank, 2016)

In addition to population growth, two other drivers have started to play a role in the Ngerengere basin since the mid-2000s, namely agricultural and industrial sector growth. In this case these terms refer to an intensification of processes and infrastructure not only related to the increasing local population but also to a growing nation-wide demand for processed food and goods. This sector development is leading to emerging respective hubs and industrial agglomerations in Tanzania, one of which is Morogoro. The increasing demand is driven both by national population growth (the population of Tanzania is expected to double within the next 25 years) and by an increase in living standards (JICA, 2013c; NBS & OCGS, 2013).

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[a] Tanzanian average household size = 4.8, population density = 51 per km² NBS & OCGS, 2013. 2012 Population and Housing Census. National Bureau of Statistics (NBS) of the United Republic of Tanzania and Office of the Chief Government Statistician (OCGS) of Zanzibar, Dar es Salaam/Stonetown, pp. 264pp.

7. Expected development of main pressures and impact on streamflow in the Ngerengere river basin

Climate

The ISI-MIP climate scenarios imply an increase in precipitation in the northern countries of East Africa (i.e. Ethiopia, Kenya) and a decrease in southern countries (i.e. Mozambique, Zambia) over the coming decades. The signal for Tanzania is inconclusive, and expected changes are rather small. They tend to become more pronounced towards the end of the 21st century (Gornott, 2016). For the Wami-Ruvu basin, an increase of 2.1 - 2.9 % is expected (GLOWS-FIU, 2014a; JICA, 2013c).

Regarding temperature, the climate scenarios imply a clear increase of temperature for all of Sub-Saharan Africa in the range of 2 to 8°C until 2100 (Gornott, 2016). In the Wami-Ruvu river basin, annual mean temperatures are assumed to increase between 2 to 4°C, with a marked increase in very hot days (> 32°C). This would affect an increase of potential evapotranspiration (PET) by around 200-250mm/year by the 2090s. Generally an increasing frequency of extreme events – high rainfall events, periods of scarce or no rainfall – and a shift in rainfall patterns must be expected (GLOWS-FIU, 2014a; JICA, 2013c).

Land use and land cover change

Table 2: Projected development of LULC classes

YEAR	Built-Up (km²)	Cropland (km²)	Woodland (km²)	Bushland (km²)	Grassland (km²)
2005	151	896	890	653	74
2025	247	1067	676	622	51
2035	293	1112	599	607	53

It is expected that the observed expanse of built-up area and cropland in the Ngerengere Basin will continue throughout the next decades. This process will happen at the cost of natural vegetation, i.e. woodland, bushland, and grassland (Table 2 & Fig.15). Forests are except from this development because the remaining patches in the Uluguru mountains are within a forest reserve and strictly protected. It is highly likely that in the future, further land *use* change will play a growing role, i.e. through the intensification of agriculture regarding tillage, irrigation, and crop choice (GLOWS-FIU, 2014a; NBS & OCGS, 2012a; NBS & OCGS, 2012b).

