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Drainage Basin Water Resources Development and Attributed Causes in Eastern and Southern Africa

Literature review report in frames of the Trans-SEC project study on water resources development in the Wami-Ruvu river basin, Tanzania

Meike Pendo Schaefer, Ottfried Dietrich
Institute of Landscape Hydrology
Leibniz Centre for Agricultural Landscape Research (ZALF)
Müncheberg, Germany

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Müncheberg, Germany

zalf. Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V.

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"Drainage Basin Water Resources Development and Attributed Causes in Eastern and Southern Africa"

1. INTRODUCTION

In many regions of the world, water availability is already the main limiting factor for food production. On the other side, water demand for agricultural land use increases, especially water demand for irrigation to raise and stabilise yields [*Rajabu et al.*, 2005]. In frames of the recently launched **research project Trans-SEC**[1], 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, an embedded study will analyse the water resources development in the project region. In addition to a wide range of social, economic and natural resource factors influencing food systems, water resources play a crucial role. The basis for a valid evaluation of upgrading strategies and a sustainable allocation of the usable water resources is a comprehensive knowledge of the natural resource water in the context of population growth, economic development, climate change and increasing pressure on natural resources [*Mango et al.*, 2011].

The Trans-SEC project region encompasses the districts of Chamwino, Dodoma and Kilosa, Morogoro, both of which are located within the Wami-Ruvu river basin. The research focus of the project will therefore lie on these areas; however, in order to better place regional dynamics within a larger context, the literature review at hand will look at water resources developments in all of Eastern and Southern Africa.

Fig. 1: Tanzania Locator Map ([*AllTravels*, 2014])

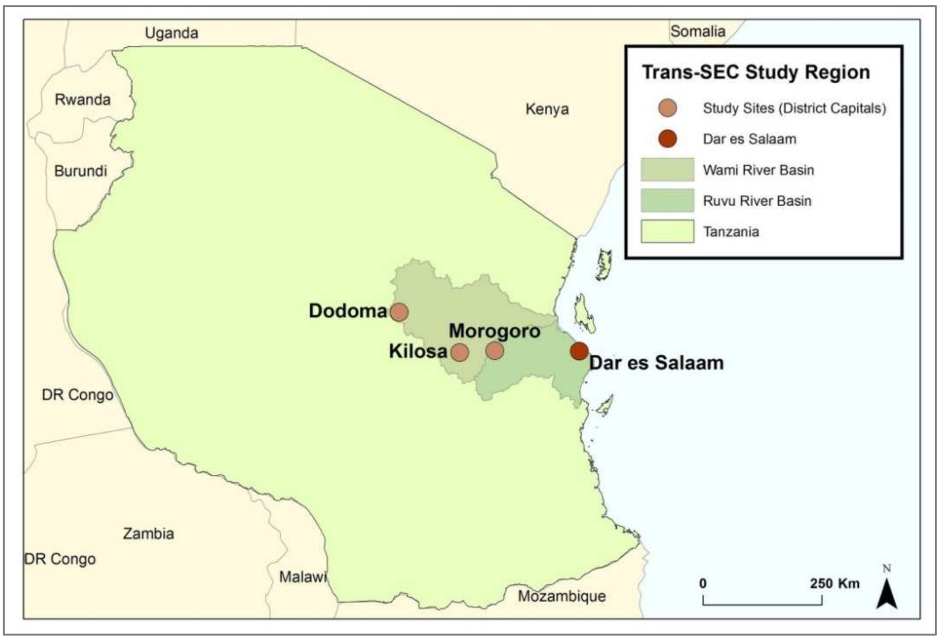

Fig. 2: Map of Tanzania with Trans-SEC study sites and Wami-Ruvu basin

[1] Trans-SEC: Innovating pro-poor Strategies to safeguard Food Security using Technology and Knowledge Transfer, 2013 to 2018

From human consumption to agriculture, industries, fisheries, transport/navigation and electricity generation, water resources form the basis of almost all human development [*Calder et al.*, 1995; *Mwanza*, 2003]. The magnitude of human water demand, and its ratio to natural water availability, can be determined through water balance assessments on drainage basin scale. The thus obtained knowledge on the hydrological regime of lakes and rivers is an important instrument in water resources planning and management [*Vörösmarty et al.*, 2000].

Over the last century, **changes in the water balance of drainage basins have been observed in many African countries.** These changes manifest themselves in both increases and decreases of hydrologic parameters; however, often a resulting water scarcity is described [*Conway et al.*, 2009; *Mitchell*, 2013; *Snoussi et al.*, 2007]. Especially in urban regions of developing countries, an increasing number of studies report negative impacts of poor water quality on human health and economic production [*Baker and Miller*, 2013; *Vörösmarty et al.*, 2000]. In fact, shortage of (clean) water already constitutes one of the major reasons for constrained development and ensuing water conflicts in sub-Sahara Africa [*Calder et al.*, 1995; *Wolf et al.*, 2003].

The reasons for the described changes are diverse, and it is often difficult to establish unequivocal relations due to their complexity and interlinkages. Natural factors, such as climate change and tectonic activity, are encountered together with human induced factors i.e. construction of dams and reservoirs, water abstraction and land use change, which in turn are driven by population growth, national policies, and macroeconomic developments [*Chimtengo et al.*, 2013; *Githui*, 2008; *Legesse et al.*, 2003; *Murimi*, 1994].

In order to better understand past and current water resource dynamics both in a geographic as well as in a content-related way, one of the first steps of the Trans-SEC water resources study was to conduct **a literature review on the issue of drainage basin water resources development in Eastern and Southern Africa**. Of particular interest were the described hydrologic changes and the attributed causes. The latter cover a wide range from climatic to anthropogenic factors, and are especially important for an in-depth comprehension of processes affecting water resources. Many of these processes are associated with human, particularly agricultural, development. In order to establish a sound scientific research approach and eventually define sustainable upgrading strategies concerning food security, these direct and indirect consequences of human action need to be known and taken into consideration.

Another matter of interest was the question whether any patterns or trends can be discerned, either regional or temporal, from the findings described. This would be helpful in placing observed changes within the project region in a larger regional and/or timely context. It could also help in estimating future developments and trends more precisely, for example for hydrologic modelling. Last but not least, the knowledge of proceedings from a large number of drainage basins with varying backgrounds will facilitate the possible extrapolation and regionalization of findings, which would be beneficial for a long-term and extensive applicability of Trans-SEC project findings.

It can thus be subsumed that it is the aim of this study to investigate the findings of research studies conducted in Eastern and Southern Africa in recent decades to discern possible patterns or trends of hydrologic change and attributed factors.

Evaluation of review situation

Before embarking on the literature search for specific references to drainage basin developments, a cross-section search was performed to look for previously conducted review studies. It was found that there are only four review studies describing the development of a larger number[2] of drainage basins, in this case exclusively river drainage basins, in Africa. *Snoussi et al.* [2007] describe the development of four river basins (two of them, Tana and Rufiji basin, located in Eastern Africa) in respect to the impacts of damming and human water abstraction. *Conway et al.* [2009] present the broadest approach both geographically as well as in respect to impact factors, however, they still only look at four basins (Nile, Tana, Okavango and Zambezi river catchments) in Eastern and Southern Africa compared to ten in Western and Central Africa. *Mitchell* [2013] focuses on the transformation of wetlands in sub-Saharan Africa, in frames of which they consider eleven river basins, six of them in Eastern and Southern Africa (Nile, Victoria, Great Ruaha, Rufiji, Zambezi and Okavango river catchments). *Mahe et al.* [2013] finally exclusively investigate hydrologic changes in twelve river basins of North Africa, West Africa and Central Africa. It can thus be concluded that no review of drainage basin water resources development of the scope intended within the Trans-SEC project has yet been carried out.

Structure of report

The present literature review is structured in six chapters. An introduction and short reference to the Trans-SEC project is followed by chapter 2, which presents the review approach, selection criteria and analysis assumptions. Chapter 3 establishes the applied terminology and hydrologic parameters investigated in the reviewed references, and briefly describes the main causes of hydrological change in sub-Saharan Africa. Chapter 4 and 5 constitute the core of the report. The first concludes with some aggregated findings on drainage basin water resources developments and attributed causes in Eastern and Southern Africa since around the year 1900. The latter provides a more detailed analysis of reported changes of selected hydrologic parameters in drainage basins within the last 40 years[3], with special focus on individual pressures behind the stated causes of change. The report concludes with a short summary and outlook on expected developments and an assessment of their relevance for the Trans-SEC project in chapter 6.

[2] More than four

[3] For matters of comparability, the timeframe for this analysis was narrowed to changes described between 1970-2010

2. METHODICAL APPROACH

The following chapter provides background information on the approach and methodology applied in creating the present literature review. The setup is roughly oriented by the sequence of working steps.

2.1 Study selection criteria

The literature analyzed for this report was compiled during an extensive literature search including databases on peer reviewed publications, publication databases of hydrologic/environmental research institutes and NGOs, as well as government institutions. The search was **aimed at references in studies or reports describing observed changes in drainage basin hydrology** in sub-Saharan Africa, which complied with the following selection criteria:

1. **Hydrologic delineation**, i.e. study must refer to a river or lake drainage basin/ catchment/ watershed as spatial boundary
2. **Selected parameters of surface hydrology**, i.e. reference must be made to runoff, streamflow, river/lake water levels or lake extent (references to precipitation were not considered)
3. **Observed data records**, i.e. reference must be based on observed data covering a period of min. 10 years; if modelling was applied, modelled data sets must refer to past developments and be backed by observed data periods at least two times as long as the modelled period
4. **Rural area**, i.e. no references to hydrologic developments in urban areas were considered
5. **Geographic** relevance, i.e. described basin lies within mainland Eastern and Southern Africa[4]
6. **Temporal** relevance, i.e. reference describes historic or recent changes within the 20st and 21st century (changes referring to previous centuries or geological eras were not considered)
7. **Water quantity,** i.e. reference describes changes in water amount within drainage basins

The first two criteria are a prerequisite for any valid hydrological analysis under the given circumstances[5]. Criteria three to six were established in order to narrow down the findings to a geographic and temporal context which is most relevant for the research frame of the Trans-SEC project. In the same respect, criteria seven was set because changes in water quantity constitute the primary water resources issue observed within the project region. Drainage basin size, physical properties (e.g. mean annual precipitation, rainfall pattern, topography) and the attributed causes of change were other variables recorded for the analysis but did not serve as selection criteria lest unnecessarily reducing the sample size.

When complying with all above criteria, we applied a last concluding principle stating that if the same author described the same drainage basin with basically the same data set in different publications, only the most recent publication and reference was considered. Solely if new or additional data or additional sub-basin areas were included did this merit a second entry in the database.

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[4] According to the geographical classification of the United Nations; mainland Eastern Africa comprises Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Somalia, South Sudan, Uganda, United Republic of Tanzania, Zambia, Zimbabwe; mainland Southern Africa encompasses Botswana, Lesotho, Namibia, Republic of South Africa, Swaziland UN (2013), Composition of macro geographical regions and sub-regions, edited, United Nations Statistics Division.

[5] Strictly speaking, river flow can be deduced from rainfall, however, the process is time intensive and requires a lot of detailed input data, which is the reason why only references providing the results of such analysis were included in this review.

2.2 Database structure

The foundation of the present review is a collection of 132 **references**[6] from studies or reports describing observed changes in the hydrology of drainage basins as defined by above criteria. While reviewing these references, a number of information was collected on each and entered into a MS Excel spreadsheet according to a previously elaborated structure. The respective keywords as well as the most important definitions are presented in fig. 3 and described in the subsequent passage.

Firstly, basic information on the source of each reference was recorded as detailed by the keywords on "reference background". The study time span relates to the exact time period (first to last year) a publication is referring to in respect to the analyzed data and described changes. Each reference was also labeled with a consecutively numbered **internal reference number**. This number was used as an ID to link information and sources throughout different analysis tables.

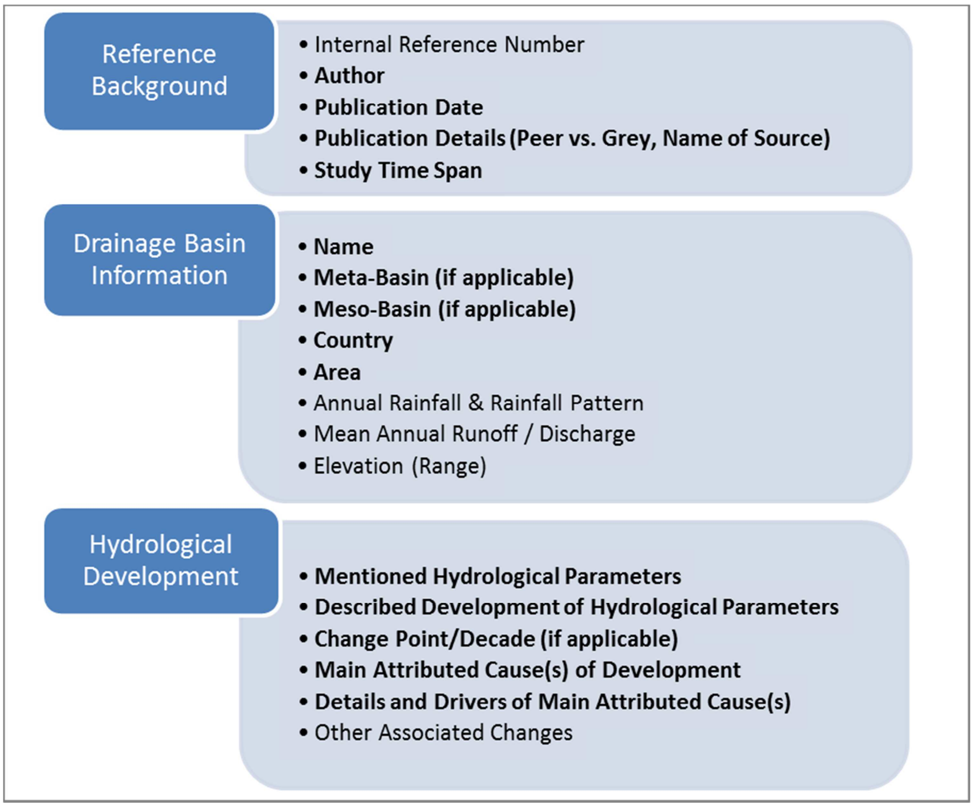

Fig. 3: Overview of information collected in literature review database
(bold lettering indicating points that were used for analysis)

A second subject area was dedicated to information on the described drainage basin. All entries were listed by the name they were referred to in the reviewed references (if the given name was outdated as for example in the case of some of the East African lakes, it was endorsed by the name currently in use). If the original mention was made to a sub-basin, information on the **meta-basin** was included**.** A meta-basin herein is defined as the entire drainage basin of a river eventually draining into the ocean, or terminating in a lake without outflow[7]. In cases of especially large rivers, a further meso-basin scale for better distinction was introduced, which was generally named after the main tributaries of a meta-basin.

↳ E.g. ***Birr*** river basin (sub-basin) < ***Blue Nile*** basin (meso-basin) < **Nile basin** (meta-basin)

[6] Throughout this report, **reference** is used as the term describing each account of separate drainage basins. This term was chosen because a publication may contain more than one description of independent drainage basins. If one author for example published a paper comparing the development of two distinct drainage basins, these would be counted as *two references* but only as *one publication*.

[7] For this review, the FAO delineation and names for African meso- and meta-basins (hydro basins) were employed (FAO (2009), Hydrobasins as delineated from HydroSHED Project in *GeoNetwork - Database of Geo-Spatial Data*, edited, Food and Agriculture Organization of the United Nations.)

Furthermore, the area of a drainage basin and the country/countries it lies within were parameters gathered in this context. Data on annual rainfall in mm as well as on the pattern of rainfall (bimodal, unimodal, mixed), on mean annual runoff/discharge and on the elevation (average, range from min. to max.) of a drainage basin were recorded when available.

The third subject area revolved around the observation of water resources development in the given drainage basin. The **hydrologic parameter** refers to the parameter(s) chosen for the description of the respective development, e.g. annual streamflow or river/lake water levels, occurrence of floods, low flow, etc. A change point/decade is understood as the point in time were a significant change in parameter value can be quantified/determined. If a change was mentioned, the **attributed cause(s)** of the described development as indicated by the author of the reference were noted along with the most relevant information about each cause. Finally, if other associated changes, either hydrological or from any other field (e.g. effects on local economies or infrastructure) were mentioned, this too was recorded.

The information collected in the review database is supplied in Annex 1 and 2 of this report. These tables provide an aggregated overview of all mentioned entries on the above keywords[8]. By introducing the internal reference numbers, they also constitute the link to the subsequent frequency and analysis tables of Annex 3 to 8.

2.3 Definition of terminology

Definition of attributed cause and distinction between drivers, pressures and states

The great majority of reviewed studies contained a statement on the most likely reason for the described developments in drainage basins. In order to provide a stringent and clear frame for this review, a **modified DPSIR (Driving forces, Pressures, States, Impacts and Responses) model** was chosen to structure these causes and underlying drivers of observed change. The DPSIR concept has been applied in several studies assessing drainage basin changes [*Arthurton et al.*, 2008; *Schulze*, 2004] and, to our current knowledge, represents the best framework for our means. The structure and attributed terms relevant for this review are summarized in fig. 4. As the aim of the review purely lies in *quantifiable* hydrologic changes, the *Responses* section of the framework will hereby be disregarded. Based on [*Schulze*, 2004], the elements of the model are defined as:

- ***Driving forces:*** General, background features of change
- ***Pressures****:* Specific, proximal causes of change
- ***States*** : Conditions of hydrological parameters/entities (compared to their history)
- ***Impacts:*** Results of state changes for environment and people

The focal aspects of the model for this report are *Pressures* and *States*.

[8] Keywords here only represent the part of information collected which was relevant for this report. In fact, a broad range of additional data e.g. on water quality, water conflicts, the methodology applied in the reviewed studies, and so on was also surveyed. It is expected that the not yet processed entries will find application in a separate analysis at a later time

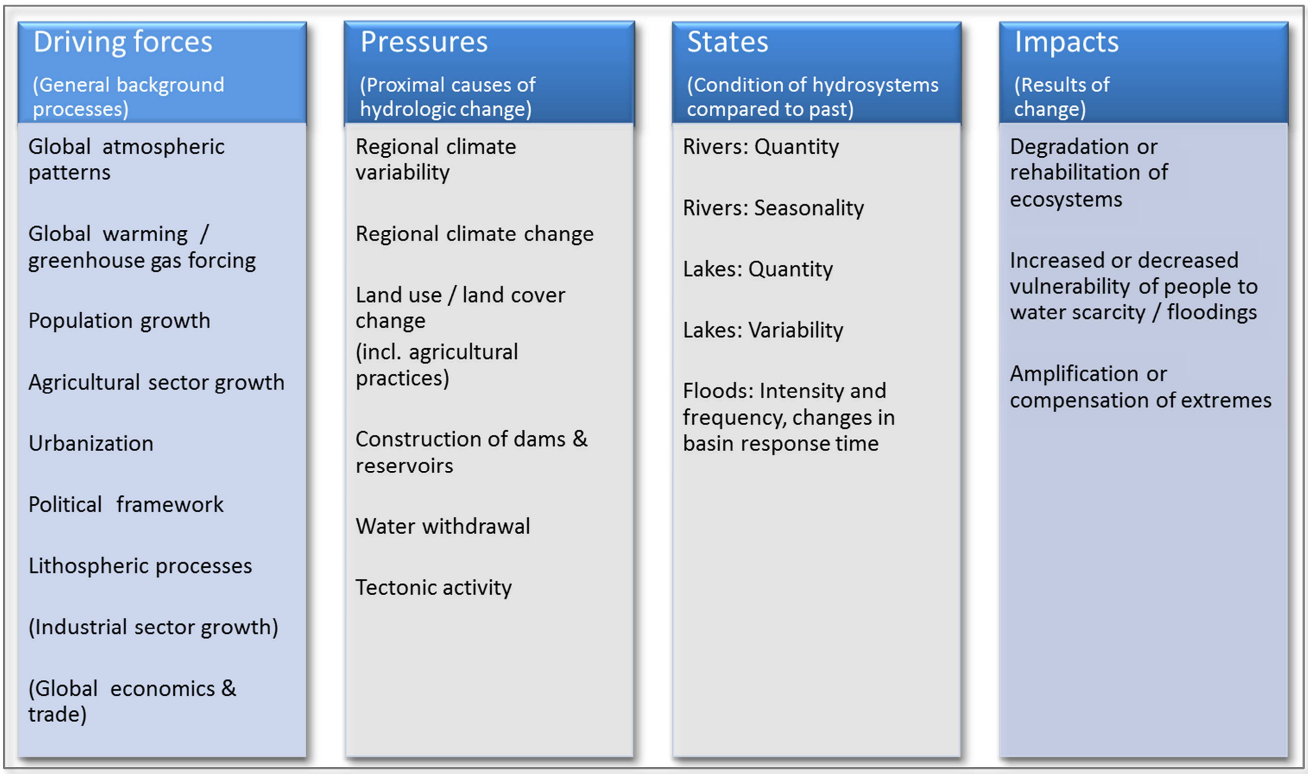

Fig. 4: Hydrologic changes at drainage basin scale structured in terms of a modified DPSIR model
(adapted from *Schulze* [2004], supporting data from *Arthurton et al.* [2008])

Information on ***Driving forces*** as well as ***Impacts*** was collected during the review, but only considered marginally at relevant passages in chapters 5 and 6. The most frequently cited *Driving forces* among the reviewed references were population growth, agricultural sector development, and global warming respective global atmospheric patterns. Urbanization, political framework and lithospheric processes were named by a handful of references only. Industrial sector growth and global economics were not mentioned explicitly by any reference, but the influence of industries on water resources and linkages to global agricultural trade were described for a few basins[9].
The issue is that driving forces are hard to be attributed to specific pressures, and they can and do affect and interplay with each other. The same is true for pressures; the resulting level of interconnectedness and backlashes is highly complex and any direct attributions and generalizations in regard to *Impacts* become almost impossible. Furthermore, *Driving forces* are inherently important as background drivers, but they constitute a level that is beyond any potential intervention in frames of the Trans-SEC project. These two aspects were therefore not closely focused upon here but would surely merit an own study.

An aspect we did focus on was ***Pressures***. The pressures were organized by grouping the original proximate causes of changes as named by the authors into the following categories[10]:

- **Climate variability / change** = Changes in rainfall and temperature

[9] Which references exactly can be seen from the parameter-pressure overview table provided in Annex 4.1 through 8.
[10] More details on these main causes of hydrologic change in Africa will be provided in chapter 3.2.

- **Land use and land cover change** = All processes leading to land cover and land use changes, i.e. deforestation, afforestation, expanse of agricultural land, urbanization, drainage of wetlands, agricultural mismanagement (e.g. overgrazing, soil degradation through inappropriate plowing techniques, ...)
- **Water withdrawal** = Abstraction of water (primarily from surface source) with differentiation of specific use e.g. irrigation, livestock, domestic, urban, industrial
- **Dams and reservoirs** = Damming of rivers with differentiation of purpose of dam, e.g. for irrigation, generation of hydropower, or urban water supply
- **Tectonic activity** = Morphological changes through earthquakes, fault lines, emergence of hot springs, …

These pressures were then put in relation with respective ***States***, i.e. changes in annual or seasonal streamflow, lake water levels, but also changes in the frequency and intensity/duration of floods, low flow, no flow days, and flashier basin response[11]. The resulting testimony on qualitative and quantitative relations constitute the core of the literature review and provide the basis for chapters 4 and 5.

It is important to mention that the respective terminology used in the reviewed references is diverse and, at times, fuzzy. For example, a recurring term is 'environmental change', which is variably used to describe either pure land use change impacts, or sometimes incorporates water withdrawal and/or climate change impacts [*Githui*, 2008; *Notter et al.*, 2007; *Stoof-Leichsenring et al.*, 2011].

For the entry into the database and ensuing categorization, we therefore tried to track down mentioned causes to the most precise category possible. Where viable, we sometimes made assumptions for the categorization, e.g. when a pressure such as land use change in an agricultural context was not further defined, we assumed "agricultural expansion" as long as no urbanization or industrialization trends were mentioned. If the context was unclear altogether, the reference was classed in a general group such as "LULCC" only.

In addition, we sometimes renamed the causes stated by the authors. For example, if an author stated "climate change" as the main pressure, but the analyzed data only covered 20 years, the term used for the report analysis would be "climate variability" because in frames of our report, "climate change" implies a trend of 30 or more years.

Great care was applied in recording and interpreting all above information on the level of highest available detail; however, if at this stage an error should have occurred it was most likely by misinterpretation of context and we are happy to receive clarification on the matter.

[11] For more details on these hydrologic indicators, please see chapter 3.1.

Definition of trend

We applied the term **trend** to investigate the development of water resources in drainage basins, hereby more closely defined as *a specific change of any described hydrological parameter persisting for more than two decades*[12]. How and when this change had been brought about was then itemized in additional, respectively detailed passages. As for the main findings, the developments of hydrologic parameters in drainage basins in this report are broadly divided into the following categories as modified from [*Shahin*, 2002]:

No trend → no discernible change, resp. cyclic fluctuations around a long-term average

Trend → changes over time with distinctive increasing/decreasing tendency, either

a) gradual changes over time
b) abrupt changes at certain points in time

Mixed → Both increasing and decreasing trends within a drainage basin in observation period

In case of changes in a hydrologic regime, a further general distinction can be made between a) changes of the overall water availability in a drainage basin, and b) the seasonal distribution of available water. Both aspects are investigated and play an important role in the attribution of main pressures.

Obviously, the reported trend is highly dependent on the observation period. During the two centuries considered in this review, the same drainage basin may have experienced all of the above states at some point. The general analysis of trends among all drainage basins for the entire data period (1900-2010) can therefore only be an approximation. The analysis over the second, shorter time span (1970-2010) is more expressive in this regard.

2.4 Analysis approach

The above outlined database constitutes the source for the results presented in this report. These were arrived by in two steps.

a) Analysis of trends and patterns in entirety of drainage basin studies

Upon categorization and recording of reported trends for each basin study, the entirety of entries was statistically analyzed for frequencies in regard to annual streamflow/lake water level trends, spatial/ geographical characteristics, basin size, lake type, and attributed cause during the entire period of data availability (1900-2010)[13]. River and lake drainage basins were separately analyzed for matters of better comparability. The findings are briefly presented and discussed in chapter 4.

[12] This time span is in following with the WMO distinction between climate variability and climate change, which is based on a reference period of 30 years. It does not refer to any trend analysis, but rather reflects the wording found in many of the reviewed studies.

[13] Only topics with a large enough number of entries were chosen for the analysis; this lead for example to the exclusion of mean annual runoff/discharge. Also both mean annual rainfall and elevation was predominantly expressed in ranges with a very large variability between minimum and maximum values. Therefore, this information too was excluded from the analysis at this point, even though it might be used at a later point given some additional editing of the database.

b) Detailed analysis of pressures and reported changes in hydrologic parameters
In a second step, all references to either river or lake drainage basins which depict a trend in water resources development in the last 40 years (since 1970) were condensed in a sub-group and further scrutinized for details on the extent of change and main pressures associated with the observed changes. In this group, annual streamflow /lake water levels but also other manifestations e.g. floods, low flow, and basin response time, were considered as hydrologic parameters. The timespan was reduced for matter of better comparability; the specific period was chosen because the majority of changes occurred in that era, and also the majority of basin studies completely or at least partially referred to it. In addition, the more recent developments were of greater interest and relevance for the project. For this purpose, contingency tables and again frequency analysis were employed. Findings are presented in chapter 5.

Before embarking on an introduction to the hydrological terminology and main causes of change as indicated by the reviewed studies, this section shall conclude with some reminders of the framework of hydrological research, particularly in Africa.

Firstly, the tropics are characterized by a high variability of climate and rainfall per se, which in turn causes equally variable hydrologic parameters even over short spatial distances. Secondly, a large number of processes affecting water resources are quite drainage basin specific, which may lead to different developments or contradicting trends even within neighboring sub-basins. Thirdly, certain processes manifest their consequences only at larger scales, or after a certain period of time, and it is very difficult to separate the respective impacts especially with growing basin size [*Awange et al.*, 2008; *Gebrehiwot et al.*, 2013b; *Legesse et al.*, 2003; *Smakhtin*, 2001; *Tekleab et al.*, 2013; *Warburton et al.*, 2012].

All of these aspects complicate hydrological research, and clear attributions of behavior to specific changes are not trivial [*Conway et al.*, 2009; *Rientjes et al.*, 2011]. Furthermore, the ascertainment of trends as well as the attribution of causes is highly affected by the temporal and spatial focus of the researcher. By establishing appropriate criteria for the selection of references, as well as guidelines for the ensuing analysis, we attempted to create solid entries and a large enough sample size with homogenous and thus comparable sub-groups. Despite these efforts, we are aware that the frames of all references are too diverse and that a direct comparison of any but the most similar publications and drainage basins must be flawed. **The following findings, therefore, should be understood as a general quintessence of the developments of drainage basin water resources, and as a first inventory of concrete changes in hydrologic parameters and respective pressures as reported for the specific context of Eastern and Southern Africa in the past two centuries.** The present report shows that in this respect, some comprehensive and quite revealing insights can be formulated which are of importance for current developments and future assumptions in all water-related fields.

3. DEFINITION OF TERMINOLOGY AND DESCRPTION OF MAIN FACTORS

3.1 Hydrologic parameters employed to determine changes in drainage basins

In order to provide a common basis for the present report, a short definition and description of important hydrologic terms and parameters shall be provided in the following section.

As a means to ensure comparability among the review findings, the first hydrologic selection criteria was that the frame of reference of each considered study must be a **drainage basin**. Drainage basin has been chosen as the standard term in this report because it applies to rivers, lakes and aquifers and is commonly used in literature[14] [*USGS*, 2014; *WMO*, 2012].
A drainage basin is a hydrologic unit which is defined as an area where precipitation runs off from the land towards one common point such as a river, lake or aquifer[15]. The boundaries of a drainage basin are often marked by landscape features such as ridges or mountain flanks, which cause a distinctive divide of the direction the runoff is channeled to. Usually, drainage basins are named after the longest-running river or largest lake within a basin. Large drainage basins, such as the Nile river basin, can consist of up to thousands of smaller sub-basins [*USGS*, 2014; *WMO*, 2012].

The drainage basin was chosen as a common boundary for this review because it constitutes a standard reference frame for hydrologic analysis, e.g. allowing for the comparison of responses within and across basins. Another advantage is that at the basin scale[16], both very small (soil-related) and very large (climatic) processes have approximately the same effect on hydrology. Last but not least, many operational tools and models are geared towards analysis at basin scale, and water management practices or policies are commonly applied at that scale [*Schulze*, 2004] .

The processes occurring within a drainage basin can be quantified by an accounting of inflow to, outflow from, and storage in the respective basin for a given period of time. This method is known as hydrologic budgeting or calculating the water balance [*USGS*, 2014; *WMO*, 2012].

In addition, the term basin regime is applied to describe the state and variation of certain variables (e.g. volume, flow velocity, sediment load, changes in cross-section) of water bodies within a catchment and their correlation with and repetition over time (e.g. seasonal changes) [*USGS*, 2014; *WMO*, 2012].
In the analyzed references, changes observed in drainage basins were often identified by changes in basin regime and water balance. However, these terms can sometimes be used very broadly, as they encompass several variables. Therefore, a second hydrologic selection criteria was set up which required that the observed changes must be attributed to specific hydrologic parameters. These parameters were chosen according to a) the frequency of their use and mention among a sample set of studies and b) according to their capacity of attributing changes in surface drainage basin responses to both natural and anthropogenic causes.

It is in this respect that the report focuses on a few selected **hydrologic parameters** and their manifestations, namely **streamflow, river/lake water level, lake extent, floods, basin response time, low flow** and **no flow.**

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[14] River basin, watershed and catchment are terms that may be used synonymously.
[15] Wetlands constitute a further important type of water storage in drainage basins. In the herein reviewed studies, changes in wetlands were primarily reported in association with lake or river regime changes, which is why they will be subsumed in the respective context.
[16] Which can range from areas of 10-1,000,000km²

The review did explicitly not consider references describing changes in precipitation amount and pattern only. It is also important to mention that the review did not aim at investigating or explaining individual processes that underlie the hydrological responses of drainage basins, e.g. interception, evaporation, evapotranspiration, soil and groundwater processes, etc. [*Maidment*, 1993].

3.1.1 Hydrologic parameters in rivers

When precipitation occurs over a land area[17], water will eventually infiltrate, evaporate or be stored in depressions with impermeable surfaces. When the capacity of the land to support these processes is reached, surplus water will start flowing downslope towards the nearest stream channel or watercourse (see fig. 5). This water is called overland flow or surface runoff if it occurs on the surface, and interflow or subsurface runoff if it moves downslope within the soil layer. Base flow or groundwater runoff depicts the water which leaks into a stream from the aquifer. All water thus naturally entering into a watercourse is called runoff [*Shahin*, 2002; *USGS*, 2014; *WMO*, 2012].

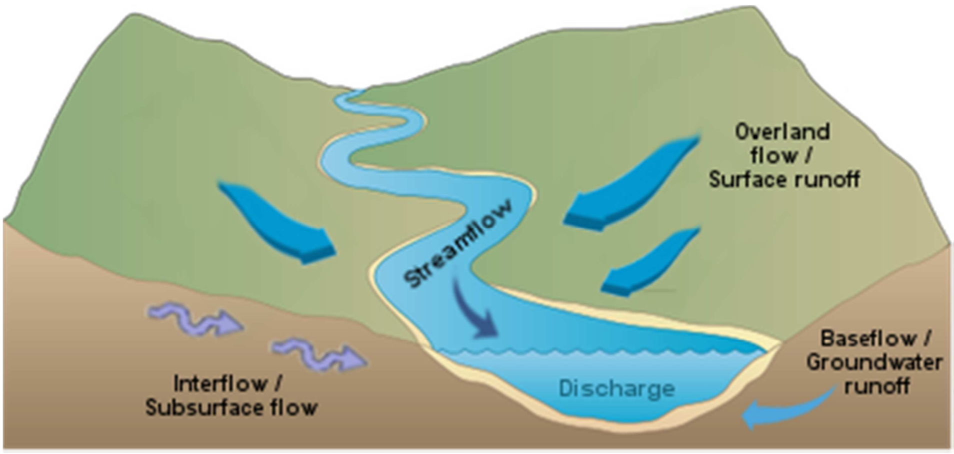


Fig. 5: Components of runoff, featuring streamflow and discharge
(own illustration, background image from [*Saxby*, 2005])

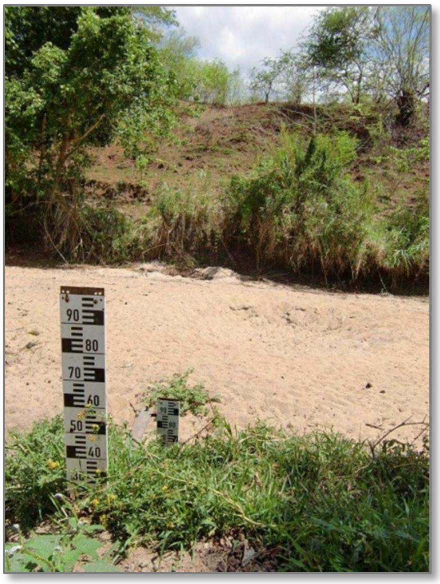
Streamflow[18] depicts the total volume of water flowing in a surface stream course. It is a more general term than runoff in that it also includes water which is affected by human processes, e.g. diversion and regulation for hydropower stations, sewers, etc. Streamflow can be measured in artificial canals by installing fixed weirs with standardized amount of water passing through in a given time. In natural channels, however, streamflow is a difficult parameter to measure as such. Therefore, the concept of discharge is applied. Discharge in this sense means the volume of water moving through a stream or river cross-section per unit of time. It is usually calculated by multiplying the area of water in a channel cross section by the average velocity of the water in that cross section, thus allowing inference to streamflow [*USGS*, 2014; *WMO*, 2012].

A channel with flowing water is referred to in different terms (e.g. creek, stream, river) depending on the volume of the water carried. Subject literature further differentiates between natural surface channels and man-made canals. However, in frames of this review, which features mainly perennial

[17] Precipitation occurring over a water body will directly join that water body.
[18] Synonymously, *river flow, flow or discharge* may be used. In this report, **streamflow** is used continuously to describe the volume of water flowing in a channel, while **discharge** is explicitly used to depict the rate of flow, i.e. the volume of water flowing through a channel cross-section per unit time.

channels of at least stream volume, such distinction will not be made and the term river shall be used in the sense of all surface water channels[19] [*USGS*, 2014; *WMO*, 2012].

The **river water level**, or stage, refers to the elevation of the water surface respective to a specified datum[20]. Systematic daily or hourly observations of river water levels are carried out by manual or automatic readings from gauges (see fig. 6). River water level is expressed in units of length above the datum, e.g. cm, m, yard [*USGS*, 2014; *WMO*, 2012].



Continuous records of water levels can convey a general understanding of the development of streamflow in a given river over time. More importantly, water levels can be used to calculate discharge if the function between water level and discharge at a particular gauging station is known. For that purpose, so called rating curves are established for most gauging station by measuring discharge as well as stage over the observed range of flow conditions within a certain time (at least a year, usually several years, with regular updates to incorporate changes in the river cross-section due to e.g. floods or sedimentation) [*Maidment*, 1993; *Shahin*, 2002; *USGS*, 2014; *WMO*, 2012].

Fig. 6: River water level gauge at the seasonal Ngerengere river, Tanzania

If gauging is done thoroughly, discharge and river water level measurements provide the most accurate hydrologic appraisal of river basin surface water resources [*Maidment*, 1993]. The method also allows for comparison over time. This is especially valuable since streamflow and river water levels have been recorded by humans for a very long time. In Sub-Saharan Africa, observations of most of the major river basins date back to the beginning of the 20th century, though with various gaps especially during times of political upheaval surrounding e.g. independence or armed conflicts. The longest ascertained chronicle in Africa comes from a gauging station on the Nile river close to Cairo, which shows that river water level has been recorded as early as 641 A.D. [*Conway et al.*, 2009; *Nicholson*, 1998].

Please note that in the describing chapters of this report, generally the term "streamflow" will be used in describing changes in river drainage basin, as the vast majority of references were made to this hydrological indicator (even if some changes were depicted for discharge, or river level).

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[19] Traditionally, a distinction is made between a) *perennial* rivers, flowing continuously throughout the year, b) *seasonal* rivers, flowing at certain times of the year in response to recurring weather patterns/seasons and c) *ephemeral* rivers, flowing in direct response to heavy precipitation events only and never receiving any base flow influx.
(USGS (2014), Water Science Glossary of Terms, edited, United States Geological Survey, United States Department of the Interior.)

[20] The datum is a permanent installation, often in form of a measuring stick, which is fixated in stable ground close to the site of river stage measurement. Annual levelling of this datum or benchmark is mandatory, and if possible the same gauge datum should be used for the entire record period. WMO (2008), *Hydrology - From Measurement to Hydrological Information*, 296 pp., World Meteorological Organization, Geneva.)

With a short description of the riverine parameters provided, the following section will briefly present a short overview of the most important manifestations related to these parameters:

- **Annual flow** / annual runoff:
  Describes the total streamflow / runoff in a channel during a year. It mostly refers to the outflow of a drainage basin or the point before a smaller river joins a larger river. Annual flow and streamflow are expressed either in total volumes or, just as discharge, in volumetric variables per time, e.g. m^3/s, cubic feet/second, gallons/day. Runoff is measured in mm per time (per area) [*Gebrehiwot et al.*, 2013b; *USGS*, 2014; *WMO*, 2012].

- **High flow / peak flow / floods:**
  Describes the maximum instantaneous discharge observed at a river gauging site either within a given period, e.g. a year, or during the entire observation history. High flow usually coincides with the observation of maximum water levels. Peak flow is often used synonymously for flood. If a flood is severe enough it can cause a stream to leave its channel and result in flooding of surrounding areas. An alteration of flood characteristics is commonly associated with either changes in input (e.g. rainfall) or modification of surface parameters (e.g. vegetation cover, sealing of surfaces) [*Kiersch*, 2000; *Rientjes et al.*, 2011; *USGS*, 2014; *WMO*, 2012].

- **Basin response time:**
  The response time describes the period which elapses between a change in input in a drainage basin (e.g., onset of rainfall event) and a measurable change in affected drainage basin parameters (e.g., streamflow). In an undisturbed catchment, this period reaches a relative stability over time. A shift in response time therefore is an indicator of changes within the drainage basin. Most commonly, a shortened response time (i.e., faster accumulation of water in the channels) is associated with decreased interception and infiltration rates of land, hinting at a disturbance of vegetative cover and soils [*WMO*, 2012].

- **Low flow / dry season flow**:
  The term is used here to depict streamflow during prolonged dry weather. In the context of Sub-Saharan river basins, this explicitly refers to dry seasons rather than droughts and is a recurrent phase in the flow regime of any river [*Gebrehiwot et al.*, 2013b; *Smakhtin*, 2001; *USGS*, 2014; *WMO*, 2012]. Decreasing dry season flows (especially when appearing in conjunction with increased frequency of floods, or increased flow in the rainy season) can be an indication of altered water storage capacity in the catchment [*Gebremicael et al.*, 2013; *Kiersch*, 2000; *Yanda and Munishi*, 2007].

- **No flow:**
  Describes a situation with non-existent streamflow; it is usually expressed in days per year or season [*Gebrehiwot et al.*, 2013b]. This can be a normal characteristic for streams, but if no flow increases in frequency or duration, it is a strong indicator for changes in a basin.

3.1.2 Hydrologic parameters in lakes

As explained in detail in the previous sub-chapter, precipitation falling over a drainage basin will eventually drain into a watercourse. Apart from rivers, lakes are the second important group of surface freshwater courses featuring in the hydrologic cycle. In the present report, the term lake is used in its most general way, i.e. describing any depression filled with standing water, regardless to its natural or man-made origin [*USGS*, 2014].

Over the course of time, the volume of water in a lake can vary significantly (see fig. 7). This variation can be observed through changes in **lake water level**, which, just as in rivers, refers to the elevation of the lake water surface relative to an established datum. Again, water levels can give some indication of the development of lake water resources over a given time. Combined with the knowledge of the lake cross-section and its extent, the lake water volume[21] can be calculated [*WMO*, 2008].

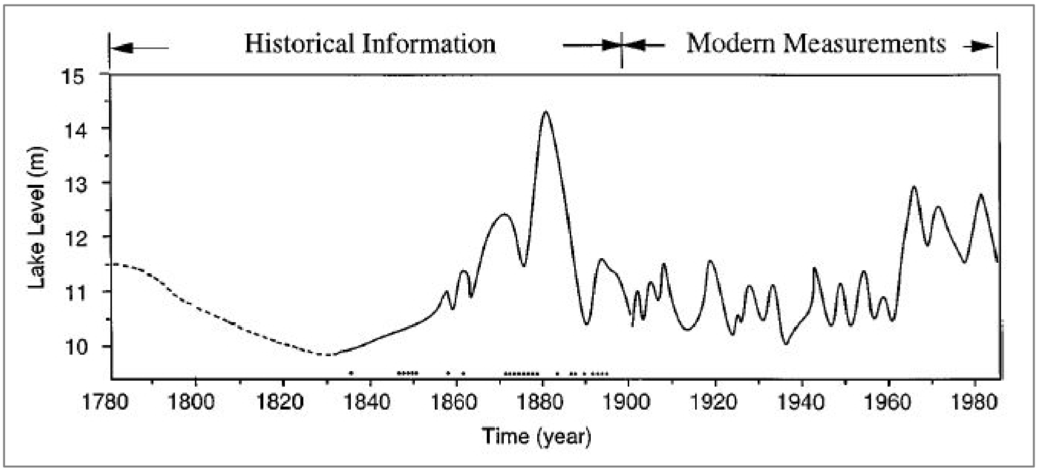


Fig. 7: Variation of Lake Victoria water level over time ([*RealClimate*, 2014])

Although lakes often constitute complex systems with interlinkages to groundwater processes that bear special recognition, the hydrologic parameter “lake water level” provides an excellent mirror of past water volume development. In Sub-Sahara Africa, water level records for example for the Great Rift Valley lakes date back to the early 1910s. In contrast to most rivers, the temporal sequence of developments in lakes is recorded in high resolution through sediments and shoreline features. This introduces additional indirect methods which allow for lake water resource estimation over time22 even in the absence of direct observations. Additionally, the measurement of **lake extent** changes through remote sensing (i.e., satellite images) is another method gaining importance with growing technical capabilities [*Conway et al.*, 2009; *Nicholson*, 1999].

Please note that in the describing chapters of this report, generally the term “lake water level” will be used as this parameter was employed by the majority of studies (even though almost a third of the lake drainage basin studies refer to “lake extent”).

21 Additionally, the discharge of lakes feeding into rivers can be calculated based on flow and water level measurements. However, this parameter was only named in a negligible number of reviewed studies, which is why it was not selected as one of the hydrologic criterions for this report.

[22] Shorelines can be visible up to a century, and lake sediment core analyses have been used to derive lake water developments over thousands of years. (Nicholson, S. E. (1999), Historical and modern fluctuations of Lakes Tanganyika and Rukwa and their relationship to rainfall variability, *Climatic Change*, *41*(1), 53-71.)