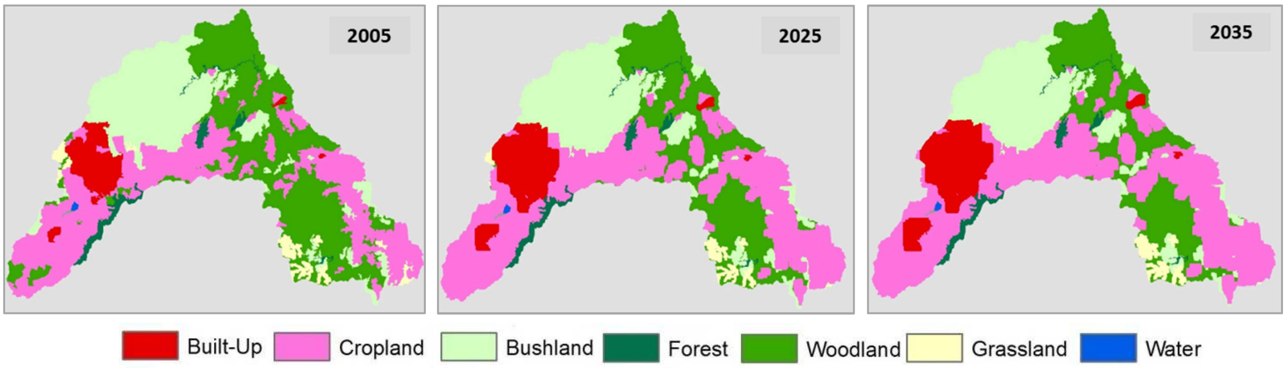


Figure 15: Time series maps of LULC in the Ngerengere Basin (2025 & 2035 projected)

Water abstractions

With the forecasted high population growth, and the strong correlation of water demand and population count, future water abstraction amounts are expected to keep increasing. The scenarios applied in our study show almost a tripling of expectable total water abstractions from 2005 to 2035 in the Ngerengere Basin (Fig.16). More water will be needed for the population and a growing industrial sector, but also for irrigation. There are corresponding plans to increase the capacity of Mindu dam and build additional reservoirs to satisfy growing water demand (JICA, 2013b).

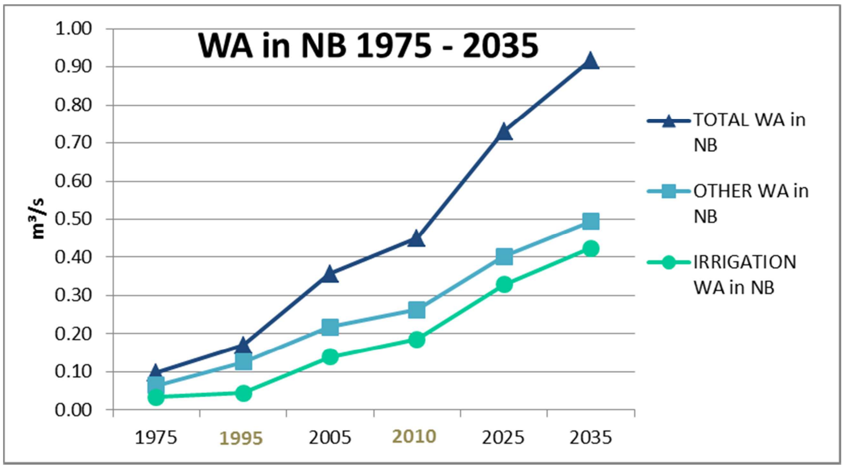


Figure 16: Water abstraction per main use in the Ngerengere Basin over time (1995 and 2010 = present data, rest = projections)

Impact on streamflow

Changes in precipitation obviously alter basin water balance, but also the forecast temperature increases will have strong effects: with increasing evapotranspiration, soil moisture is expected to decrease throughout the basin, thus reducing infiltration to waterbodies and increasing the demand for irrigation water (GLOWS-FIU, 2014a; JICA, 2013c). This example shows very well how climatic effects (e.g. reduced infiltration = reduced low season flow) may be even further exacerbated by simultaneously induced anthropologic actions – i.e. the abstraction of water from rivers and lakes to safeguard crop production during dry spells.

LULCC specifically affects vegetation and soil parameters which determine a whole range of hydrologically relevant processes (i.e. interception, evapotranspiration, infiltration, transmissivity) (Kiersch, 2000; Schulze, 2004). Large scale LULC may even influence local climatic conditions. LULC is reported as one of the leading causes of increased floods and decreased dry season flow in Eastern and Southern Africa (Fig.17) (Schäfer et al., 2016).