3.2 Main causes of hydrological change in Eastern and Southern African drainage basins

The hydrological regime of drainage basins is influenced by a broad range of factors. These include natural factors such as climate, topography, geomorphology, geology, soil and land cover and anthropogenic factors such as construction of dams and reservoirs, drainage of wetlands, and water withdrawal. Human activities in drainage basins often further indirectly affect natural factors, especially climate, soil, and land cover. Changes in any of these components may alter drainage basin regime and watercourse characteristics [*Gebrehiwot et al.*, 2013a; *Kundzewicz*, 2004; *Maidment*, 1993; *Schulze*, 2004].

The main causes of hydrological change relevant in frames of this review were identified as **climate variability and climate change, land use / land cover change, water withdrawal, construction of dams and reservoirs** and **tectonic activity**. In the following sub-chapters, these terms and the related processes in drainage basins shall be briefly described in rough order of prominence.

3.2.1 Climate variability and climate change

In the reviewed references, both climate variability and climate change were often stated as causes for hydrological change. In order to provide a clear understanding of the terms, we shall in this matter comply with the definitions of the World Meteorological Organization (WMO).

The WMO defines climate as "the statistical description in terms of the mean and variability of relevant surface quantities such as temperature, precipitation, and wind over a period of time", and stipulates the classic period of reference as 30 years. Climate can be described locally, regionally or even globally. It is driven by atmospheric and energetic processes which are shaped by solar activity and terrestrial parameters (global circulation patterns, composition of the atmosphere, etc.). The latter are subject to natural variations but can also be affected by anthropogenic forcing. Such human forcing is in turn related to a number of driving forces as indicated in the presented DPSIR framework (e.g. population growth, agricultural sector growth, growing standards of living [*Schulze*, 2004; *WMO*, 2014].

Climate is a key driver of natural landscape processes at drainage basin scale [*Kundzewicz*, 2004; *Maidment*, 1993; *Schulze*, 2004]. Changes in rainfall amount, location, intensity and patterns can directly impact runoff, as can changes in air temperature, wind speed, radiation, and evaporation. In addition, climate also indirectly affects other factors of drainage regimes such as vegetation cover and evapotranspiration, soil parameters, as well as water withdrawal and construction of dams. Changes in land use, i.e. deforestation, can in turn contribute to regional changes in climate parameters [*Githui*, 2008; *Maidment*, 1993; *Troy et al.*, 2007]. It is therefore often difficult to exactly attribute changes in drainage basin response to globally, regionally or locally induced climatic variability or change. However, the pre-eminence of climate as a cause of hydrological change should be obvious.

Climate variability denotes deviations of said surface parameters within a given period, e.g. season, year or span of years, from the long-term statistics. These deviations are called anomalies, and the sum of anomalies constitutes climate variability. [*WMO*, 2014].

In Eastern and Southern Africa, climate is generally characterized by high interannual to decadal variability [*Legesse et al.*, 2003; *Spinage*, 2012].

Interannual variability is hereby primarily marked by the seasonality of rainfall, which is accompanied by respective changes in temperature, evaporation and wind speed. The pattern of rainy seasons in Eastern and Southern Africa is very complex. In a very general way it can be said that in Eastern Africa, two rainy seasons occur per year, often a "long rainy season" in the boreal spring, and a "short rainy season" in the boreal fall. The countries farthest to the west in Eastern Africa can be classified as humid and hardly display any seasonality. With growing distance to the equator, a singular rainy season which often falls within the boreal summer, becomes the norm in most of Southern Africa. However, this classification can only be very coarse, as the onset of rainy seasons even within a single country can display high regional and spatial differences. The timing and intensity progression of rainy seasons from year to year can vary significantly [*Cook and Vizy*, 2013; *Herrmann and Mohr*, 2011].

The most extreme effects of interannual variability are mainly caused by rapid and often short-dated surplus changes in drainage basin regimes, resulting i.e. in extensive flooding - as observed repeatedly in many African countries, e.g. most recently in 2007 in Uganda, or in 2010 in Mozambique [*Spinage*, 2012].

The opposite extreme, namely drought conditions, are rather attributed to decadal variability, when anomalies with low rainfall persist over several years. Droughts are a repeating feature of African climate and well documented, e.g. the Ethiopian drought from 1984-85, or the Sahelian drought during the 1970s-1990s [*Legesse et al.*, 2003; *Todd et al.*, 2011].

Both interannual as well as decadal climate variability in Eastern and Southern Africa has been linked to teleconnections with other regional climate systems in Africa and Asia, especially the West African and Indian monsoon systems. These connections are explained by the influence of the El Niño Southern Oscillation (ENSO), which is associated with patterns of long-term large-scale Sea Surface Temperature (SST). Both phenomena cause periodic weather anomalies which are known to last for a certain period and recur in cycles of 2-10 (ENSO) up to 50 years. Yet longer cycles, e.g. over the course of millennia, may be attributed to orbital frequencies or sunspot activity ([*Collins*, 2011; *Cook and Vizy*, 2013; *M. R. Jury and Gwazantini*, 2002; *Wolski et al.*, 2012].

Climate change, describes statistically significant modifications of either mean state or variability of climate which continue over several decades (i.e. the stated reference period for climate), leading to a new state which differs substantially from the one observed before. This persistence is the most important distinction from climate variability[23] [*WMO*, 2014].

As climate records only cover a very short time compared to the earth's age, above distinction can only be made from the current state of scientific knowledge. This knowledge reveals that major climatic changes have taken place in Africa in previous eras, often prompting alternating periods of dry or humid conditions. It is thus quite possible that even exceptional sequences of events occurring over a period of decades constitute a long-term pattern of climatic variability rather than climate change as it is hereby understood. In any case, the impact on hydrologic processes can be dramatic, which is why above uncertainty should be kept in mind but will not be further addressed in this review [*Murimi*, 1994; *Spinage*, 2012; *WMO*, 2014].

[23] Some definitions, e.g. by the Framework Convention on Climate Change (UNFCCC), take this further and implicitly define *climate change* by its attribution to direct or indirect human activity and consequent alteration of the composition of the global atmosphere, commonly referred to as 'global warming'. However, in frames of this review, this differentiation will not be made.

The recently detected long-term trend of major changes in the earth's climate also manifests itself in African climate records. Said trend shows a significant gradual increase of global temperatures since around 1880, with an accelerated increase for the past 25 years (often referred to as 'global warming'), as well as possible alterations of the earth's wind patterns. The changes are most probably linked to increases in atmospheric carbon dioxide, caused by anthropogenic burning of fossil fuels, which result in the suppression of thermal radiation (also referred to as the 'greenhouse effect') [*Beilfuss*, 2012; *Spinage*, 2012].

The impact of this global shift can be observed in several climate parameters in Africa, showing significant changes of mean state over the last decades which are not attributable to climatic variability alone. Some of the recorded changes display a magnitude which has only been observed three or four times in the past three centuries [*Collins*, 2011; *Spinage*, 2012]. The following will provide a brief overview of the most important observed trends in Eastern and Southern Africa in the 20th and 21st century:

- **Rainfall:** Equatorial Eastern Africa has witnessed a general decrease in total rainfall from ca. 1890 to the 1930s, followed by an overall increase peaking in the 1960s. Since then, rainfall amounts have been relatively stable on a high level [*Mango et al.*, 2011; *Spinage*, 2012].
The sub-tropical regions of Eastern Africa, especially in the Greater Horn of Africa, have received decreasing amounts of total rainfall since the 2000s [*Omondi et al.*, 2013].

  For Southern Africa, total rainfall trends have been decreasing since 1961, cumulating in an overall negative trend for the 20th century [*Mark R. Jury*, 2012; *Spinage*, 2012].

  At the same time, a trend of increased heavy rainfall events is reported for the early 21st century in both Eastern and Southern Africa, with some of the heaviest rainfall incidents in the history of African climate records observed in 2007 [*Spinage*, 2012]. It seems that rainfall has become more concentrated in few, intense events over the past decades without necessarily affecting the total annual rainfall amount [Githui, 2008].

- **Seasonality:** During the past decades, the seasonality of rainfall patterns has changed in Eastern and Southern Africa. Evidence for such shifts are most telling in Eastern Africa, where the bimodality of rainfall patterns has become more pronounced. In addition, the date of rainfall peaks has shifted significantly, e.g. in Uganda where the long rainy season used to have its peak during April in 1961, but routinely peaks in May in the 2000s. Also the short rainy season ends a month earlier than in the 1960s, markedly reducing the total number of rainfall days [*Spinage*, 2012].

- **Temperature:** Significant increases in temperature in the past two centuries can be observed all over Africa (see fig. 8). The average warming amounts to 0.7°C over the 20th century, or 0.05°C per decade[24] [*Collins*, 2011; *Mango et al.*, 2011; *Spinage*, 2012; *Todd et al.*, 2011].

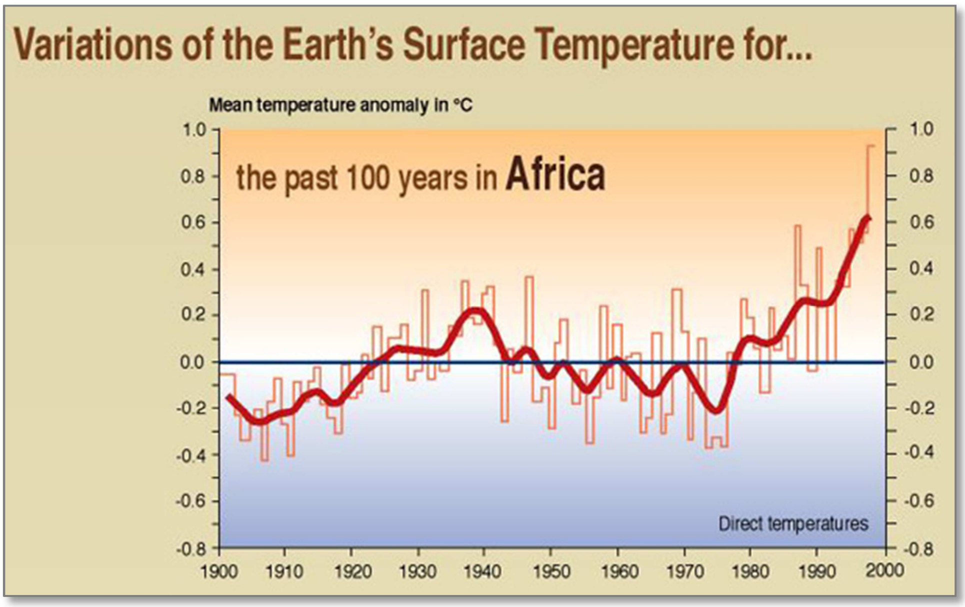


Fig. 8: Surface temperature curve for the 20th century in Africa
([*GRID-Arendal*, 2001])

In addition, an increase of extremely hot days/nights as well as a decrease of extreme cold days/nights is reported for many subtropical regions [*Omondi et al.*, 2013; *Todd et al.*, 2011].

- **Extreme Events:** Both in Eastern and Southern Africa, the incidence of extreme events such as heavy rainfalls and resulting floods, but also heat waves and droughts, has increased since the 1970s ([*Githui*, 2008; *Spinage*, 2012; *Todd et al.*, 2011].

3.2.2 Land use and land cover change

If climate roughly specifies the amount of water entering into a drainage basin, land use and land cover substantially influence its further pathways and ensuing hydrological processes [*John F. Mustard and Fisher*, 2004; *Troy et al.*, 2007]. The reviewed references confirm that land use and land cover are one of the leading causes of change in a multitude of systems, including the hydrological cycle. This is especially important because feedbacks of these changes are now more rapidly impacting human livelihoods, while at the same time anthropogenic and climatic pressure on ecosystems continues to rise [*Alemayehu et al.*, 2009; *Githui*, 2008].

[24] Warming did not proceed linearly but with intermittent cooler decades, however, a clear general trend is verified.

The term **land cover** hereby refers to the physical and biological surface cover of a particular area. It is usually categorized into different vegetation cover types (e.g. forest, shrubland, or desert - with sub-categories such as primary forest, second-growth forest, plantation), water bodies, and bare/sealed soil or artificial structures [*Ellis*, 2013; *Githui*, 2008].

Subsequently **land use** describes human uses of a landscape, such as settlements, agriculture, reserves/national parks, infrastructure etc. Land use often leads to changes in land cover, e.g. when forests are cleared for agricultural land. On the other hand, cases where changes in land cover lead to changed land use are less common but conceivable (e.g. permanent natural flooding of areas which were formerly agricultural land). If land use is unsustainable, such as overgrazing, it may lead to degradation of land cover to such an extent that it renders future use by humans impossible [*Alemayehu et al.*, 2009; *Ellis*, 2013; *Githui*, 2008; *Snoussi et al.*, 2007].

Due to the interlinkages of the two concepts, often the term **land use/land cover change (LULCC)** is used to subsume human modifications of the Earth's surface. In the present review, the term will be taken up, however keeping in mind that some if very few land cover changes are not necessarily caused by humans. The major part of LULCC, however, can be attributed to humans, who have been modifying the earth's surface for thousands of years in order to fulfil their needs. Diverse studies arrive at the conclusion that about 50% of ice-free land surface has been affected by anthropogenic disturbance in one way or another. In recent decades, the extent and intensity of LULCC has increased drastically, leading to enormous changes in ecosystems at local, regional and global scale [*Ellis*, 2013; *Githui*, 2008; *John F. Mustard et al.*, 2004; *Schulze*, 2004; *Snoussi et al.*, 2007].

LULCC is driven by a large number of direct and indirect factors, i.e. climatic patterns/change, population growth, increasing economic development (incl. agricultural & industrial sector growth), increasing standards of living, urbanization, government policies, and natural forces such as volcanism and tectonic activity [*Ellis*, 2013; *Snoussi et al.*, 2007; *Troy et al.*, 2007].

Changes in LULCC affect many of the components controlling flow generation and discharge characteristics, often resulting in alterations of the hydrological balance of drainage basins. Specifically, LULCC affect vegetation and soil parameters which can be grouped by *above ground* (changes in canopy, (litter) interception, evapotranspiration of plants, shading), *ground/surface* (compaction of soils, sealing/crusting of surfaces), and *below surface* (bulk density, infiltration capacity & water transmissivity changes) [*Kiersch*, 2000; *Schulze*, 2004].

In addition to its effects on hydrology, other important consequences of LULCC include an often marked reduction in biodiversity caused by landscape fragmentation and habitat losses, and the alteration of basin biogeochemistry [*Ellis*, 2013; *John F. Mustard et al.*, 2004; *Palamuleni et al.*, 2011].

The latter is strongly **linked to climate variability and climate change**. At regional scales, changes in surface cover can alter the reflection of sunlight, heat balance/transfer, and evaporation flux to such an extent that atmospheric variations and feedback effects can occur[25]. On a global scale, the disturbance of terrestrial soils and vegetation leads to an increased release of carbon dioxide to the

[25] The associated processes are highly complex, and while the existence of feedback effects is undisputed, their extent is a matter of ongoing discussion. Various studies indicate that the changes in energy balance linked with LULCC may be offset by the simultaneous release of particulates and sulfur dioxide, resulting in atmospheric cooling through the reflection of sunlight and generation of cloud cover. (Ellis, E. (2013), Land-use and land-cover change edited, The Encyclopedia of Earth.)

atmosphere, significantly enhancing the 'greenhouse effect' and thus climate change [*Ellis*, 2013; *Maidment*, 1993; *John F. Mustard et al.*, 2004].

The main **human-induced processes** leading to LULCC include land clearing, burning, farming activity[26], grazing activity, deforestation and fuel wood consumption, introduction of invasive alien species, mining, construction of infrastructure, urbanization, and industrial development. In addition, climate-related vegetation changes, fire activity and natural regeneration processes constitute **natural processes** associated with LULCC [*Githui*, 2008; *GLCN*, 2010; *Mumba and Thompson*, 2005].

There is a general description of LULCC occurring along a kind of vector from undisturbed, natural land surfaces/ecosystems to intensely anthropogenic altered surfaces, sometimes resulting in the complete removal of ecosystems such as in heavily urbanized or industrialized areas. It is important to keep in mind, though, that changes can and do occur in both directions, i.e. that heavily modified surface areas can return to natural states upon cessation of human use, or application of protection/ management measures [*Kiersch*, 2000; *John F. Mustard et al.*, 2004; *Schulze*, 2004].

In frames of this report, three LULCC processes emerge to be of highest importance. In the following section, a short description of the particularities of these processes and their manifestations in Eastern and Southern Africa will be provided.

3.2.2.1 LULCC - Farming and grazing activities

Agriculturally used land[27] by far constitutes the largest part of land use in Eastern and Southern Africa. The ramifications from the ensuing vegetation cover changes and soil disturbance caused by agricultural practices such as tillage, ripping and, very importantly, grazing, have marked impacts on drainage basin hydrology because they strongly alter surface and infiltration parameters [*Maidment*, 1993; *Mango et al.*, 2011; *Schulze*, 2004].

Fig. 9: Evidence of recent land use and land cover change in the Uluguru Mountains, Tanzania
([*Earlham College*, 2012])

Currently, large, semi-arid territorial states such as Botswana and Namibia feature a percentage of land under cultivation of about 0,4-1%, while larger states with more favorable climatic conditions such as Ethiopia, Kenya, Tanzania, South Africa and Zimbabwe figure at about 10-14%. The ratio is highest for smaller countries with a high population density, e.g. Burundi, Malawi, Rwanda and Uganda, where 30-55% of the total area is dedicated to agricultural use[28] [*FAO*, 2014].

[26] An important aspect of the land use process "farming activity" is the specific farming practice applied. Due to its relevance in regard to hydrologic parameters and the Trans-SEC project, this factor will – although related to LULCC with regard to the content- be separately described in chapter 3.5.

[27] Here, the FAO definition is applied, encompassing a) land under permanent crops/plantations, meadows or pasture as well as b) land under temporary crops, meadows or pasture (including fallows of not more than 5 years). (FAO (2013b), Food and Agriculture Glossary - FAOSTAT Database edited, Food and Agriculture Organization of the United Nations, Statistics Division.)

The percentage of agriculturally used land to total country area has doubled, in some cases tripled, in the past 50 years in Eastern and Southern Africa. It is important to note that the majority of agricultural land in above countries is cultivated by small-scale, subsistence farmers, with only about one tenth being cultivated by large-scale commercial farming. Due to often limited land and water resources, a growing overlapping of cropping and grazing areas can be observed. In the same line, land degradation because of overgrazing and poor agricultural management has increasingly been reported over the past decades [*Arthurton et al.*, 2008; *Bewket and Sterk*, 2005; *Biggs and Scholes*, 2002; *FAO*, 2014; *Legesse et al.*, 2003; *Mati et al.*, 2008].

Fig. 10: Gully erosion as an example of advanced land degradation in Africa ([*Marshall*, 2014])

3.2.2.2 LULCC – Deforestation and afforestation

Another process of LULCC in Africa with strong impacts on drainage basin hydrology is the change of forest[29] cover, including both removal of natural forests and establishment of plantations [*Calder et al.*, 1995; *Maidment*, 1993; *John F. Mustard et al.*, 2004].

A lot of research has been done in this field, with varying results regarding the extent and intensity of impacts. However, the majority of studies arrive at the conclusion that the consequences of forest cover change on drainage basins are especially significant due to the interference with several basin parameters: trees constitute plants with high evapotranspiration rates, have roots that can reach deep into the groundwater table and stabilize soils, and form a canopy cover which provides efficient interception and beneficial ground moisture/temperature conditions [*Bruijnzeel*, 2004; *Chimtengo et al.*, 2013; *Kiersch*, 2000; *Schulze*, 2004].

Especially if forest cover changes occur widespread, the resulting changes in evapotranspiration and surface-atmosphere heat transfer can lead to effects on local and regional climate such as reductions in recursive rainfall patterns [*D'Almeida et al.*, 2007; *Schulze*, 2004; *Voldoire and Royer*, 2004].

Fig. 11: Slash-and-burn farming in Africa ([*Marshall*, 2014])

[28] In comparison: the ratio in Germany has been stable at about 33% for the past 50 years. FAO (2014), AQUASTAT Database, edited, Food and Agriculture Organization of the United Nations.

[29] Here, the FAO definition is applied, namely that forest is an area of land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ FAO (2010), Global Forest Resources Assessment 2010*Rep.*, 378 pp, Food and Agriculture Organization of the United Nations, Forestry Division, Rome.

In Eastern and Southern Africa, deforestation constitutes an important factor of environmental change. While the development in different countries are quite diverse, annual deforestation rates (i.e. the percentage of total forested land that is clear cut each year) in total lay around -0.62% for the past decades. In both regions, deforestation is strongly related to agricultural activity of mainly smallholder farming expanse (see fig. 11) - the rate of conversion from forest to cultivated land in Africa is the second-highest in the world (only surpassed by South America). Afforestation has equally strong effects on drainage basin hydrology, however, it quantitatively plays a major so far only in Southern Africa [*Biggs and Scholes*, 2002; *FAO*, 2010] .

<u>3.2.2.3 LULCC – Fire</u>

Fire is a process of LULCC highly relevant especially in most of Eastern and Southern Africa, where biomass built up during the rainy season provides ample fuel for fires in the hot dry season. Fires are caused by both human action (deliberately, as in burning for land clearing or as part of landscape management, and accidentally) and natural events (e.g. spontaneous ignition during extreme heatwaves, or lightning strikes during thunderstorms). The effect of fire on drainage basin hydrology can be massive, because it may affect large areas abruptly over a short period of time. Fire hereby not only results in vegetation cover changes, but can also lead to a heat-induced water repellency of the top soil layer, thus markedly changing soil infiltration capacities [*FAO*, 2000; *Scott*, 1993; *Wolski and Murray-Hudson*, 2006].

Many regions in Eastern and Southern Africa are prone to fire and feature adequately adapted ecosystems. In frames of human land use, however, burning can take place more frequently, at different times and intensities, and in more sensitive ecosystems than would have occurred naturally. In addition, the effects of climate variability and climate change can amplify stresses. This could be observed in Ethiopia in 2000, where the delay of the rainy season overlapped with traditional land burning practices, causing massive wildfires which spread to consume thousands of hectares of protected forest. Some studies indicate that globally, anthropogenic burning has decreased over the past two decades, however, this could not be confirmed for Africa where the areas of heaviest burning seem to coincide with regions affected by climatic drying conditions, strong population growth and extension of agriculturally used land (e.g. Botswana, Ethiopia, northern Mozambique, Tanzania and Zambia). In total, it is estimated that at least 130 million hectares of grasslands and forests – an area somewhat larger than the size of South Africa - are burned in Africa south of the equator every year. Luckily, this is not reflected by casualty figures, which are remarkably low given the extent of burning [*FAO*, 2000; 2010].

Fig. 12: Dry season fires in the Uluguru Mountains, Tanzania

3.2.3.4. LULCC - Soil-water management practices

Soil water management practices play a as of yet minor role in regard to the sample of drainage basin references analyzed in this report. Due to the importance of these practices in regard to the evaluation and sustainability assessment of Trans-SEC upgrading strategies, however, they shall be briefly discussed in the following passage.

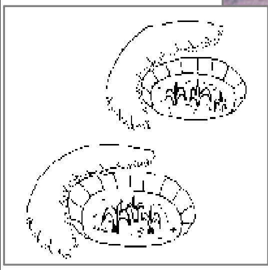
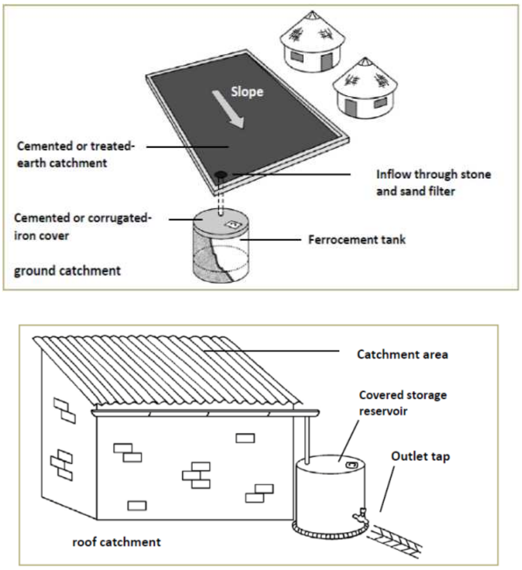
In this report, the term **soil-water management practices (SWMP)** is used to describe a set of agricultural techniques aiming at improved utilization of the natural resources soil and water within traditional cropping systems[30] [*Biazin et al.*, 2012]. SWMP can be broadly grouped according to the 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 [*Biazin et al.*, 2012; *FAO*, 2008]. The comprised techniques are mentioned in table 1.

A lot of research has been conducted in regard to soil-water management and its effect on yields and soil parameters on plot scale. The influence on water resources on a drainage basin scale has not yet been as widely studied, however, a few studies indicate that said practices do have a measurable effect on drainage basin hydrology, especially in smaller catchments [*Alemayehu et al.*, 2009; *Kiersch*, 2000; *Nyssen et al.*, 2010; *Rockström et al.*, 2002].

Table 1: 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])

[30] In the reviewed literature, a number of terms are applied synonymously, such as 'soil-water conservation measures' or 'rainwater harvesting and management'. We opted for the stated titling because *management* best captures the full connotation and encompasses both soil and water specific processes.

(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**   **'Zai' planting pits 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])

In Eastern and Southern Africa, SWMP have been widely applied in numerous countries, with soil water content in the root zone for example increasing by up to 30%, and yields doubling (even sextupling, if fertilizer is being applied at the same time) [*Biazin et al.*, 2012; *Rockström et al.*, 2002].

Conservation agriculture is successfully practiced in a number of countries. The ratio of conservation agriculture pro rata the total land under cultivation lies at about 0.2-0.6% for Botswana, Kenya, Lesotho, Namibia and Tanzania. In Mozambique, South Africa and Zimbabwe, this figure climbs to 2.8-3.3%. The country with the largest percentage of conservation agriculture is Zambia, with 5.8% [*FAO*, 2014].

In respect to improved ploughing techniques, both highly mechanized special ploughs utilized in Kenya as well as animal-drawn and manually based rippers tested in northern Tanzania have shown improvements in yields and water productivity [*FAO*, 2008; *Rockström et al.*, 2002]. Micro-catchment rainwater harvesting methods are widespread in Ethiopia, Kenya, Tanzania, South Africa, Uganda, and Zimbabwe. Generally, it can be said that micro-catchment rainwater harvesting and soil parameter enhancing techniques are most widespread, and macro-rainwater harvesting systems are scarcest [*Biazin et al.*, 2012; *Rockström et al.*, 2002].

In addition to the so far described physical structures, an important part of SWMP especially for degraded areas is the implementation of institutional vegetation protection measures, i.e. setting up of enclosures for vegetation restoration, and agreeing on post-harvest or general non-grazing policies for sensitive areas [*Nyssen et al.*, 2010].

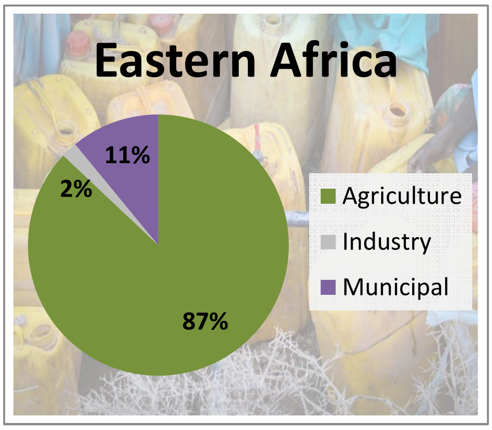
All in all, SWMP are promising tools for locally adapted sustainable agriculture not only in Sub-Saharan Africa. Their potential benefits especially in regard to water resources impacts up to basin scale should be more thoroughly considered in projects such as Trans-SEC.

3.2.3 Water withdrawal

A factor of growing importance with regard to drainage basin water balance is **water withdrawal**, which in frames of this review shall be broadly defined as the removal of water from its source within a drainage basin for a specific use. By its nature, water withdrawal is a process which can be purely attributed to anthropogenic actions. The ensuing alterations of groundwater or surface water flows can directly impact on the quantity, seasonality and often quality of drainage basin water resources [*Arthurton et al.*, 2008; *FAO*, 2014; *Maidment*, 1993; *Troy et al.*, 2007; *USGS*, 2014].

The term water withdrawal is often employed synonymously with water use. It can be further distinguished into *temporary abstractions* (i.e. water which is used for cooling of industrial/power plants, and later returned to a river) and *consumptive water use* (i.e. water which is used in a way that no material return into the drainage basin water cycle[31] is possible, e.g. because it has been consumed by man or livestock, been incorporated into products or crops, or has evaporated). If the distinction between the two types can be made, it will pointed out in the report, however generally the broader term will be applied [*HR Wallingford*, 2003].

The **main drivers** of water withdrawal include population growth, climatic instability, industrial and agricultural development, urbanization, and the ensuing growing need for power generation (hydropower). Again, many of these drivers show clear interrelations [*Maidment*, 1993].



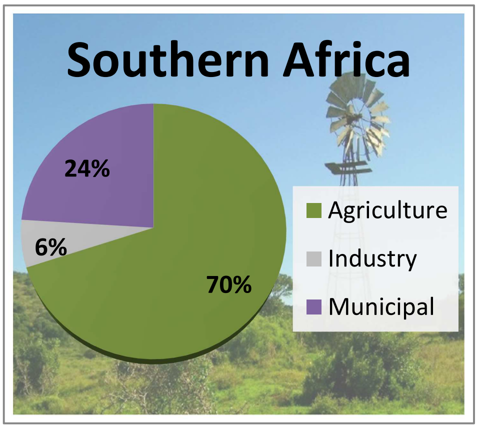


Fig. 13: Water withdrawal by sector in Eastern & Southern Africa in 2002
(own rendering, data from [*FAO*, 2014])

[31] Obviously, all water returns into the global hydrologic cycle at some point and through some way.

In Eastern and Southern Africa, **agricultural activities by far constitute the largest factor of water withdrawals** (see figure 13). Due to a larger share of the industrial and mining sector, and a pronounced investment in hydropower infrastructure (including inter-basin water transfers in several transnational drainage basins[32]), Southern African countries show a slightly different ratio of water use by sector compared to Eastern African countries [*Nkomo and van der Zaag*, 2004]. In both regions, rates of water withdrawal for both irrigation and livestock have been increasing, sometimes by up to 50%, in the past decades [*FAO*, 2007; *Mati et al.*, 2008; *John F. Mustard et al.*, 2004; *Snoussi et al.*, 2007].

3.2.4 Dams and reservoirs

Another solely anthropogenic impacting factor of drainage basin hydrology is the construction of dams and reservoirs [*Arthurton et al.*, 2008; *Kundzewicz*, 2004; *World Comission on Dams*, 2000].

A **dam** describes a barrier constructed across a valley with the aim of retaining water (either runoff or from a river). The term **reservoir** is used to describe the resulting impoundment upstream of the dam, or a body of water made by other means (e.g. excavation) to store and manage water [*WMO*, 2012].

Dams are classified according to two types – above mentioned reservoir dams, which are mainly constructed for the storage and regulation of flow, and the so-called run-of-river dams. These latter describe dams which are built for the purpose of creating a hydraulic head in a river to generate power or divert flow to a canal. Both types constitute highly significant interventions in drainage basin water balance [*Schulze*, 2004; *World Comission on Dams*, 2000].

In addition, dams are often classified by size. A widely applied categorization is provided by the International Commission on Large Dams (ICOLD), which defines a[33] dam as large if it has a height of 15m or more from the foundation, or a reservoir volume of more than 3 million m³. In accordance with this definition, over 45 000 large dams exist worldwide. Their main purpose is to provide dependable water resources for irrigation, domestic and industrial water supply, generate hydropower and manage flood events [*FAO*, 2007; *World Comission on Dams*, 2000]. Kariba dam, bordering Zambia and Zimbabwe, is an example and one of the largest dams of the world with a height of 128m [*International Rivers*, 2014].

Fig. 14: Kariba dam ([*International Rivers*, 2014])

[32] Inter-basin transfer is common in Southern Africa but was only mentioned for one East African country (Ethiopia, Tana river basin) Arthurton, R., M. Le Tissier, M. Snoussi, J. Kitheka, Y. Shaghude, A. Kane, G. Flöser, and H. Kremer (2008), Global Change Assessment and Synthesis of River Catchment - Coastal Sea Interactions and Human Dimensions in Africa*Rep.*, 122 pp, Land-Ocean Interactions in the Coastal Zone (LOICZ) / Core Project of the International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP), Geesthacht.

[33] In the following, the term *dam* will generally refer to a reservoir type of dam unless stated otherwise.

The construction of dams and reservoirs is therefore mainly driven by agricultural and industrial development, stresses from climate variability and change, population growth, urbanization, rising standards of living, and an ensuing ever increasing demand for reliable and inexpensive electric power. Since the 1950s, large dams have provided many benefits and enabled an unprecedented increase in agricultural productivity, but also caused some serious negative social and environmental impacts (e.g. displacement of local communities, fragmentation and destruction of ecosystems and fisheries) [*Arthurton et al.*, 2008; *Schulze*, 2004].

Besides large dams and reservoirs, smaller storage reservoirs play a major role in many African drainage basins. These can range from hand-dug earthen pits of 50m² to community-run retention basins of several 1000m², and are often built to store diverted runoff water from rivers during the rainy season for use in the drier periods. Any single reservoir of such kind is probably negligible, but they can impact drainage hydrology if they exist in large numbers. There is, however, still very little quantifiable information on these often informal reservoirs in Africa.

Fig. 15: Commonly found "Charco dam" for flood water diversion/runoff collection in Kenya ([*InfonetBiovison*, 2010])

The majority of the inventoried 1300 large and medium dams in Eastern and Southern Africa were constructed in the past 40 – 50 years. Of these, over half can be classified as large, and 40% are located within South Africa alone. A 1998 survey of dams in Africa revealed that the vast majority of recorded dams were built to provide reliable irrigation water supply, with only 1% reportedly built for flood control purposes only (see fig. 16).

Also note that although only 6% of dams were built for electricity generation, hydropower constitutes for 50-80% of the total power source of African countries. This might be explained by the sheer volume of some of the African dams, i.e. the Kariba dam on the Zambezi river with a capacity of 188 billion m³, or the Aswan dam at river Nile river with 162 billion m³ capacity[34] [*Arthurton et al.*, 2008; *FAO*, 2007; *World Comission on Dams*, 2000].

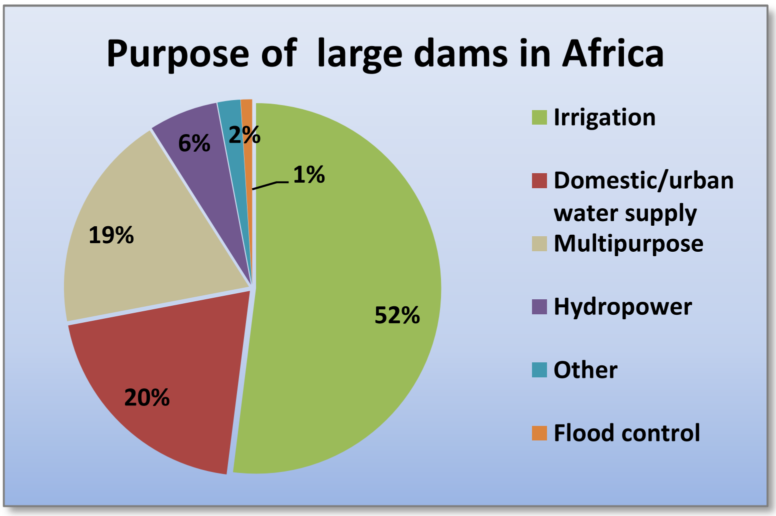


Fig. 16: Percentage of main construction purpose of inventoried large dams in Africa in 1998 (own rendering, data from *World Comission on Dams* [2000])

[34] For comparison: Europe's largest reservoir, Lake Kuibyschewer in Russia, has a capacity of 53 billion m³.

3.2.5 Tectonic activity

The geology of drainage basins has not been discussed before, mostly because processes associated with change in that respect unfold over timespans not relevant in frames of this review. One exemption, however, concerns tectonic activity. Rifting and drifting can cause abrupt and massive changes in drainage basin hydrology by e.g. modifying the slope and thus flow paths of an entire basin. These events are very rare but they do occur, especially in zones of high tectonic and volcanic activity along the East African Rift Valley. Among the reviewed studies, two references were made to this exceptional natural impacting factor, which is why it was briefly presented as a separate category here [*Murimi*, 1994; *Ngongondo*, 2006; *Wolski and Murray-Hudson*, 2006].

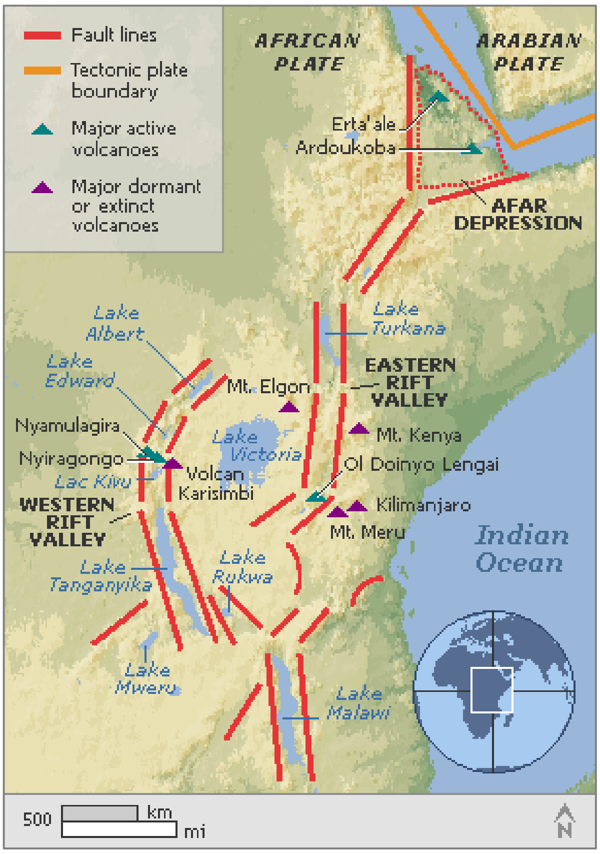


Fig. 17: The Great Rift Valley in Africa
([*Hormann*, 2007])

4. <u>OVERVIEW OF AGGREGATED ANNUAL WATER RESOURCES TRENDS IN EASTERN AND SOUTHERN AFRICA FROM 1900-2010</u>

In this chapter, a first overview of the reported general trends of annual streamflow and lake water levels across all reviewed drainage basins and over the entire timespan will be provided. This will be done separately for river and lake drainage basins, and preceded by a short description of the publication base, composition of references, and encountered limitations.

The meta-basin level was chosen for the presentation of this chapter as it allows for at least some comparability of the very diverse drainage basins. For that purpose, information on trends and causes was compiled for each meta-basin based on the references from all associated drainage basins. After grouping all references according to the associated meta-basin, the aggregate trend was calculated by relating the number of statements regarding certain trends , i.e. if 50 or more of recorded studies described a trend, this trend was reflected on meta-basin level. While allowing at least some form of illustration, it should be kept in mind that these can only be rough approximations, as this method does not consider imbalances in the ratio of number of references vs. size of meta-basin. Tables 2 and 3 towards the end of this chapter offer more detailed information about developments on meso-basin and sub-basin scale. To reduce the possibly ensuing bias, this approach was only chosen for a first outline; all later analyses are carried out on sub-basin scale (see Annex 1 and 2 for details on all drainage basin references).

4.1 Background and composition of reviewed references

Publications

In the present report, a **total of 85 individual publications** containing references to water resources development in drainage basins in Eastern and Southern Africa in accordance with the stated criteria were reviewed.

The publications considered within this review were from the following **sources**:

- peer reviewed international journals (60 publications)
- conference proceedings or papers (7 publications)
- reports published by government institutions (mostly water authorities; 6 publications)
- reports published by research institutions or NGOs (5 publications)
- refereed national journals (4 publications)
- project related dissertations/theses (2 publications)
- reference books (1 publication).

About one sixth (15 of 85) of the publications were from a context not governed by scientific quality control mechanisms, which shall herewith be termed "grey literature". In light of scarce data availability especially for Tanzanian drainage basins, and the high quality of the often state-approved reports, we think this ratio is reasonable.

The earliest considered **publication dates** back to the year 1983, and the latest was released in 2013, with a distinct and strong increase of publications after 2007 as can be seen in fig. 18. This marked temporal allocation may be ascribed to the nature of present-day scientific literature databases and search engines, which are often limited to the digital-era content not only of scientific publications. Beyond this structural condition, it can be easily perceived that the overall number of publications worldwide has steadily increased over time. Lastly, and most interesting in regards to content, a new interest in water resources development especially in the light of global dynamics seems to have stemmed from the long-term focus of natural resources research on climate change which dominated the better part of the 1990-2000s.

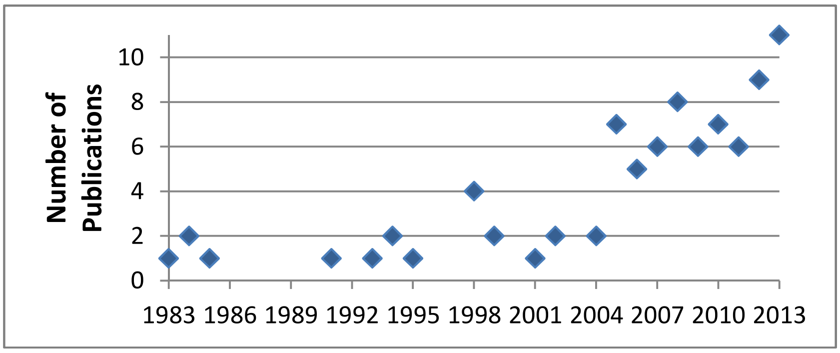


Fig. 18: Number of publications per date (year) of publication

References

The reviewed publications contained a **total of 132 references** to water resources development in 92 separately defined drainage basins in Eastern and Southern Africa[35]. Of these, 80% (106 references) referred to hydrologic parameters in rivers, while 20% (26 references) referred to lake levels. The reviewed references cover respective developments within the period from 1901 to 2011.

[35] This digit refers to the total number of *differently defined* drainage basins. It includes sub-, meso- and meta-basins as well as river and lake basins of the same drainage system *if they differ in spatial extent*. That is, if one reference described the drainage basin of Lake Victoria, another the drainage basin of the White Nile, and a third a sub-basin of the White Nile drainage basin, these were counted as three drainage basins although they are all attributed to the same overarching meso-basin, i.e. White Nile Basin. This distinction was maintained because water resources developments can be highly drainage basin specific, and some processes can only be investigated at certain scales.

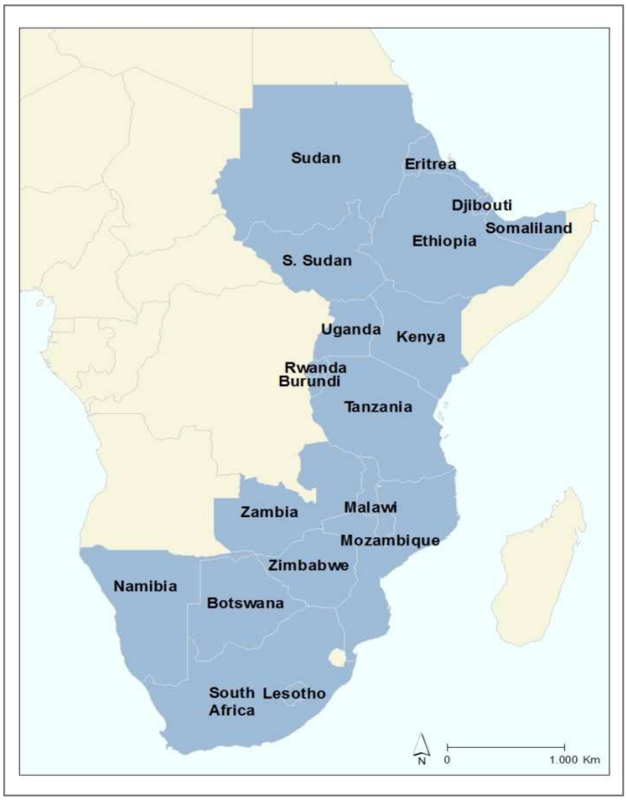


Figure 19 provides an overview of the **geographical distribution** of the mentioned drainage basins, which are located within the territory of 20 countries classed with the region. Only Somalia and Swaziland are not mentioned in any references.

Please also note that neither the Democratic Republic of Congo nor Angola are indicated here because they do not fall within the regional definition, however, a small stretch of the Eastern part of DR Congo and the southern-most part of Angola belong to drainage basins that do (i.e. Lake Tanganyika and Okavango river drainage basins, respectively).

Fig. 19: Distribution of drainage basins in reviewed references by country

Of the represented countries, four draw the clear majority of references: Tanzania, Kenya, Ethiopia and South Africa. Another considerable part of references relates to the large trans-boundary river and lake drainage basins in Eastern Africa. Comparable trans-boundary basins in Southern Africa as well as basins within the remaining countries are only referred to relatively seldom (see fig. 20). There thus seems to be a clear geographical focus on certain areas, most notably in Eastern Africa .