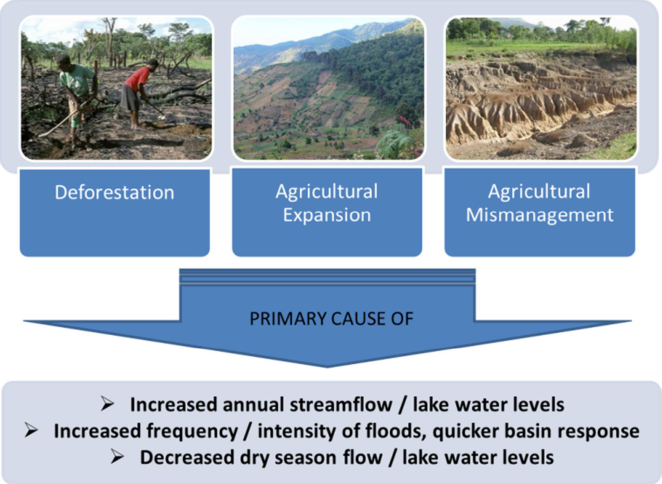
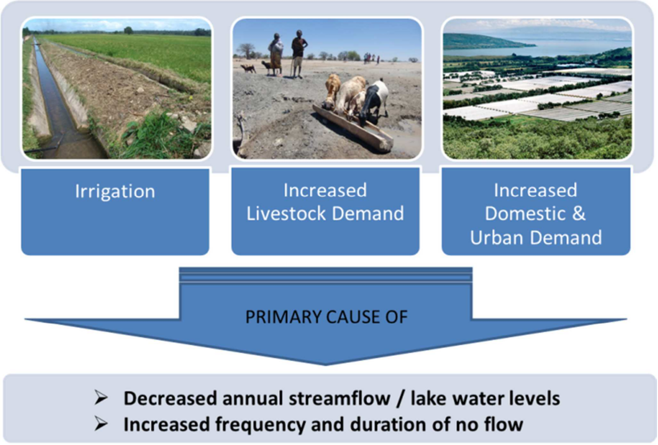


Figure 17: Most frequently mentioned LULCC manifestations and attributed streamflow changes



By its nature, water abstraction is a process which can be purely attributed to anthropogenic actions. The ensuing alterations of groundwater or surface water flows are the leading cause of decreased flow and no flow in Eastern and Southern African river basins (Fig.18) (Arthurton et al., 2008; Maidment, 1993; Schäfer et al., 2016).

Figure 18: Most frequently mentioned WA manifestations and attributed streamflow changes)

The described interlinkages between pressures and streamflow underline our hypothesis that under the given scenarios (assumed increase of LULCC and WA), streamflow in the Ngerengere Basin will feature more flood events, a decrease in low flow, and further increase in no flow days. The question is how strong these effects will be, and at which point they multiply in a way that the entire river water supply (and ecosystem) is seriously endangered. The completed SWAT model runs are currently being evaluated, and the results will be shared as soon as they are available.

On a simple water balance level, current calculations indicate that deficits will arise for the Wami-Ruvu river basin within the next two decades despite assumed stable rainfall levels. Figure 19 shows the monthly water balance for the outflow river gauge of Ngerengere basin. The balance is based on the monthly average discharge of a dry year (year of drought water discharge with 10 year return period), environmental flow and present water use (2011) respective future water demand (2035). It clearly shows that seasonal water deficits (red line in below images) are already present, and will exacerbate in the future (JICA, 2013a) .