Country (each)	References
Tanzania	26
Kenya	23
Ethiopia	21
Transboundary – Eastern Africa	18
South Africa	16
Zimbabwe	9
Transboundary – Southern Africa	7
Malawi	5
Botswana, Uganda, Zambia	2
Lesotho	1

Fig. 20: Overview of references per country

This impression is further reinforced when the number of reviewed references are counted per meta drainage basin. Figure 21 illustrates some notable **research "Hot Spots"** in this regard.

With a total of 22 meta-basins referred to, only five are mentioned by more than eight references, and three stand out especially because they each combine over 15 references. These "Hot Spots" of drainage basin water resources research naturally tend to be large-area basins situated in countries with strong economic and social dynamics such as the Blue Nile and Tekeze basin, the Lake Victoria basin, the Rift Valley basin or the Zambezi River basin. Most likely due to its importance for the many countries along its course, research of the Nile river sub-basins receives special attention. In addition, the developments in the unique Rift Valley lakes systems, which as mostly endorheic lakes easily indicate variances in the drainage basin water balance, are of prime scientific concern. In the Zambezi, Limpopo and Orange River basin especially, but increasingly also in Eastern African basins, hydropower generation is an important factor of change in water resources development and is respectively investigated in scientific publications. In this respect it is noteworthy to include that in Southern Africa, an additional vast number of studies are published in regard to water engineering and water demand vs. water availability scenarios, however, most of these did not fit our more observation-oriented selection criteria and are thus not represented in this review.

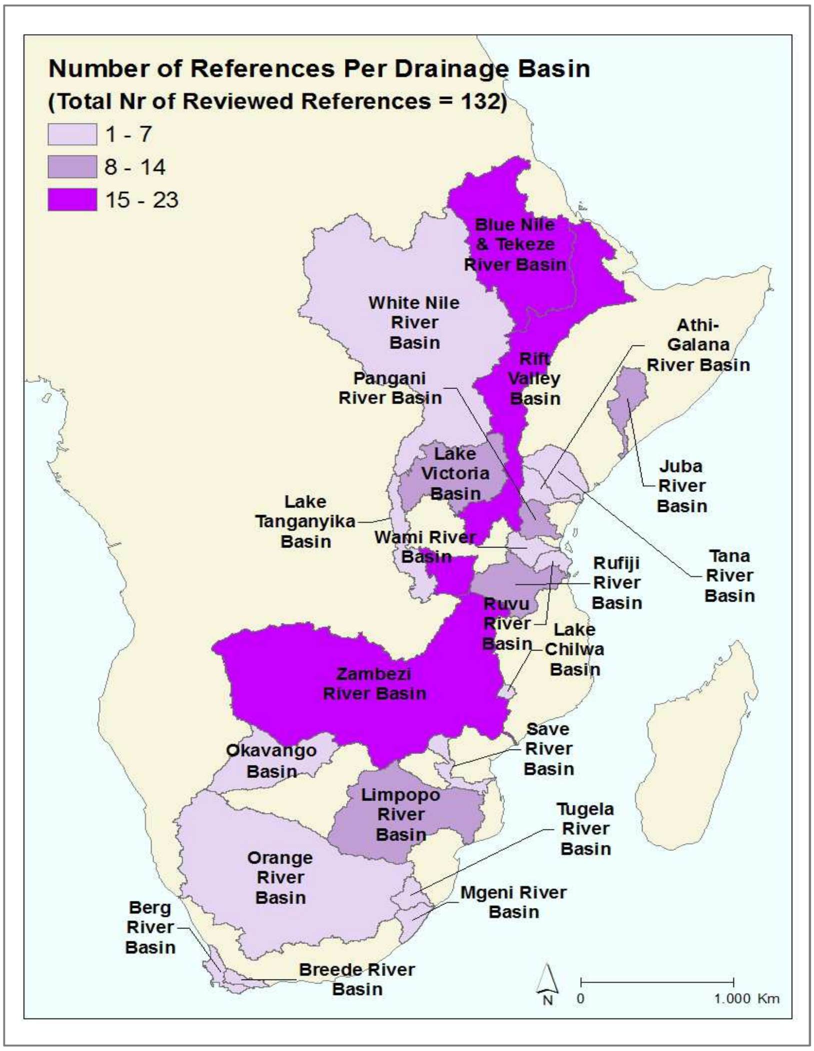


Fig. 21: Overview of research "Hot Spots"

In addition to the above rather obvious "Hot Spots", a few other drainage basins draw attention in regard to the number of references they combine. The Juba, Pangani or Rufiji River basin for example are smaller catchments with comparatively high numbers of research studies and publications. A closer analysis of the underlying cause of such clusters was not part of this review, but based on the recurring names of certain affiliated authors, it can only be speculated that these drainage basins might be the sites of longer-term research projects, or of special interest to certain institutions. Of course, special interest from our Trans-SEC side was on Tanzanian drainage basins, resulting in a more extensive search on publications on the latter and thus possibly translating into a higher ratio among the results.

Important for this review is to know of, and keep in mind, the bias introduced by the uneven distribution of references per drainage basin. Interestingly, the areas of intensified research mostly coincide with areas of major economic, social, and environmental change. Whether the research sites were selected on the grounds of such change, or whether any closer investigation of other drainage basins would reveal as of yet unidentified similar dynamics, remains unclear.

Another important aspect to keep in mind is the **time span** each reference relates to. This figure is defined by the time frame of the underlying data. If a reference for example is based on the analysis of yearly river discharge rates from 1970-2005, the respective time span would be 35 years.
In regard to our interest in long-term developments and trends, obviously longer time frames provide a more suitable base for such inferences. The selection criteria therefore already established a minimum time span of 10 years, and it has proven that the type of references we were interested in were based mainly on longer-term data sets. As can be seen in fig. 22, the vast majority of references relates to a time span of more than 30 years, with a mean value of 45 years across all considered

references. Only three references draw on less than 15 years of data, and 17 references even exceed the time span of 75 years or roughly an average human life span. Based on these figures, it can be safely concluded that the underlying time spans are reasonable and provide a consistent basis for the type of analysis conducted.

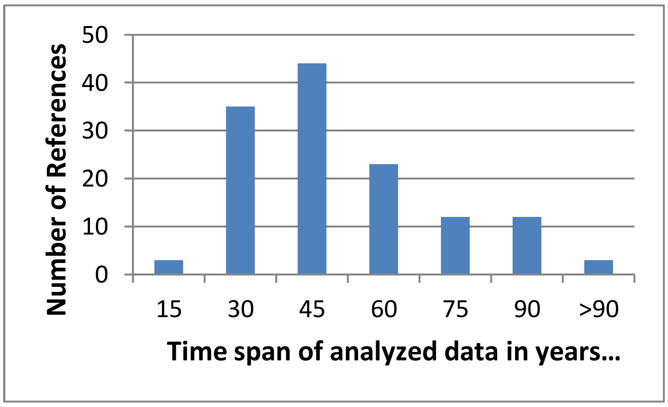
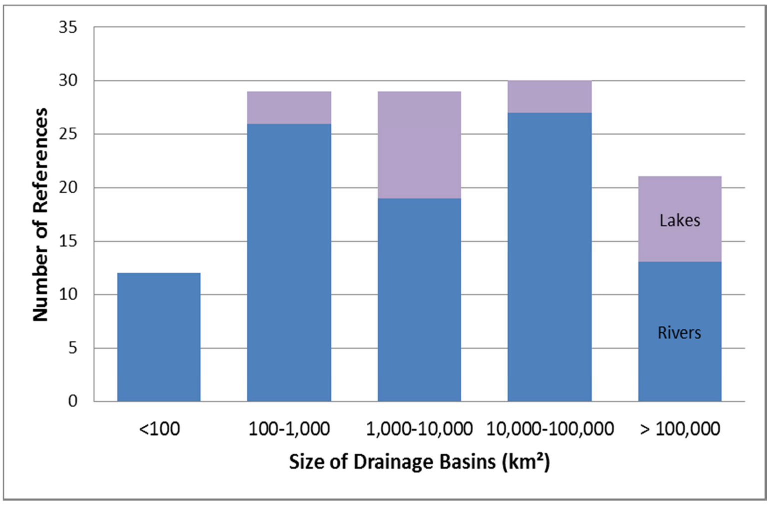


Fig. 22: Overview of time spans of reviewed references

Lastly, the **spatial extent** of the analyzed drainage basins plays an important role in many aspects. The reviewed references describe developments in basins ranging from 1.4 to 1.4 million km². This huge variance poses a serious limitation for any comparison or description across basins. For the present report, the references were therefore grouped according to threshold values[36] as indicated in fig. 23. It can be seen that the majority of described basins fell within three large groups: basins with an area of 100-1,000km² (29, or 21.6%), basins with an area of 1,000-10,000km² (29, or 21.6%), and basins with an extent of 10,000-100,000km² (30, or 22.4%).



The other groups were constituted of 12 references (or 9%) depicting basins smaller than 100km²; two of these were smaller than 10km². 21 references (or 15,7%) were depicting basins of more than 100,000km². Of these, only 4 references were made to basins larger than 500,000km². Eleven references did not provide information about the size of the respective drainage basin.

Fig. 23: Number of references per size class of reviewed drainage basins

The relation between the spatial extent of drainage basins and reported trends and causes received special attention; respective findings will be discussed separately in chapter 5.5.

[36] Chosen on the basis of forming homogenous groups, while also considering leaps in basin hydrology sensitivity.

4.2 Synopsis of findings from entirety of river drainage basin studies

A total of 106 references to river drainage basins described 75 separate catchments spread from northern Ethiopia to South Africa.

Fig. 24 provides a first overview of the reported aggregated development of annual streamflow in the 22 respective meta-basins from 1900-2010.

For all subsequent analyzing chapters, the following four categories are introduced to describe the **development within basins:**

- Decreasing trend reported by >80% = More than 80% of studies for this meta-basin mention a decreasing trend[37] (at sub-basin to basin level)
- Decreasing trend reported by >50% = More than 50% of studies for this meta-basin report a decreasing trend (at sub-basin to basin level)
- Opposing trends = No majority can be established on reported trends among studies for this meta-basin
- No trend = All studies for this meta-basin report the absence of trends (at sub-basin to basin level)

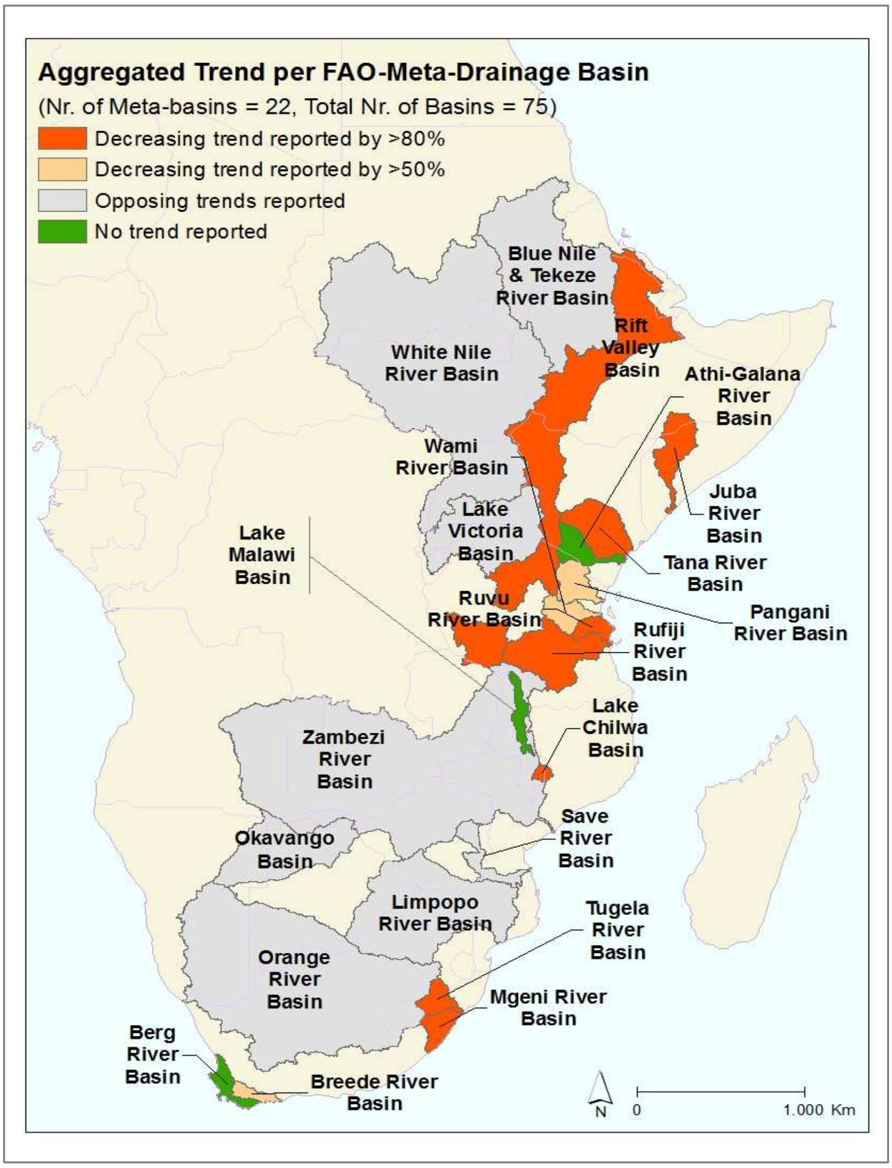


Fig. 24: Reported trends in annual streamflow aggregated per meta-basin

Note that no meta-basin showed an increasing trend on this aggregated level (but at sub-basin level, see table 2).

In accordance with above categories, 8 meta-basins featured **more than 80% of studies reporting a decreasing trend** (Rift Valley, Juba River, Tana River, Ruvu River, Rufiji River, Lake Chilwa, Tugela River, and Mgeni River basins[38]).

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[37] The term trend is defined as **a specific change of any described hydrological parameter persisting for more than two decades**. For more information, see chapter 2.

[38] If not otherwise stated, the enumeration of drainage basins always take place from north to south.

3 meta-basins featured **more than 50% of studies reporting a decreasing trend** (Pangani River, Wami River, and Breede River basin), while another **8** meta-basins found **opposing trends** among the associated studies (Blue Nile & Tekeze River, White Nile River, Lake Victoria, Zambezi River, Cubango-Okavango River, Save River, Limpopo River, and Orange River basins).

Only **3** meta-basins feature a consensus among studies on reporting **no trend** in annual streamflow development (Athi-Galana River, Lake Malawi, and Berg River basins).

When observing the respective trend groups for **spatial patterns**, a clear statement can be made that the bulk of meta-basins with a majority of studies reporting decreasing trends are located within Eastern Africa. Meta-basins with reportedly opposing trends, as well as no trends, on the other hand, seem to be equally represented in both regions.

At the same time it becomes obvious that the **basin size** seems to be correlated with the reported development. Meta-basins with a decreasing trend reported by the majority of studies all tend to be based on references from relatively small (sub-)basins (20-15,000km², with the exception of Tana River basin where the reference covers the entire basin of 132,000km² - for all information on (sub-) basin attributes, see table 2). The same holds true for meta-basins with no trend. Not surprisingly, meta-basins displaying aggregate opposing trends are based on references to predominantly large (sub-)basins (1,000-238,000km²).

While aggregating the information on streamflow trends, we also compiled the stated **cause of developments** (=pressures) as reported in each reference (attributed causes may apply even if no trend was determined, as fluctuations in annual streamflow were usually reported and causes thereof stated). When comparing the aggregated findings for each meta-basin, the following interesting observations can be made.

Firstly, **climate variability and/or change** is named as an impacting factor for the changes in all meta-basins. However, only 5 of the 22 meta-basins are reported to relate to it as a leading cause; mostly, it is stated as a contributing factor. Out of these, the Athi-Galana-Sabaki and Cubango-Okavango River basins are alleging climatic factors as the sole cause of changes.
It can thus be safely concluded that climate plays a role for all meta-basins, irrespective of the location or reported trend.

If climate is taken as a given, the remaining factor affecting streamflow is **anthropogenic impact.** Fig. 25 presents an overview of the stated pressures per meta-basin. A cursory scan for patterns does not reveal any striking spatial relationships with the established trend groups - in fact, the same causes seem to be reported for all basins throughout Eastern and Southern Africa. A tentative assessment would be that meta-basins with distinctive declining trend seem to feature a larger number of pressures in relation to their size. However, such conclusions are difficult at the aggregated level, and will be more closely analyzed in chapter 5.

In general it can be resumed that meta-basins with distinctive or mostly decreasing trend are predominantly influenced by anthropogenic causes plus climate as a contributing factor, while meta-basins with opposing or no trends were predominantly driven by climatic causes plus contributing human impact.

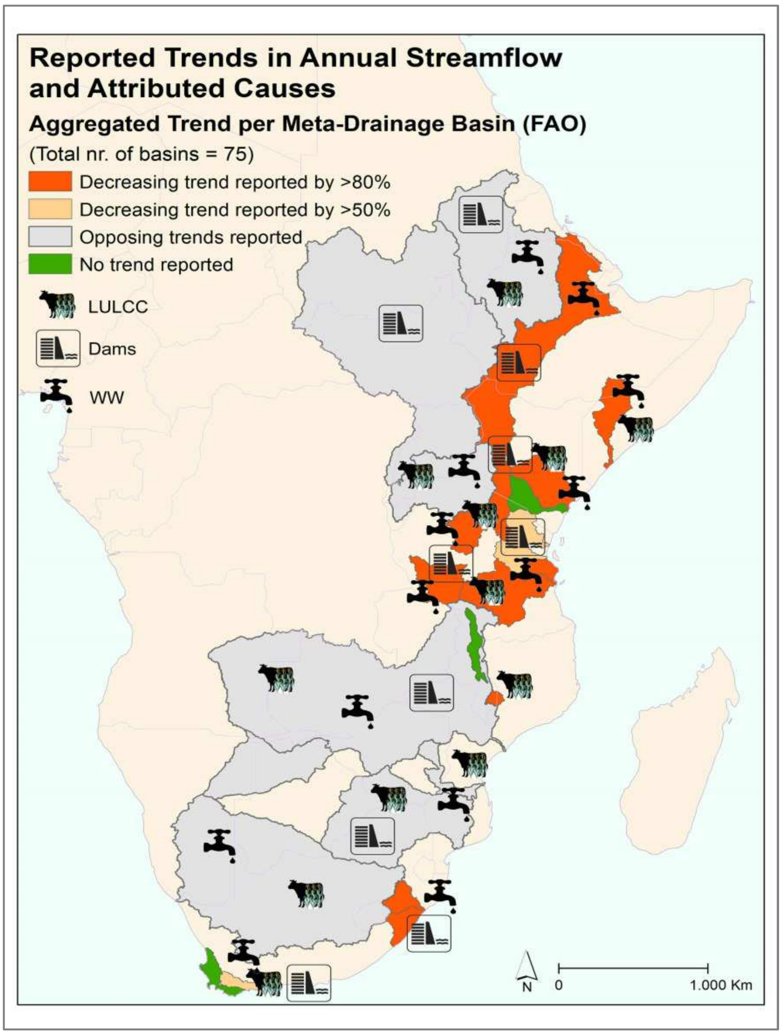


Fig. 25: Trends in annual streamflow and attributed pressures per meta-basin[39]

LULCC – land use/land cover change, WW – water withdrawal

Information on reviewed river drainage basin details

Table 2 on the next page provides a condensed overview of the most important details and findings for each river drainage from north to south. These include the associated meta-basin, the country where the basin is located, and the basin as well as the lake surface size in square kilometers.

The reported trend is indicated by a respective abbreviation and underlying color: +- = no trend (green), + = increasing trend (blue), - = decreasing trend (orange). In the case that different references reported different results for a single drainage basin, this segmentation is presented by the known abbreviation plus the number of references stating this trend, e.g. +- (2), - (1). If a majority of references points towards a trend, the background will be striped based on the already introduced color code. If no majority is distinguishable, the background color will be grey. In addition to the change point/decade and attributed pressure named by the already established abbreviations (CV – climate variability, CC – climate change, WW – water withdrawal, LULCC – land use/land cover change), a column will provide more details on the manifestations of the respective pressure. Please note that the causes and drivers are listed in the order of the frequency of their mention. The last column lists the author(s) and year of publication for all references regarding a given drainage basin.

[39] Please note that climate variability and change are not represented in this map as they feature in each meta-basin except for Juba River, Tana River, Zambezi River, and Berg River basin.