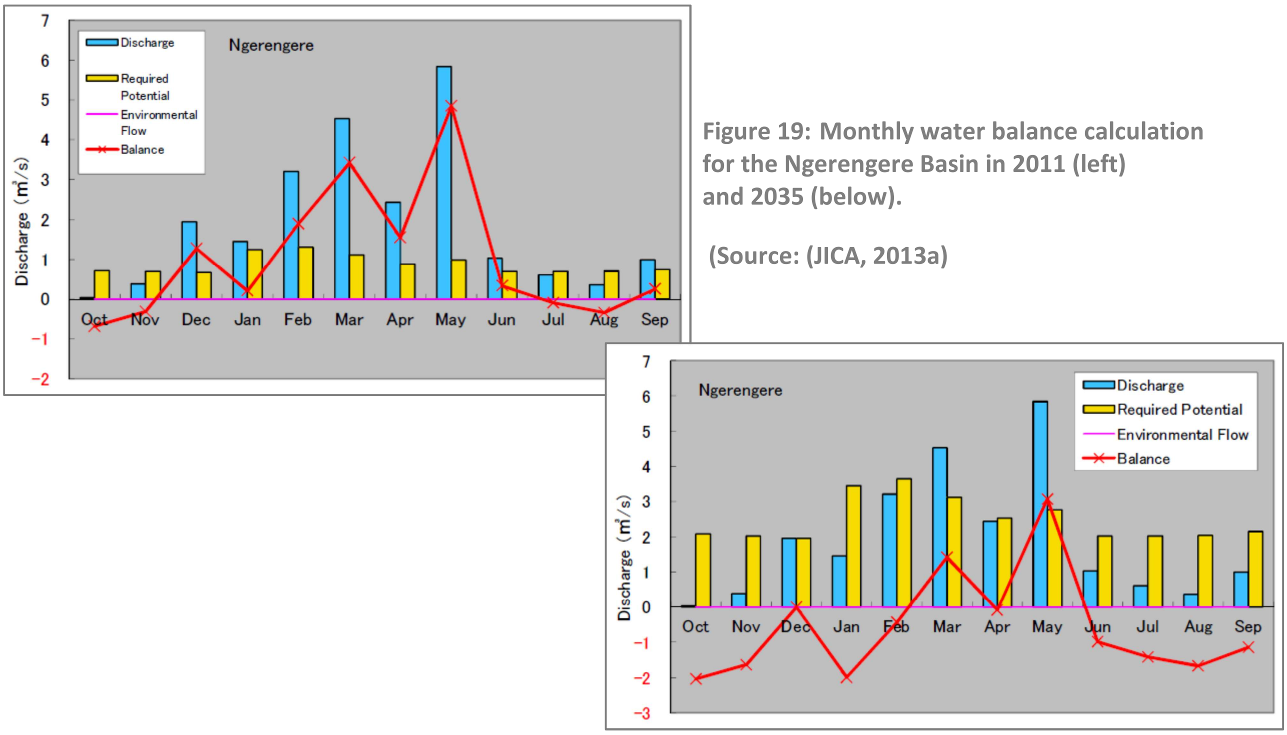


Figure 19: Monthly water balance calculation for the Ngerengere Basin in 2011 (left) and 2035 (below).

(Source: (JICA, 2013a)

8. Implications for agricultural food security strategies

The presented details on the current situation and even more importantly, the outlook on expected future developments, should give a first overview of implications arising for sustainable agriculture and food security efforts in the Ngerengere Basin. It becomes clear that a physical natural resource boundary – in that case for water – already exists at certain times, and that a range of pressures are affecting streamflow with potentially negative consequences. In simple terms, food security is likely to be affected by a) the quantitative limitation of crop production potential (= low yields due to less/shifting rainfall, increased runoff and decreased soil moisture retention capacity, inefficiently used or unavailable irrigation water) and b) the danger of complete crop failure due to extreme events like floods and dry spells.

In terms of basin water resources, the primary problem arising from all described pressures is a negative basin water balance as shown in Figure 19. Even if the same level or more of rainfall is assumed, the loss of basin water storage capacity coupled with the depletion of existing surface water sources will lead to the situation that a growing number of farmers and households will face water scarcity, especially at most critical times such as the dry season. On basin level, natural factors hereby intertwine with anthropogenic factors.

Natural factors can, to a certain extent, be prepared for and countered on a farmer's level. Anthropogenic factors, however, are only controllable by institutions and agreed laws and regulations. In regard to resource management, these two issues have been brought together with the two scales of action distinguishable for recommended measures to ensure sustainable water resources in stressed basins (Fig.20). Basin water authorities play an important role. Access to sufficient and clean water is also a matter of distributive justice. Water sources are often unequally distributed, and down-stream users are completely dependent on up-stream users. A positive water balance at farmer and basin scale is key to food security and long-term development of rural livelihoods. This statement is not only true for the Ngerengere Basin, but for any catchment operating under limited available water resources like the majority of Eastern and Southern African basins.