Table 2: Details of reviewed river drainage basins (from north to south)

MetaBasin (& Trend)	Country of Meso / Sub-Basin(s) (underscored = countries related to in sub-basins)	MesoBasin (& Trend)	Sub-basin(s) / *Basin*	Size (Range) of Basins	Itemized Trend of Annual Streamflow [a] (n=nr of references)	Change Point / Decade	Attributed Pressure(s) [b]	Details on Pressure(s)	References
Nile Basin	Transboundary (Ethiopia, Sudan)	**Blue Nile & Tekeze Basin**	Chemoga, Jedeb, Koga, Hara Swamp Basin	48-364km²	- (2) + (2) +- (1)	1960s / 1980s / 1990s	**LULCC; WW; CV**	**LULCC** - Agr. Expansion; Deforestation; Degradation by overgrazing & poor farming practices; Afforestation (eucalyptus plantations); Urbanization **WW** - Agr. Intensification (Irrigation); Increased domestic demand; Increased livestock numbers **CV** - Rainfall variability	*Bewket and Sterk* [2005], *McHugh et al*. [2007], *Gebrehiwot et al.* [2010, 2013], *Tekleab et al.* [2013]
			Birr, Upper-Didesa, Upper-Gilgel, Lake Tana Basin	980-15,300km²	- (3) +- (1) ≈ (1)	1960s / 1970s / 1990s / 2000	**LULCC; CV; Dams**	**LULCC** - Deforestation; Agr. Expansion; Degradation by overgrazing & poor farming practices **CV** - Period of decreased rainfall (1970s) **Dams** - Hydropower (1996)	*McCartney et al.* [2010], *Gebrehiwot et al.* [2013], *Rientjes et al*. [2011]
			Blue Nile Basin	200,000km²	- (1) + (1) +- (1) mixed (1)	1996s / 1990s / 2000	**LULCC; CV; CC; Dams**	**LULCC** - Deforestation; Agr.Expansion; Degradation by overgrazing **CV** - Rainfall variability **CC** - Decreasing rainfall (since 1960s) **Dams** - Irrigation (1996)	*Conway and Hulme* [1993], *Tesemma et al*. [2010], *Gebrehiwot et al.* [2013], *Gebremicael et al.* [2013]
Nile Basin	Transboundary (Burundi, DR Congo, Kenya, Rwanda, Tanzania, Uganda)	**White Nile Basin**	Upper-Ssezibwa Basin	175km²	- (1)	1990s	**CV**	**CV** - Increasing temperatures	*Nyenje and Batelaan* [2009]
			White Nile Basin	911,000km²	+ (1)	1950s	**CV; Dams**	**CV** - Period of increased rainfall (1950s-1966) **Dams** - Irrigation (1960s)	*Conway and Hulme* [1993]
Nile Basin	Transboundary (Burundi, DR Congo, Kenya, Rwanda, Tanzania, Uganda)	**White Nile Basin - Lake Victoria**	Nyangores Basin	700km²	nn (1, increased flooding, decreased low flow)	1990s	**LULCC**	**LULCC** - Agr. Expansion; Deforestation	*Mango et al. [* 2011]
			Nyando, Nzoia, Mara Basin	3,550-13,750km²	- (1) nn (3, increased flooding, decreased low flow)	1960s	**LULCC; CV; WW**	**LULCC** - Agr. Expansion; Deforestation; Degradation through overgrazing and poor farming practices **CV** - Rainfall variability **WW** - Increased domestic demand	*Githui* [2008], *Mati et al.* [2008], *Melesse et al*. [2008], *Olang and Fürst* [2011]
			Lake Victoria Basin	210,000km²	+ (1) nn (1, increased flooding)	1970s / 1990s	**CC; LULCC**	**CC** - Increasing temperatures (since 1970s); Increasing rainfall & rainfall variability (since 1990s) **LULCC** - Agr.Expansion; Deforestation; Urbanization	*UNEP* [2006], *Mbungu et al*. [2012]
Rift Valley Basin	Transboundary (Djibouti, Eritrea, Ethiopia, Kenya, Tanzania, Sudan, Uganda)		Lake Elementeita, Lake Nakuru, Hare River, Njoro River Basin	167 - 335km²	- (4) + (1)	1960s / 1970s / 1980s / 1990s	**WW; LULCC; Dams; CC**	**WW** - Increased domestic demand; Agr. Expansion & Intensification (Irrigation of apple orchards); Increased livestock numbers; Increased urban demand **LULCC** - Agr. Expansion; Deforestation **Dams** - Irrigation/domestic demand (since 1960s) **CC** - Increasing temperatures; Decreasing rainfall (since 1960s)	*Mwaura and Moore* [1991], *Murimi* [1994], *Tadele* [2009], *Raini* [2009], *Baker and Miller* [2013]

Table 2: Details of reviewed river drainage basins (continued)

MetaBasin (& Trend)	Country of Meso / Sub-Basin(s) (underscored = countries related to in sub-basins)	MesoBasin (& Trend)	Sub-basin(s) / *Basin*	Size (Range) of Basins	Itemized Trend of Annual Streamflow [a] (n=nr of references)	Change Point / Decade	Attributed Pressure(s) [b]	Details on Pressure(s)	References
Juba River Basin	Kenya		Burguret, Likii, Nanyuki, Naro Moru, Timau Basin	11-173km²	- (7) +- (1)	1960s / 1970s / 1980s	**WW; LULCC**	**WW** - Increased domestic demand; Agr. Expansion & Intensification (Irrigation of horticulture); Increased livestock numbers; Increased urban demand **LULCC** - Agr. Expansion; Deforestation; Urbanization; Degradation through overgrazing and poor farming practices	*Aeschbacher et al.* [2005], *Liniger et al.* [2005], *Notter et al.* [2007], *Ngigi et al.* [2008]
			Upper Ewaso Ngiro Basin	15,200km²	nn (1, decreased low flow)	1970s	**LULCC; WW; CV**	**LULCC** - Agr. Expansion; Degradation through overgrazing, Sand mining **WW** - Agr. Intensification (Irrigation); Increased domestic demand; Increased livestock numbers **CV** - Rainfall variability	*Gichuki* [2004]
Tana River Basin	Kenya		*Tana River Basin*	132,000km²	- (1)	1980s	**Dams, WW, LULCC**	**Dams** - Hydropower (2 large dams, 1968 and 1988) **WW** - Increased urban water demand (= water transfers to neighbouring basin) **LULCC** - Agr. Expansion; Deforestation	*Snoussi et al*. [2007]
Athi-Galana-Sabaki River Basin	Kenya		*Athi-Galana-Sabaki River Basin*	70,000km²	+ - (1)		**CV**	**CV** - Rainfall variability	*Snoussi et al*. [2007]
Pangani River Basin	Transboundary (Kenya, <u>Tanzania)</u>		Luengera, Mkomazi, Sigi, Umba Basin	705-3,340km²	- (3) + (1) nn (2, increased flooding, decreased low flow)	1960s / 1970s	**CV; LULCC; CC**	**CV** - Rainfall variability **LULCC** - Deforestation; Agr. Expansion; Degradation through poor farming practices **CC** - Increasing rainfall	*Mtalo et al.* [2005], *Yanda and Munishi* [2007], *Valimba* [2008]
			Pangani River Basin	43,650km²	- (upstream of dam, 2) ≈ (downstream of dam, 2) nn (1, decreased low flow, increased no flow)	1950s / 1960s / 1970s	**WW; Dams; LULCC; CV; CC**	**WW** - Agr. Expansion & Intensification; Increased domestic demand; Increased urban & industrial demand; Water abstraction for power generation **Dams** - Hydropower & Irrigation (2 large dams, 1957 and 1965) **LULCC** - Agr. Expansion; Deforestation; Urbanization **CV** - Rainfall variability **CC** - Decreasing rainfall; Increasing temperatures (since 1960s)	*PBWO/IUCN* [2007], *Valimba* [2008], *King et al.* [2009]
Wami River Basin	Tanzania		*Wami River Basin*	43,742km²	- (2) +- (1)	1970s	**LULCC; CC**	**LULCC** - Deforestation; Agr. Expansion; Urbanization **CC** - Decreasing rainfall; Increaseing temperature	*Mtalo et al*. [2005], *Nobert and Jeremiah* [2012], *JICA* [2013]

Table 2: Details of reviewed river drainage basins (continued)

MetaBasin (& Trend)	Country of Meso / Sub-Basin(s) (underscored = countries related to in sub-basins)	MesoBasin (& Trend)	Sub-basin(s) / *Basin*	Size (Range) of Basins	Itemized Trend of Annual Streamflow [a] (n=nr of references)	Change Point / Decade	Attributed Pressure(s) [b]	Details on Pressure(s)	References
Ruvu River Basin	Tanzania		Ngerengere Basin	2,780km²	- (1)	1990s	**CC; Dams; LULCC**	**CC** - Slightly decreasing rainfall; Increased length of dry periods (since 1990s/2000s) **Dams** - Urban water supply (large dam, 1983) **LULCC** - Agr. Expansion; Deforestation	*Natkhin et al.* [2013]
			Ruvu River Basin	11,790km²	- (3)	1960s / 1980s /	**LULCC; WW; Dams; CC; CV**	**LULCC** - Deforestation; Agr. Expansion; Degradation through poor farming practices **WW** -Illegal abstraction for irrigation **Dams** - Urban water supply (large dam, 1983) **CC** - Increased temperatures (since 960s); Contradicting findings on rainfall (both increasing and decreasing reported) **CV** - Rainfall variability	*Mtalo et al*. [2005], *Yanda and Munishi* [2007], *JICA* [2013]
Rufiji River Basin	Tanzania	Great Ruaha River Basin	Mkoji, Usangu Basin	3,400-20,800km²	- (4)	1980s / 2000s	**WW; LULCC; CC**	**WW** - Agr. Expansion & Intensification (Irrigation of wet-rice); Increased domestic demand; Increased lifestock numbers **LULCC** - Agr. Expansion; Deforestation; Degradation through overgrazing **CC** -Decreasing rainfall; Increasing dry spells and longer dry season; Increased rainfall variability (all since 1990s)	*Ministry of Water, TZ* [2001], *Rajabu et al*. [2005], *Kashaigili* [2008], *Shu and Villholth* [2012]
		Kilombero River Basin, Great Ruaha River Basin		14,136-68,000km²	- (3) mixed (1)	1970s / 1990s	**WW; LULCC; CV**	**WW** - Agr.Expansion & Intensification (Irrigation of wet-rice) **LULCC** - Deforestation; Agr. Expansion ; Degradation through poor farming practices **CV** - Rainfall variability	*Mtalo et al*. [2005], *Mwakalila* [2005, 2011], *Mitchell* [2013]
			Rufiji River Basin	177,400km²	- (1)	1980s	**Dams; LULCC; CC**	**Dams** - Hydropower (3 large dams, in 1980s) **LULCC** - Deforestation; Agr. Expansion **CC** - Increased rainfall trend over upper basin region	*Snoussi et al*. [2007]
Zambezi River Basin	Transboundary (Angola, Botswana, DR Congo, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe)		Kafue Flats, Rivirivi, Nyatsime, Upper-Shire Basin	500-6,500km²	- (2) + (1) ≈ (2)	1970s / 1980s	**LULCC; WW; Dams; CV; CC**	**LULCC** - Agr.Expansion; Deforestation; Drainage of wetlands; Urbanization **WW** - Agr. Expansion & Intensification (Irrigation); Increased urban demand; Increased domestic demand **Dams** - Hydropower (3 large dams, 1959, 1971, 1978) **CC** - Decreased rainfall trend in upper river basin (since 1970s) **CV** - Rainfall variability	*Lørup et al.* [1998], *Mumba and Thompson* [2005], *Palamuleni* [2011], *Chimtengo et al*. [2013], *Mitchell* [2013]
			Zambezi River Basin	1,400,000km²	- (upstream of dam, 2) + (upstream of dam, 1) +- (upstream of dam, 1) mixed (upstream of dams, 1) ≈ (downstream of dams, 1)		**Dams; CV; LULCC**	**Dams** - Hydropower (3 large dams, in 1950s-1980s) **CV** - Long term variability of rainfall **LULCC** - Abandonment of agriculture and return of indigenous land cover due to civil war (1975)	*Langenhove et al.* [1998], *Mazvimavi and Wolski* [2006], *Conway et al.* [2009], *Beilfuss* [2012], *Jury* [2013]
Zambezi River Basin - Lake Malawi	Transboundary (Malawi, Mozambique, Tanzania)	**Lake Malawi Basin**	Luchelemu, Ruhudji Basin	13-500km²	+ - (2)				*Mwendera* [1994], *Atwitye* [1999]

Table 2: Details of reviewed river drainage basins (continued)

MetaBasin (& Trend)	Country of Meso / Sub-Basin(s) (underscored = countries related to in sub-basins)	MesoBasin (& Trend)	Sub-basin(s) / *Basin*	Size (Range) of Basins	Itemized Trend of Annual Streamflow [a] (n=nr of references)	Change Point / Decade	Attributed Pressure(s) [b]	Details on Pressure(s)	References
Lake Chilwa Basin (no outflow)	Malawi		Mulunguzi, Namadzi Basin	19-27km²	- (2)	1980s / 1990s	**CC; LULCC**	**CC** - Decreasing rainfall **LULCC** - Afforestation (commercial pine plantations)	*Mbano et al.* [2009]
Cubango-Okavango River Basin (no outflow)	Transboundary (Angola, Botswana, Namibia)		Okavango Delta Basin	13,000km²	+- (1)		**CV**	**CV** - Rainfall variability	*Wolski et al*. [2012]
			Cubango-Okavango River Basin	120,000-238,700km²	- (1) + (1)	1950s / 1960s	**CC; CV**	**CC** - Decreasing rainfall over headwater basins **CV** - Large-scale rainfall variability	*Conway et al.* [2009], *Jury* [2010]
Sabi/Save River Basin	Transboundary (Mozambique, Zimbabwe)		Mshagashi, Popotekwe, Roswa, Turgwe, Upper-Sabi Basin	165 - 1,010km²	- (2) + (1) +- (2)	1970s / 1980s	**LULCC; WW**	**LULCC** - Deforestation; Agr. Expansion; Drainage of wetlands **WW** - Increased domestic demand	*du Toit* [1985], *Lørup et al.* [1998]
Limpopo River Basin	Transboundary (Botswana, Mozambique, South Africa, Zimbabwe)		B71C Quarternary Mohlapetsi, Westfalia-D Basin	4-263km²	+ (1) +- (1)	late 1990s	**LULCC; CV**	**LULCC** - Agr.Expansion; Drainage of wetlands; Urbanization **CV** - Rainfall variability	*Troy et al.* [2007], *Scott and Prinsloo* [2008]
			Insiza, Luvuvhu, Mzingwane, Shashe Basin	3,400-18,900km²	- (2) + - (1) ≈ (1) mixed (1)	1960s / 1970s / 1980s	**Dams; LULCC; CC; WW**	**Dams** -Irrigation (three large reservoirs, 1966, 1967 and 1973, and many small dams since 1960s) **LULCC** - Afforestation; Deforestation; Agr. Expansion; Degradation through overgrazing **CC** - Decreasing rainfall trend (since 1960s); Increased drought occurence; Increasing	*Kileshye Onema et al.* [2006], *Love et al.* [2010], *Odiyo* [2011], *Warburton et al.* [2012]
		Olifants River Basin		54,695km²	+- (1)				*McCartney et al.* [2004]
Orange River Basin	Transboundary (Lesotho, Namibia, South Africa)			13,127 - 30,344km²	- (1) + (2) +- (1)	1930s / 1970s	**CV; CC; LULCC; WW**	**CV** - Rainfall variability **CC** - Increasing rainfall; Decreasing rainfall **LULCC** - Agr. Expansion; Deforestation; Massive increase of barren land **WW** - Not specified	*Sene et al*. [1998], *Lakhraj-Govender* [2010], *Kabanda and Palamuleni* [2013]
Tugela River Basin	South Africa		Cathedral Peak Basin	2km²	- (1)	1960s	**LULCC**	**LULCC** - Afforestation (commercial pine plantation)	*Zhao et al.* [2012]
			Tugela River Basin	29,100km²	- (1)	1930s	**CC; WW; Dams**	**CC** - Decreasing rainfall **WW** - Transfer scheme **Dams** - Not specified	*Lakhraj-Govender* [2010]
Mgeni River Basin	South Africa			4,349km²	- (2)	1960s	**WW; LULCC; Dams**	**WW** - Agr. Intensification (commercial sugarcane); Urban demand **LULCC** - Afforestation (pine plantations); Urbanization **Dams** - Urban water supply (4 large dams, in 1960s); Irrigation (several hundred small dams, since 1960s)	*Lakhraj-Govender* [2010], *Warburton et al.* [2012]
Berg River Basin	South Africa	Jonkershoek Valley Basin	Tierkloof Basin	16km²	+ - (1)				*Scott and Prinsloo [* 2008]
Breede River Basin	South Africa		Upper-Breede River Basin	2,060km²	- (1)	**1960s**	**WW, LULCC**	**WW** - Agr. Intensification (commercial orchards and vineyards) **LULCC** - Agr. Expansion	*Warburton et al.* [2012]
			Breede River Basin	17,951km²	- (1) +- (1)	**1920s**	**WW; Dams; CC**	**WW** - Agr.Expansion & Intensification (grape industry) **Dams** - Not specified (2 large and many small dams, in 1960s) **CC** - Increasing temperature; Increasing rainfall (since 1960s)	*Lakhraj-Govender* [2010], *Lloyd* [2010]

4.3 Synopsis of findings from entirety of lake drainage basin studies

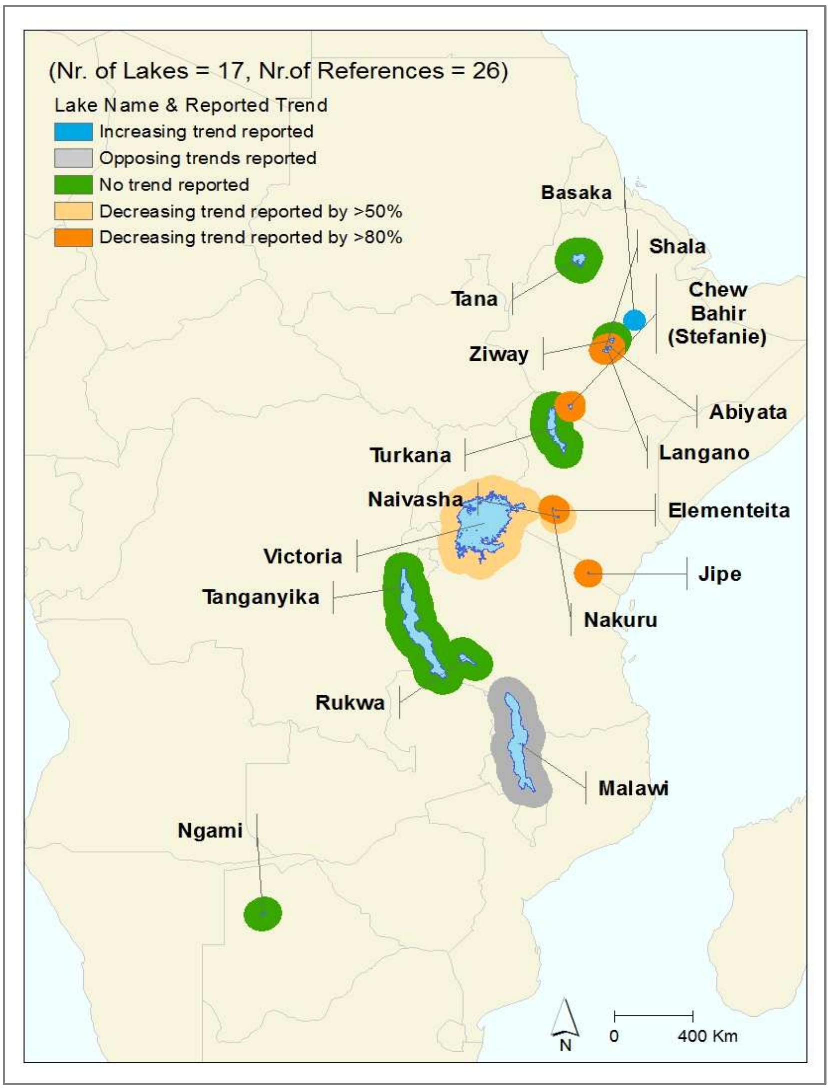


Fig. 26: Reported annual trends in lake water level

The group of lake drainage basins constitutes 26 references which describe 17 separate drainage basins from Ethiopia to Botswana. The majority of basins are located in Eastern Africa.

Figure 26 provides an overview of both the more detailed location as well as the reported annual water level trends[40] of the respective lakes within the period of 1900-2010.

Of all mentioned lakes, **7** were attested a **decreasing trend by all references** (Lakes Langano, Shala, Abiyata, Chew Bahir, Elementeita, Nakuru, Jipe) with another **2** being ascribed **decreasing trends by the majority of references** (Lake Naivasha, Lake Victoria). **6** were homogenously reported to have **no detectable trend** (Lakes Ziway, Tana, Turkana, Tanganyika, Rukwa, Ngami), while the information on **1** lake (Lake Malawi) amounted to **opposing trends** according to the consulted references. Only **1** lake (Lake Basaka) was mentioned as having an **increasing trend**.

For more detailed information on the composition of attributed trends, causes and other drainage basin attributes, see table 3 on page 45.

Looking at the type of trends among the described drainage basins, a **spatial pattern** mirroring the one observed for river basins seems to emerge. While lakes without distinctive trend in water level are fairly evenly distributed over Eastern and Southern Africa, those with a declining trend are unambiguously located in Eastern Africa. So, too, is the only lake with increasing levels. The one lake with opposing trends can be found in Southern Africa.

In regard to **basin size** it can be stated that lakes with declining water levels feature, with the exception of Lake Victoria, relatively small drainage basins of 335-7,000km² . The same is true for Lake Basaka with its rising water levels. The group without attributable trend, on the other hand, features three medium sized drainage basins of 3000-16,500km² (Lakes Ziway, Ngami and Tana) but also three of the largest drainage basins in the region with an extension of 88,000-200,000km² (Lakes Turkana,

[40] For more information on the process and definition of the applied categories, see chapter 2. In the following, the lakes are always listed in the order of their location from north to south.

Tanganyika and Rukwa). Lake Malawi, featuring opposing trends, also belongs to this latter group in respect to basin size.

Another classification which reveals a possible pattern can be made by comparing **lake types,** such as terminal lakes (i.e. lakes with no outflow) and headwater lakes (i.e. lakes whose outflow contributes to a river drainage basin). It shows that lakes with decreasing trend are – again with the exception of Lake Victoria, and Lake Jipe - exclusively terminal lakes situated in the Rift Valley Basin. Again, Lake Basaka shares this trait. Lake drainage basins without or with opposing trends are much less homogenous in this respect, spanning both four terminal (Lakes Ziway, Turkana, Rukwa and Ngami) and three headwater lakes (Lakes Tana, Tanganyika and Malawi).

When comparing the stated **causes of change (=pressures) in relation to the trend groups** (fig. 27), some interesting overlaps can be observed. Please note that even for lakes were no trend was mentioned, fluctuations in water level were usually reported and a cause thereof stated.

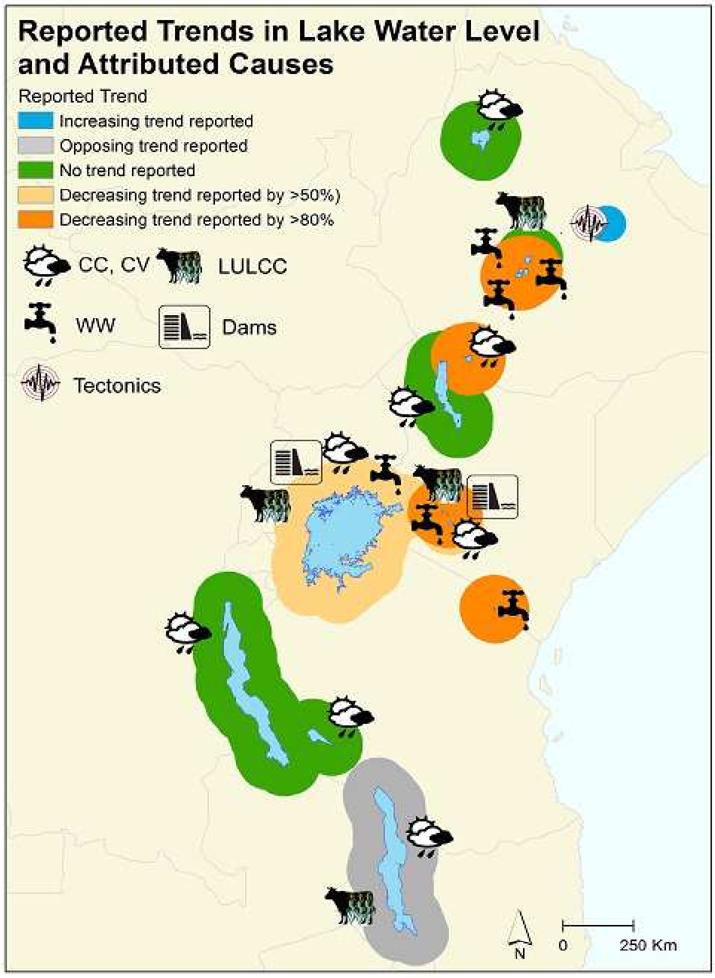


Fig. 27: Reported annual trends in lake water level and attributed pressures[41]

CV – climate variability, WW – water withdrawal,
LULCC – land use/land cover change

Firstly, the developments in all lake drainage basins **without distinctive trend** (with the sole exception of Lake Ziway) were reported to be **driven by climate variability.**

Lake Malawi, too, falls into this category: even though two references state that no trends are observable and two contrastingly report increasing water level trends, all references agree that climate is the main pressure to be attributed. In addition, LULCC was reported by one reference as causing changes in the variability of water level and flashiness of floods in the basin, but not changes in the water level per se.