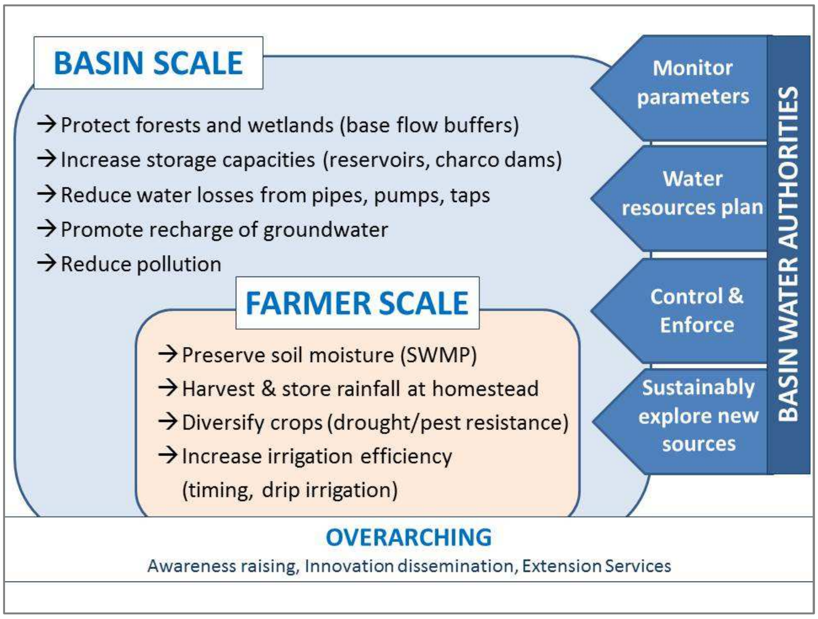


Figure 20: Simplified schema of potential measures for ensuring sustainable river basin water resources
(Own rendering, compilation of recommended actions from reviewed literature.
An overview of SWMP (Soil Water Management Practices) is provided in Annex 1)

9. Next steps

Both the applied methodology as well as the evaluated model results will be presented and discussed in peer-reviewed papers within the next year. The papers are understood and will be presented as part of the Trans-SEC project.

The papers are also part of a proposed Ph.D. thesis on “Water use and land use change in the Ngerengere river basin and its impacts on river discharge – Past and projected developments and implications for agricultural development”, to be elaborated for the Department of Earth Sciences at the Freie Universitaet Berlin. Details are currently being discussed and will be shared as soon as available.

Appendix I:
Soil Water Management Practices (SWMP)

In light of the described prospects, agricultural strategies to ensure food security must factor in *limitations of total and/or seasonal water availability.* This implies two important aspects to maintain and/or increase overall production and contribute to ensured food security: firstly, the efficiency of water use needs to be increased in all respects; secondly, water needs to be used more specifically to combat potential shortages during sensitive cropping periods.