Lake Ziway holds a special role in this regard as the unchanging lake water levels are attributed to the somewhat paradox circumstance that the reportedly high abstraction rates from the lake are compensated by the inflow of excess irrigation water from nearby drainage basins and groundwater sources. In fact the over-abstraction of groundwater has led to a rise of the groundwater table, which

[41] Please note that Botswana's Lake Ngami (no trend, main factor = climatic variability) is not included in this sectoral view.

in turn causes a stagnation of lake water levels despite the persistent large water withdrawals (a similar occurrence can be observed for Lake Basaka).

Quite contrastingly, for all drainage basins with **decreasing trend** except Lake Chew Bahir, water level changes were **attributed predominantly to anthropogenic impact** – chiefly through water withdrawal, but also through the construction of dams and LULCC. Basins with especially drastic changes, such as Lake Victoria, Lake Nakuru and Lake Naivasha, were reported to have experienced several of these humanly induced factors together, in addition to unfavorable climatic conditions. However, climate variability, although considered in nearly all studies, was stated as the sole cause of declining water levels only for Lake Chew Bahir. Note that climate change in the sense of a shift in climate persisting for more than 30 years was only reported as a pressure in three cases, namely for Lake Naivasha and Lake Victoria (both decreasing trend according to majority of studies) and for Lake Malawi (opposing trends).

As the only lake with a reportedly increasing trend, Lake Basaka is extraordinary in that its increasing water levels are attributed excess irrigation water from nearby basins as well as to **tectonic activity** and the resulting emergence of underground springs which feed the lake. This phenomenon is only reported for one other Lake, Lake Langano, where underground springs seem to at least partially compensate for the growing abstraction rates thus resulting in a slower decrease of water levels than would be expected.

All in all, it can be stated that lake drainage basins without distinctive trend are reported to be mainly driven by climate variability and distributed throughout Eastern and Southern Africa, while those lake drainage basins with decreasing trends are chiefly impacted by anthropogenic factors and exclusively located in Eastern Africa. These findings mirror the general impression relayed by the results from the river drainage basins. Two main regions with strong anthropogenic impact seem to be identifiable, one covering the northern, mostly Ethiopian Rift Valley area, the other stretching from Lake Victoria and the Southern Rift Valley region in Kenya towards the Indian Ocean coast.

Table 3 on the next page provides a condensed overview of the most important details and findings for each lake drainage from north to south. For a detailed description of the table content and used abbreviations please refer to chapter 4.2, page 38. A more detailed discussion of the findings and especially the relations between pressures and the extent of change will be presented in chapter 5.

Table 3: Details of reviewed lake drainage basins (from north to south)

a) lake surface area varies over time/season **b)** +- = no trend (green), + =increasing (blue), - =decreasing (orange), mixed trends = grey, mixed trends with majority decreasing = orange striped **c)** CV – climate variability, CC – climate change, WW – water withdrawal, LULCC – land use/land cover change

Meta-Basin	Lake	Country	Basin Size (Lake Size) [a]	Trend in Water Level [b]	Change Point / Decade	Attributed Pressure(s) [c]	Details on Pressure(s)	References
Nile Basin	**Lake Tana**	Ethiopia	16,500km² (2100-3000km²)	+ -		CV	**CV** - Rainfall variability	*Kebede et al.* [2006]
Rift Valley Basin	**Lake Basaka**	Ethiopia	401km² (42km²)	+	1970s; 2007-onwards	LULCC; Tectonics	**LULCC** - Agr. Expansion & Intensification (excess water of irrigation projects discharges into lake); Deforestation **Tectonic** - Emergence of underground hot springs	*Dinka* [2012]
Rift Valley Basin	**Lake Ziway**	Ethiopia	6,834km² (485km²)	+-		WW	**WW** - Agr. Intensification (Irrigation) - both large-scale abstractions & excess irrigation leading to capillary rise	*Legesse and Ayenew* [2006]
Rift Valley Basin	**Lake Langano**	Ethiopia	1,750km² (226km²)	-	1970s	WW; Tectonic	**WW** - Agr. Intensification (Irrigation) **Tectonic** - Underground springs counterbalance human abstractions	*Legesse and Ayenew* [2006]
Rift Valley Basin	**Lake Shala**	Ethiopia	3,280km² (318km²)	-	1970s	WW	**WW** - Agr. Intensification (Irrigation); Soda-Ash industry	*Legesse and Ayenew* [2006]
Rift Valley Basin	**Lake Abiyata**	Ethiopia	1,100km² (159km²)	-	1970s	WW	**WW** - Agr. Intensification (Irrigation); Soda-Ash industry	*Legesse and Ayenew* [2006]
Rift Valley Basin	**Lake Chew Bahir (fka. Lake Stefanie)**	Ethiopia	No info found (few km²)	-	1960s / 1970s	CV	**CV** - Rainfall variability	*Nicholson* [1998]
Rift Valley Basin	**Lake Turkana**	Transboundary (Kenya, Ethiopia)	130,860km² (6400-8860km²)	+ -		CV	**CV** - Rainfall variability	*Nicholson* [1998]
Rift Valley Basin	**Lake Elmenteita**	Kenya	335km² (18km²)	-	1960s / 1970s	LULCC; WW; Dams; CV	**LULCC** - Deforestation, Agr. Expansion **WW** - Agr. Expansion; Increased livestock numbers; Increased domestic demand **Dams** - Damming of inflowing rivers (reduced flow) **CV** - Increasing temperature; Decreasing rainfall	*Mwaura and Moore* [1991], *Murimi* [1994]
Rift Valley Basin	**Lake Nakuru**	Kenya	1,800km² (44km²)	-	1970s	LULCC; WW	**LULCC** - Deforestation; Agr.Expansion; Urbanization **WW** - Increased urban water demand	*Raini* [2009]
Rift Valley Basin	**Lake Naivasha**	Kenya	3,400km² (130km²)	- (2), +- (1)	1905 / 1980s	WW; CC; CV	**WW** - Agr. Intensification (Irrigation); Increased domestic demand **CC** - Decreasing rainfall **CV** - Rainfall variability	*Nicholson* [1998], *Becht and Harper* [2002], *Awange et al.* [2013]
Nile Basin	**Lake Victoria**	Transboundary (Kenya, Uganda, Tanzania, Rwanda, Burundi)	184,000km² (68,000km²)	- (2), +- (1)	1960s / 1970s/ 2000	CC; CV; WW; LULCC; Dams	**CC** - Decreasing rainfall; Increasing temperatures **CV** - Rainfall variability **WW** - Increased domestic demand **LULCC** - Deforestation; Agr. Expansion; Urbanization **Dams** - Damming of inflowing rivers (irrigation, hydropower)	*Nicholson* [1998], *Awange et al.* [2008], *UNEP* 2006]
Pangani River Basin	**Lake Jipe**	Transboundary (Tanzania, Kenya)	No info found (30km²)	-	1970s	WW	**WW** - Agr. Expansion & Intensification (Irrigation); Increased domestic demand	*King et al.* [2009]
Congo River Basin	**Lake Tanganyika**	Transboundary (Tanzania, DR Congo, Burundi, Zambia)	198,400km² (32,900km²)	+ -		CV	**CV** - Rainfall variability	*Nicholson* [1999]
Rift Valley Basin	**Lake Rukwa**	Tanzania	88,000km² (2300-5000km²)	+ -		CV	**CV** - Rainfall variability	*Nicholson* [1999], *Ministry of Water Tanzania* [2012]
Zambesi Basin	**Lake Malawi (aka. Lake Nyassa)**	Transboundary (Malawi, Tanzania, Mozambique)	126,500km² (28,760-29,600km²)	+- (2), + (2)	1905 / 1915 / 1967 (flashier)	CC; CV; LULCC	**CC** - Increasing rainfall **CV** - Rainfall variability **LULCC** - Deforestation (causing higher *variability* of lake level since 1970s)	*Drayton* [1984], *Neuland* [1984], *Calder et al.* [1995], *Jury and Gwazantini* [2002]
Okavango River Basin	**Lake Ngami**	Botswana	3,000km² (0-35km²)	+ -		CV	**CV** - Rainfall variability	*Shaw* [1983]

5. REVIEW OF REPORTED CHANGES IN BASIN WATER PARAMETERS AND ATTRIBUTED PRESSURES IN EASTERN AND SOUTHERN AFRICA FROM 1970-2010

The following more detailed analysis of the reported extent and main pressures associated with the observed hydrologic changes in Eastern and Southern African drainage basins was carried out with a sub-set of references covering data from 1970 to 2010. This step was taken to enable a better comparability of findings. The specific period was chosen because the majority of changes occurred in that era, and also because the majority of basin studies completely or at least partially referred to it.

After a brief overview of the composition of the herein analyzed references, a set of earlier defined hydrological parameters will be evaluated in regard to reported changes and attributed pressures. For each parameter, a short overview of quantitative findings is provided, followed by a discussion also including qualitative aspects. The relation to regional and temporal patterns as well as to drainage basin size will be discussed separately in ensuing sections.

5.1 Composition of references covering 1970-2010 period

Of the entire 132 references, 110 fell within the above timespan. These consisted of 93 (or 88% of all) references to river drainage basins and 17 (or 65% of all) references to lake drainage basins, resulting in 13 discarded river and 9 discarded lake drainage basins.

The discarded drainage basins were mainly very large. The proportion of drainage basin per size class for the 1970-2010 subset therefore only differs from the entirety of reviewed references for the class of 10,000-100,000km² (31 references, or 22% in the subset compared to 28% in the entire set) and the class of >100,000km² (21 references, or 16% in the subset compared to 19% in the entire set).

As already established in the previous chapter, the long-term development of annual streamflow or lake water levels is one of the points of interest for the herein analyzed drainage basins. In this regard, the statements of the eventually consulted references can be grouped into the following categories (fig. 28):

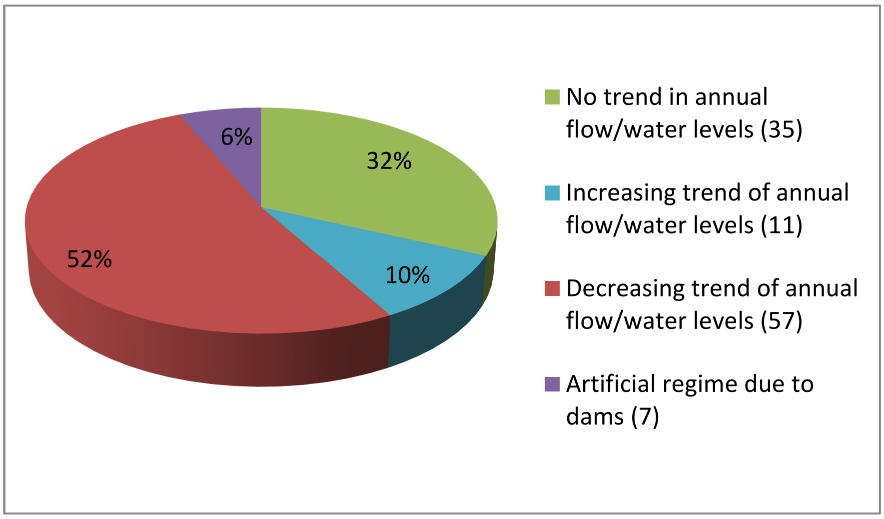


Fig. 28: Annual flow/ water level development in Eastern and Southern African river and lake drainage basins between 1970-2000

(Categories are exclusive; number in brackets indicate number of references; n=110)

About a fourth, or 32%, of all references report **no trend** in annual flow / water levels for the years from 1970 to 2010. This category encompasses 9 references which do not provide details on annual streamflow or water level development, as well as 25 references which describe both in- and decreases thereof over the course of the analyzed time span. An additional 2 references mention diverging trends at different gauges within one drainage basin.

Notably, more than half of the references within this category do mention changes in other hydrologic parameters. These primarily concern decreasing low flow, increasing flood occurrence/intensity, quickened basin response times, and shifts in seasonal flow peaks. Changes in these core hydrologic parameters will find closer consideration in chapters 5.2.3 to 5.2.5.

An **increasing trend** in annual streamflow or water levels is mentioned by 10% of all references. Chapter 5.2.1 will provide a detailed discussion of these.

The vast majority of references, namely 52%, report a **decreasing trend** in annual streamflow or lake water levels. Chapter 5.2.2 will look at this category in more detail.

Finally, a mentionable 6% of references convey that annual streamflow or water levels have been subjected to an **artificial regime**, that is, regulated by dams or reservoirs in such a way that seasonal and (inter)annual fluctuations have ceased to exist. Since this results in an artificial elimination of trends, an additional category was introduced to cover this specific reality. Findings from this category will be included in chapter 5.2.3.

In general it can be concluded that the distribution of references per category and also per attributed pressure was very similar for both river and lake drainage basins, which is the reason why they are jointly presented in this chapter. If noteworthy differences between river and lake drainage basins did arise in respect to any part of the analysis, this was mentioned in the respective sub-chapters.

In respect to the spatial distribution of references within the above established categories, it has to be noted that references to drainage basins in Eastern Africa outnumbered those to Southern Africa in most cases by at least 50% (see table 4). Only the category artificial regime was mentioned more often in Southern Africa. This imbalance has already been registered in chapter 4, and has to be kept in mind regarding the results. A more detailed discussion of observed spatial patterns and peculiarities will be provided in chapter 5.3.

Table 4: Regional distribution of number of references per category

Category of annual flow/ water level development	Eastern Africa	Southern Africa	Total
No trend in annual flow / water levels	25	10	35
Increasing trend of annual flow/water levels	8	3	11
Decreasing trend of annual flow/water levels	43	14	57
Artificial regime due to dams	3	4	7

Certainly, attention must be drawn at this point to the fact that just because a development or cause is not mentioned (either completely, or for a certain region), this does not imply that the respective factor does not play a role in hydrologic terms. For any number of reasons, said factor or region may not have been regarded in scientific studies yet, or the respective publication did not meet the selection criteria for this review. Findings based on the quantitative comparison of mentions, therefore, are only meant to provide a rough picture and are only elaborated if they are backed by a sufficient number of qualitative statements.

As the references employed in this sub-set all stem from the entirety of drainage basin studies whose publication background was already explicitly described in chapter 4.1, interested readers are welcome to consult said chapter.

5.2 Discussion of changes in and pressures attributed to selected hydrologic parameters

Each of the following passages will begin with some figures and percentages which are based on a quantitative analysis of mentions[42]. For each parameter, a short overview of mentions will be included in the respective chapter; in addition, tables with more detailed information can be found in the respectively referred to Annexes. The provided internal reference number also refers to Annex 1 and 2, which contain publication and drainage basin details of all references. Annex 3 provides a detailed register of the categories of observed developments for specific parameters. These quantitative findings are meant to provide a rough overview only, and to lay the grounds for a discussion and interpretation which also adduces qualitative statements collected during the review (e.g. not only based on the frequency of mentions, but also on an assessment and ranking of causes, or on the description of specific inter-linkages and circumstances worth considering).

5.2.1 Increased annual streamflow / lake water levels

An increasing trend of annual streamflow or water levels was reported by 11% (=11) of references. Out of these, only one reference described lake water levels.

Table 5: Increased annual flow/water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 11)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (24)	Deforestation	2	3	1	1	7
	Agricultural expansion	2	2	2	1	7
	Agricultural mismanagement (overgrazing & excess irrigation)	2		2	1	5
	Urbanization	1	1	1		3
	Agricultural intensification (sugarcane plantations)	1				1
	Drainage of wetlands			1		1
CC/CV (9)	Increasing variability of rainfall	2	1	2	3	8
	Increasing rainfall			1		1
	Total per Decade	*10*	*7*	*10*	*6*	

A frequency analysis of pressures over the course of all four decades reveals that LULCC is the most frequently mentioned cause of increased streamflow and lake water level. Three manifestations are hereby of central importance: *deforestation*, *agricultural expansion*, and *agricultural*

[42] A **mention** is a statement by a reference on specific changes in parameters and attributed pressures. Mentions were gathered in a table organized along the previously outlined pressures / manifestations, and grouped into decades from 1970 to 2000s (see Annex 4.1 as this chapter's example of such a table for). Each reference can only be mentioned once per decade, but if the entire time period is considered, references may in select cases be mentioned twice or more. If no other indication is provided, given numbers always refer to these mentions who have a varying size of "n". The indication of **%** is provided when mentions have been put in relation to a stable "n", e.g. when analyzing mentions per decade, region, etc.

mismanagement[43]. The second most commonly attributed (and in fact, only other mentioned) pressure in this category is CC/CV (see above table 5).

When combining above quantitative findings with the recorded weighted statements and qualitative information collected in the database, it can be concluded that among the reviewed references, **LULCC is reported as the primary cause of increased streamflow and lake water levels in Eastern and Southern Africa**. **CC/CV plays a contributory role**, as only two references cite increased rainfall or variability thereof as the single reason for the reported changes, while all other references point out additional stressors like deforestation and agricultural expansion.

In regard to climatic events, timing and intensity seem to be of great importance. *Troy et al.* [2007] suggests that even though annual precipitation rates may be stable over decades, very intense regional rainfalls can lead to a drastic change in hydrologic runoff regime if regional water levels reach a level of saturation and subsequent show increased surface runoff.

As for the **manifestation** of LULCC pressures, most forest and shrubland in Sub-Saharan Africa is cleared in favor of agricultural land, so *deforestation* routinely goes hand in hand with *agricultural expansion* [*FAO*, 2010]. This is attested by all references mentioning deforestation in this category, except for one which suggests that deforestation is rather linked to urbanization and the doubling of firewood demanding population between 1970 and 2000 [*McHugh et al.*, 2007]. Given the comparatively little share of sealed surfaces of urban areas and infrastructure in the studied countries in general, *urbanization* as such does not play a leading role for increased streamflow / lake water levels. More important are forms of *agricultural mismanagement*, such as the herein mentioned overgrazing (resulting in heavy soil degradation and increase of barren land) and excess irrigation (especially when irrigation water is imported from adjacent drainage basins).

The **magnitude** of increase was derived by calculating the difference between the annual streamflow / lake water level of a drainage basin in 1970 and 2010[44]. Not all publications provide such detailed information; here, four out of ten did not specify the quantity of change.

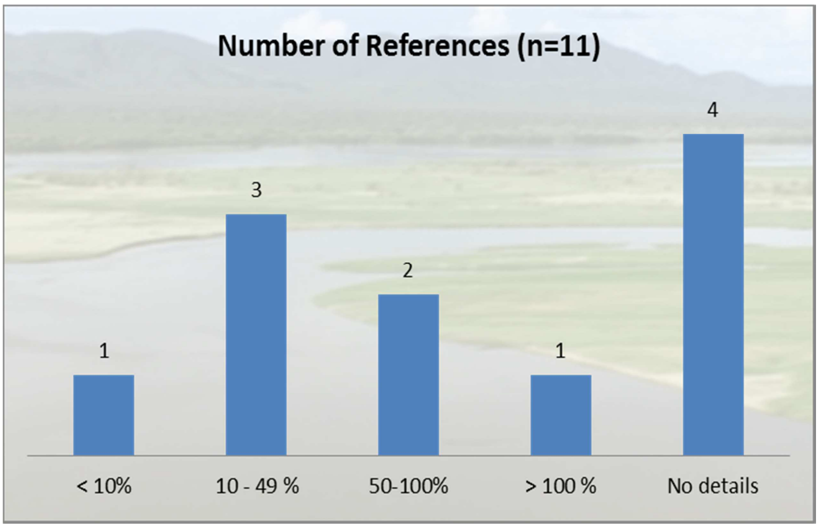


Fig. 29: Number of references per order of magnitude of streamflow/lake level increase, 1970 to 2010 subset

[43] For a brief description of manifestations please consult chapter 2.3. For more information on the way how pressures impact drainage basin hydrology, please refer to chapter 3 .

[44] 1970 to 2010 is the longest possible timespan in frames of our review criteria. Not all data series begin exactly in 1970, or last until 2010 – but this is the general frame most references cover. Of course change figures here can only be approximations given the high inter-annual variability, but since all references must meet the basic definition of "trend", these reported developments have a history of min. 20 years, so chances are high to at least cover correct tendencies.

The references with detailed information reported ranges between changes of less than 10% and more than a 100% of annual flow / lake levels (see figure 29). An increase of more than 50% constitutes a considerable alteration of drainage basin water balance. The highest value of change is attributed to an unprecedented increase in water level by more than 300% over the course of forty years.

Such increases are very uncommon and in this case attributed to a unique concurrence of tectonic activity (causing the emergence of vast thermal, underground springs) and agricultural mismanagement (massive expanse of cash crop cultivations, which are irrigated with water from adjacent drainage basins and not expertly drained, thus leading to a rise of water tables) [*Dinka*, 2012].

Generally, the magnitude of change doesn't seem to be correlated with the type of pressure as much as with the extent of its manifestation and the specific conditions of each drainage basin. Any generalization in this context is therefore impossible.

The eleven references in this category were all very recent, with publication dates ranging from 2007 to 2013 and the majority of references published after 2010. The point in time of mentions was compiled based on the respective change point/decade indicated by each reference. For this sub-group, there is no distinguishable pattern regarding the **total amount of mentions per decade** beyond a very slightly increased count for the 1970s and 1990s. In respect to the distribution **of mentions per pressure and decade**, however, a shift over time seems to have occurred from LULCC to CC/CV. This observation will be discussed in more detail in chapter 5.4.

5.2.2 Decreased annual streamflow / lake water levels

A decreasing trend of annual streamflow or water levels was reported by 52% (=57) of references. Out of these, nine references described lake water levels.