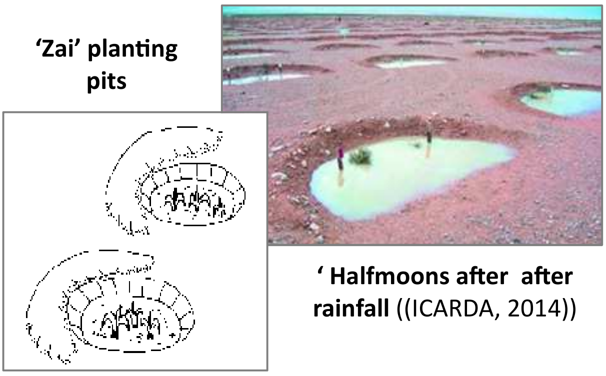
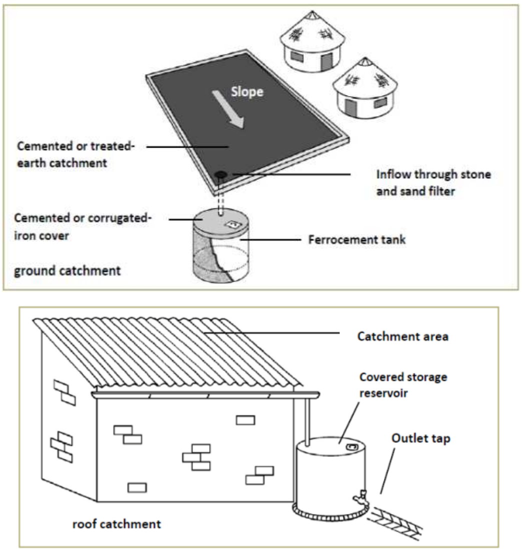
One strategy to attain these results could be the implementation of soil water management practices (SWMP). SWMP can be broadly grouped according to the following categories: (I) practices aiming at maximizing infiltration, reducing surface runoff and evaporation, and improving soil moisture storage in the root zone, (II) micro-catchment (in-situ) rainwater harvesting methods, and (III) macro-catchment rainwater harvesting and storage techniques. These measures can be implemented locally, without high investment coasts, by either individual farmers or small collective groups, and further supported by additional practices such as improved timing of seeding, or increased weeding (Biazin et al., 2012; FAO, 2008).

A lot of research has been conducted in regard to SWMP and its effect on yields and soil parameters on plot scale. The positive effects (e.g. soil water content in the root zone increasing by up to 30%, and yields doubling to even sextupling, if fertilizer is being applied at the same time) are encouraging and indicate large potential for stabilized or even increased crop production (Biazin et al., 2012; FAO, 2008; Ngigi et al., 2008; Rajabu et al., 2005; Rockström et al., 2002).

In addition, SWMP has shown to be a potential tool to stabilize hydrologic parameter development at drainage basin scale. Studies from Ethiopia for example indicate that large-scale implementation of SWMP (in this case, gully stabilization, hill side terracing, planting of forage grass and trees along exposed hillsides, abandonment of post-harvest grazing, and cordoning off of degraded land) can lead to a reversing of negatively connoted hydrological changes. In the described region, mentions of positive effects comprise the cessation of flooding hazards, the rise of groundwater tables and subsequent re-emergence of shallow groundwater wells, and the restoration of riparian vegetation. Ten years after the interventions started, overall water availability in the catchment had increased significantly (Alemayehu et al., 2009; Kiersch, 2000; Nyssen et al., 2010; Rockström et al., 2002).

Table A1: Overview and examples of soil-water management practices by categories

(own rendering, adapted from Biazin et al. (2012), with data from Rockström et al. (2002) and FAO (2008))

Overview of soil-water management practices by category		
Category	Practices	Example
(I) Maximizing infiltration, reducing surface runoff and evaporation, improving soil water holding capacity, and maximizing root depth	Ridging, mulching, application of manure, various types of furrowing and hoeing, ripping, conservation tillage/agriculture, vegetation protection policies, contouring	 **Maize under conservation agriculture (no tillage), Malawi** ((FAO, 2013a))
(II) Micro-catchment rainwater harvesting methods	Pitting (Zai pits), contouring (stone/soil bunds, vegetation barriers), terracing (Fanya Juu, hillside terraces), micro-basins (Negarims, halfmoons)	**'Zai' planting pits**  **' Halfmoons after after rainfall** ((ICARDA, 2014))
(III) Macro-catchment rainwater harvesting and storage systems	*Rainwater collection* from rooftops, paved surfaces, natural slopes, rock outcrops --- *Water storage* in containers/tanks, underground tanks, traditional open ponds, micro-dams (Charco dam) and spate-irrigation systems --- *Water application* for irrigation, livestock or domestic use	 **Rainwater harvesting and storage systems** ((ClimateTechWiki, 1998))

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