When considering the number of mentions per pressure/manifestation over the four analyzed decades, LULCC is most frequently named as the cause of decreasing stream flow and lake water levels. The most important manifestations thereof are *agricultural expansion*, *deforestation* and *agricultural mismanagement.* WW, especially in the form of *irrigation*, as well as *increased domestic and urban water demand,* comes in second place. CC/CV is reported as a subsequent pressure in the ways of *decreasing rainfall* and *increased variability of rainfall.* Lastly, dams for *irrigation purposes, hydropower generation* and *urban demand* are mentioned as factors (see table 6 for an overview and Annex 3, 5.1 and 5.2 for a detailed table of mentions per pressure/manifestation and over time).

If one however includes a ranking of the attributed pressures, the above picture has to be revised in that although LULCC is most frequently mentioned, **WW is attested to have the strongest impact on water resources in the reviewed drainage basins in Eastern and Southern Africa**. **LULCC is thereby the second dominant pressure attributed in this regard**. The contributing relevance of CC/CV and dams is confirmed by the qualitative statements collected in the database.

The frequent mention of LULCC may be explained by the fact that it was reported as a leading as well as secondary cause by close to half of all references. It is not utterly surprising that LULCC as an indicator of human impact on landscapes features prominently wherever human water consumption affects drainage basin hydrology. As already mentioned in chapter 4, drainage basins with strong decreasing trends were often located in regions with dynamic demographic and agricultural developments, and more often than not affected by several pressures at the same time.

Table 6: Decreased annual flow/water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 57)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (90)*	Agricultural expansion (incl. into hillsides & riparian zones)	17	12	4	1	34
	Deforestation	14	6	5	2	27
	Agricultural mismanagement (overgrazing & poor farming practices)	4	8	3		15
	Urbanization	6				6
	Afforestation (eucalyptus & pine plantations)	3	2	1		6
	Return of natural vegetation	1	1			2
	Drainage of wetlands		1			1
WW (62)*	Irrigation	7	11	8	2	28
	Increased domestic demand	2	12	3		17
	Increased urban demand	2	6			8
	Increased livestock numbers		5	1		6
	Industries		2			2
CC/CV (36)**	Decreasing rainfall	9	6	1		16
	Increasing variability of rainfall	7	2	2		11
	Increasing temperature	1	3			4
	Increasing rainfall	1	1			2
	Increasing drought occurrence			2		2
Dams (14)	Irrigation	1	3	1	1	6
	Hydropower	2	3		1	6
	Urban water demand	1	2			3
	Total per Decade	*78*	*86*	*31*	*7*	

(*includes one general mention of pressure w/o further details, which is not listed in above table)
(**includes two general mentions of pressure w/o further details, which are not listed in above table)

In respect to the **manifestation** of WW pressures, water abstraction for *irrigation* purposes is the single most important form of WW confirmed by both quantitative and qualitative analysis. The largest share of irrigation water is thereby reportedly used for cash crops such as horticulture, rice, flowers, orchards, and sugarcane. Improved irrigation canals are also named as one factor for increased abstraction rates.
Increased domestic water demand (used here as a collective term for increased demand due to increased population), *increased urban water demand* (increased demand due to rising living standards and needs) and *increased livestock numbers* (increased demand due to growing numbers of cattle, sheeps and goats) were other manifestations mentioned in the proximate relevance of this listing. Industries on the whole played a surprisingly minor role in the reviewed references, only two described negative impacts on streamflow due to the *establishment of industries* (in this case soda-ash factories).

As for LULCC, *agricultural expansion* and *deforestation* featured among the most important manifestations. It is noteworthy that a number of references from this category consider that deforestation and agricultural activities seem to have a more pronounced effect on runoff generation and eventually streamflow when they take place in sensitive hillside and riparian areas as compared to dryer, lowland regions of a drainage basin[45]. This is backed by a range of studies who attribute such

[45] Look for “sensitive hillside and/or riparian zone“ or respective abbreviations in Annex 4.1 to 8 to follow up on sources.

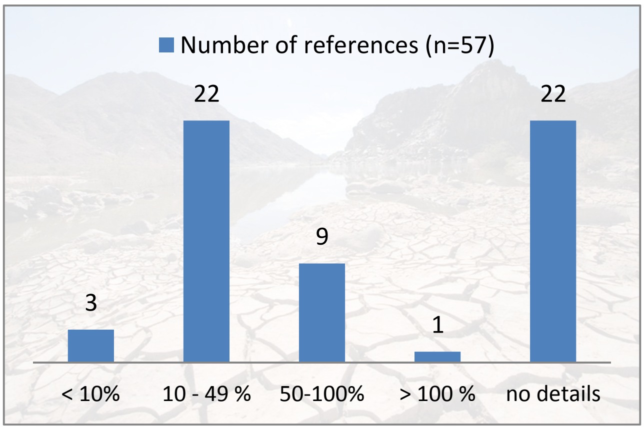
observations to differing rainfall amounts, soil properties, vegetation parameters, and recharge capacities encountered in regions of higher elevation [*Warburton et al.*, 2012; *Yanda and Munishi*, 2007; *Zhao et al.*, 2012]. *Hope et al.* [2009] adds a description of the disproportionate effect of wild fire on water resources when taking place along lowland river banks.
Other mentioned forms of LULCC were *agricultural mismanagement* (especially poor agricultural practices and overgrazing), *urbanization* and *afforestation* (with commercial pine and eucalyptus plantations). The *return of natural vegetation cover* is a rather unusual manifestation which has been observed in a country with political instability (Angola), where large areas of cultivated land have metamorphosed into forests again.

It is interesting to see that LULCC is mentioned as a prominent cause both for increasing and decreasing annual flow trends. It was not possible to establish any further patterns among the manifestations, e.g. by showing that a specific manifestation was only named for increasing, or decreasing, trends. While it is true that afforestation is mentioned only in the category of decreasing trends, this only encompasses a handful of references, with the vast majority stating manifestations identical to those from the increasing trend group.
This ambiguity therefore seems to be inherent in the matter. In fact, a brief literature search on the effect of LULCC on water resources shows that observations are equivocal. The type and intensity of changes caused by LULCC depends both on the spatial amount, the degree, and the location of the modification within the drainage basin [*Warburton et al.*, 2012]. Different studies for example report both negative and positive impacts of forest plantations on streamflow, depending on the type of trees and timeframe regarded (it seems that the initial increased water use of young trees levels off when the trees reach maturity, and the side effects of cooler ground temperature and stronger moisture interception actually lead to a decrease of water use in comparison to other land use classes) [*Bruijnzeel*, 2004; *Lørup and Hansen*, 1997; *Mbano*, 2009; *Scott and Prinsloo*, 2008]. Other authors report about similarly diverging trends of run-off and low flow in connection with deforestation and agricultural expansion [*Bewket and Sterk*, 2005; *Gebrehiwot et al.*, 2013b]. A detailed analysis of the respective type of manifestation and environmental factors as well as timeframe is therefore very important.

The manifestations of CC/CV and dams are confirmed in their relevance by the qualitative statements from the database. Three notices may be of interest in this regard. Firstly, the two mentions of increased rainfall highlight the relevance of anthropogenic actions by showing that in certain drainage basins, streamflow and lake water levels are declining despite a clear trend of increasing precipitation. Secondly, it can be assumed that dams only appear to play a minor role because they are mentioned by a limited number of references. However, the majority of references which do attribute declining streamflow / lake water levels to dams describe additional changes in a range of hydrologic parameters. This underlines the assumption that dams tend to have a stronger impact on basin water resources then would be assumed based on the frequency of their mention alone.
Thirdly, water transfer schemes were mentioned as a cause of decreasing streamflow by two references (one transfer was for urban water demand, one for hydropower and irrigation). These water transfers, often across long distances and conveyed in pipes and channels following the natural gradient, are quite common especially in Southern Africa and are another example of strong anthropogenic impacts on drainage basin hydrology[46].

[46] The mentioned Tugela-Vaal water scheme, for example, consists of transfers of around 630 Mm^3/year from the Tugela to the Vaal river basin – that is about a fourth of the annual discharge of the Rhine river Delta Alliance International (2011), The Rhine-Meuse Delta, edited, Delta Alliance InternationalORASECOM (2011), The Orange-Senqu River Awareness Kit, edited, Orange-Senqu River Basin Commission..

An overview of the **magnitude** of reported decrease is presented in fig. 30. About a third of all references did not provide detailed information on the changes in annual streamflow. The references with detailed information show a clear majority of changes in the field of a 10-49% decrease, while ten references report decreases of more than 50%. A decrease by up to 100% basically means that the affected river or lake has dried up for large parts of the year. This situation has been reported for seven rivers and two lakes in the past decades. In the case of lakes, the decrease can be more than 100% if readings refer to a zero gauge rather than to lake depth. The highest value in this data set depicts a 130% decrease of lake water levels over the course of three decades.



Based on the limited dataset, there is not distinguished pattern of correlation between the magnitude of change and types of pressure. However, a slight perceivable tendency seems to suggest that many drainage basins with less than 10% change attribute LULCC and CC/CV as the primary cause of change, while those basins with close to and more than 50% change almost all report WW and possibly dams among their main pressures.

Fig. 30: Number of references per order of magnitude of streamflow/lake level decrease, 1970 to 2010 subset

The point in time of mentions was compiled based on the respective change point/decade indicated by each reference. A comparison of the **total amount of mentions per decade** reveals that there is a clear clustering of mentions in the 1970s-1980s decade. In respect to the distribution **of mentions per pressure and decade**, the same pattern emerges - all pressures are mentioned more frequently for the 1970s-1980s period. A more detailed discussion of possible explanations will be provided in chapters 5.3 and 5.4.

5.2.3 Changes in seasonal composition of streamflow / lake water levels

Apart from total annual volume changes, influences on drainage basin hydrology can also manifest themselves in changes of a number of other manifestations of streamflow / lake water levels as introduced in chapter 3.1. One important realm thereby is the seasonal composition, i.e. the development of wet season relative to dry season flow (= low flow) / lake water levels.

Among all 110 reviewed references in the 1970-2010 subset, 51 mentioned such changes in seasonal composition. Only two of these references pertained to lake drainage basins. These both belonged to the largest group of 43 references, which described a **decrease in dry season flow / lake water levels** (see fig. 31).

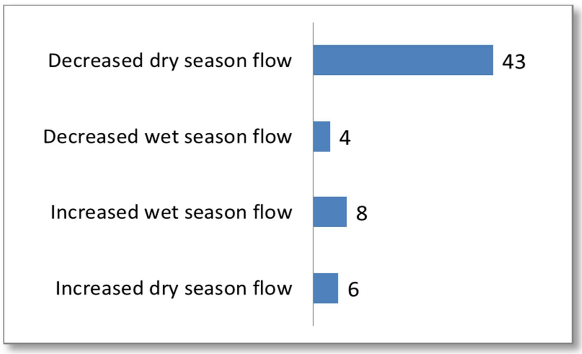


Fig. 31: Number of references per reported changes in seasonal flow composition, 1970-2010 subset
(References=51, multiple mentions possible)

In contrast, **decreased wet season flow**, **increased dry season flow** and **increased wet season flow** were reported considerably less frequently[47].

11 references of these solely describe changes in seasonal composition, while attesting no changes in annual streamflow / lake water level development. This distribution and the large number of mentions emphasizes the importance of seasonal composition as an additional hydrologic parameter.

An analysis of the **inter-relation** of seasonal flow components revealed that changes in wet season flow were frequently mentioned in combination with alterations of dry season flow. Out of the 4 references describing decreased wet season flow, for example, 3 also reported a decrease in dry season flow. Similarly, 7 of the 8 references describing increased wet season flow concurrently described a decrease in dry season flow. Changes in dry season flow, on the other hand, where predominantly reported independent of changes in wet season flow.
No reference mentioned both increased dry <u>and</u> wet season flow, or decreased wet season flow <u>and</u> increased dry season flow, for the same drainage basin.

As for the **relation of seasonal to annual changes**, another interesting pattern could be established. All references describing decreased wet season flow as well as two-thirds of the references describing decreased dry season flow pertained to the group which reported decreased annual flow / lake water levels.[48] However, only two of the references reporting increased wet season flow[49] and none of those reporting increased dry season flow[50] also belonged to the category describing increased annual flow / lake water levels.
It therefore seems that the pathways and pressures related to decreases in seasonal flow also contribute to a decrease in annual flow volumes / lake water levels, while those related to an increase in seasonal flow have less linear effects in respect to increasing annual trends.

When looking at the **pressures** attributed to **decreased dry season flow** (see table 7), it becomes apparent that these are very similar to the ones stated for decreasing trends in annual flow / water level (table 6 in previous section). Identically, LULCC is the most frequently attributed pressure, but when considering the ranking of causes and detailed statements in the references it shows that WW is the leading cause of decreased low flow in the reviewed Eastern and Southern African drainage basins. The main manifestations are abstractions related to the *irrigation* of cash crops (improved pumping and irrigation schemes for rice, horticulture, apple orchards) and *increased domestic demand* (i.e. demand caused by a growing population). LULCC comes an important second, followed by CC/CV and dams. Given this very analogical pattern, it seems comprehensible that a decreasing trend in annual streamflow / lake water levels primarily manifests itself in declining dry season flows. In addition, a number of authors state that abstraction rates are highest in the dry season - when water demand is the greatest - thus leading to a marked additional decline in low flow [*Aeschbacher et al.*, 2005; *Liniger et al.*, 2005; *Ngigi et al.*, 2008; *Shu and Villholth*, 2012].

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[47] Please note that the total of the stated categories here adds up to more than 51 because some references reported changes in several of the herewith described categories. For a more detailed overview, please consult Annex 3 and 6.

[48] The remaining one-third consisted almost exclusively of references from the no-trend-group, whereby almost half of these belonged to those references were only limited details on annual flow/ lake water levels were available.

[49] Of the remaining six, two pertained to the decrease-group, and four to the no-trend-group incl. three with limited available details on annual flow / lake water levels.

[50] Of these, four belonged to the artificial-regime-group, and two to the decrease-group.

Table 7: Decreased dry season flow (=low flow) / water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 43)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (64)	Deforestation	13	6	5	1	25
	Agricultural mismanagement (overgrazing, soil degradation & poor farming practices)	8	6	3		17
	Agricultural expansion (incl. into hillsides & riparian zones)	7	5	3	1	16
	Afforestation (eucalyptus & pine plantations)	2	1	1		4
	Urbanization	1		1		2
WW (49)	Irrigation	4	9	6	2	21
	Increased domestic demand	5	8	3		16
	Increased livestock numbers	3	3	1		7
	Increased urban demand		5			5
CC/CV (29)	Increasing variability of rainfall	8	3	2		13
	Decreasing rainfall	5	2	3		10
	Increasing drought occurrence	1		2		3
	Increasing temperature	1	2			3
Dams (6)	Irrigation	1	2	2		5
	Urban water demand	1				1
	Total per Decade	*60*	*52*	*32*	*4*	

Similarly, **the pressures** attributed to **decreased wet season flow** (see table 8) are mirrored in those for decreasing annual trends. During the rainy season, however, climatic factors as well as factors regulating water infiltration and soil water retention capacities are of more direct relevance for the water balance than water withdrawal and dams. For the reviewed references in this category, LULCC and CC/CV were accordingly mentioned as the main pressures for decreasing wet season flows.

Table 8: Decreased wet season flow/water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 4)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (12)	Deforestation	5				5
	Agricultural mismanagement (overgrazing & poor farming practices)	4				4
	Agricultural expansion	2				2
	Urbanization	1				1
CC/CV (4)	Increasing variability of rainfall	4				4
	Total per Decade	*16*	*0*	*0*	*0*	

It is again striking to see that the stated **pressures** for decreased wet season flow are more or less the same as those invoked for **increased wet season flow** (see table 9). A subtle difference lies in the ranking of specific manifestations of LULCC (e.g. agricultural expansion ranks first for increased, but only third for decreased wet season flow) and the mention of increased rainfall as a manifestation for CC/CV in the second table. The latter is interesting in that while a number of authors reported increased precipitation rates for the rainy season [*Gebremicael et al.* [2013]; *Melesse et al.* [2008]], a few also mentioned that these increases were set off by overall annual decreases of precipitation rates [*Mtalo et al.*, 2005; *Rientjes et al.* [2011]]. The interaction of such opposed climatic trends in combination with specific manifestations of LULCC can be part of an explanation why the same pressures may lead to different effects in different drainage basins. However, the sample size of both categories is not large enough to draw valid inferences from these observations.

Table 9: Increased wet season flow/water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 8)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (14)	Agricultural expansion	3		3		6
	Deforestation	3	1	1		5
	Agricultural mismanagement (overgrazing, soil degradation & poor farming practices)			3		3
CC/CV (5)	Increasing rainfall	3		1		4
	Increasing variability of rainfall			1		1
	Total per Decade	*9*	*1*	*9*	*0*	

In contrast to the matching picture of seasonal and annual decrease, only a minority of references reports both increased wet season and annual flows. Apart from a possibly skewed allocation due to the small number of cases, it is also becoming increasingly clear that incremental wet season flow is an indicator of LULCC in the drainage basin. The latter can however, as already mentioned, have many different effects on hydrology, therefore not providing a determinant as strongly inclined to one trend as for example WW. Furthermore, LULCC is often reported as a secondary pressure, which might lead to specific impacts not necessarily related to annual flow volume development. For the given references, for example, two references reported both an increased wet season flow (attributed to LULCC) coupled with a decrease in annual flow (attributed to WW in the dry season) [*K. Tadele and Förch*, 2007; *Tekleab et al.*, 2013].

A completely different **pressure** is finally highlighted when regarding **increased dry season flow:** the sole mentioned reason for such an increase was dams (see table 10). The increase in dry season flow is explained by the associated operation schemes, which generally aim at storing water during the wet season (without, apart from maybe flood control measures, impacting on wet season flow) and then releasing it in controlled volumes during the dry season.

Table 10: Increased dry season flow/water levels in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 7)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
Dams (7)	Hydropower	2		1		3
	Irrigation	2	1			3
	Urban water demand	1				1
	Total per Decade	*5*	*1*	*1*	*0*	

Depending on the management, dams very often result in the cessation of natural flow variations for the downstream river course, and the replacement of inter- and intra-annual variability by an anthropogenic driven regime. In extreme cases, excessive damming of flow in the dry season as well as emergency releases from overspilling reservoirs in the wet season can lead to additional massive impacts on other parameters of drainage basin hydrology [*Beilfuss*, 2012; *Kileshye Onema et al.*, 2006; *McCartney et al.*, 2010]. As the described are very significant changes closely linked to one joint factor, the already mentioned **artificial regime** was defined as a category of hydrologic parameter development among the reviewed drainage basins. A total of 7 references belonged with this category. Out of these, 4 also mentioned a decrease in dry season flow downstream of the dam, while another four described seasonal decreases also in upstream tributary rivers. The respective dams were mainly erected for *hydropower generation* and as *irrigation reservoir* (see table 11 and Annex 6). The predominant mention in this category of dams for hydropower generation may be linked to the fact that these dams are usually very large in volume, and thereby lead to stronger effects in the drainage basin. In addition, the operation of turbines requires a constant release of water from the reservoir. This water is commonly being returned to the river below the dam, which leads to an alteration of annual flow patterns different to dams which are primarily operated for agricultural purposes.

Table 11: Artificial regime in 1970-2010 –
Overview of mentions per pressure, manifestation and decade (References = 7)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
Dams (10)	Hydropower	5	1	1		7
	Irrigation	3				3
	Total per Decade	*8*	*1*	*1*	*0*	

A short analysis of the **total amount of mentions per decade** among all the tables in this chapter reflects the already established pattern that there seems to be a clear clustering of mentions in the 1970s-1980s decade. In respect to the distribution **of mentions per pressure and decade**, the same pattern emerges - all pressures are mentioned more frequently for the 1970s-1980s period, with a slight exception for increased wet season flow where agricultural expansion and mismanagement are stated as leading pressures also for the 1990s. A more detailed discussion of possible explanations will be provided in chapters 5.3. and 5.4..

5.2.4 Changes in frequency / intensity of floods and basin response time

Two other hydrologic parameters consulted as an indicator for changes in drainage basins within this review were floods, and basin response time. Regarding floods, mentions were grouped according to either changes in the frequency of flood occurrence, or to changes in the intensity of flood events[51].

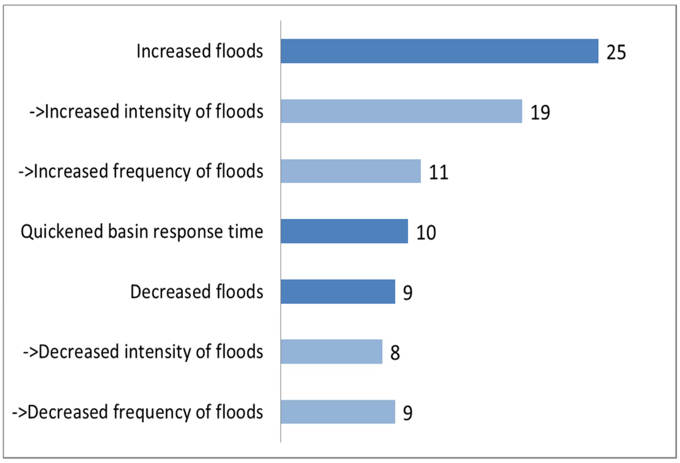

Fig. 32: Number of references per reported changes in floods and basin response time, 1970-2010 subset (References=31, multiple mentions possible)

Changes in flood and basin response time characteristics were reported by 31, or about a fourth, of the 1970-2010 subset[52]. Among these were three references to lake drainage basins.

Most frequent mentions were thereby made of **increased flood intensity**. **Increased flood frequency, quickened basin response time**, as well as **decreased intensity and frequency of floods** received matchable, fewer quotations (see fig. 32). A retarded basin response was not reported by any reference.

[51] Frequency was indicated by the number of annual events of sudden rise and fall of streamflow / discharge rates. Intensity was indicated by the related streamflow volume / river water level, and scope of destruction caused.

[52] Please note that the total of the stated categories here adds up to more than 31 because some references reported changes in several of the herewith described categories. For a detailed overview, please consult Annex 3 and 7.

A short analysis of **inter-relations** between the different categories yielded some interesting insights**.** Firstly, only 3 out of 25 references reported both increased frequency and increased intensity of floods for the same drainage basin. In the same manner, only 7 out of 28 references reported both increased flood frequency and/or intensity and quickened basin response time. Contrastingly, 8 out of 9 references reported both a decrease in flood intensity <u>and</u> frequency.
This latter, large overlap was actually also expected for the group reporting increased flood characteristics. From the present results, though, it seems that the link between mentions of increased flood frequency, flood intensity, and quickened basin response is not as strong as the link between decreased flood frequency and intensity. However, conclusions must be drawn with caution since mentions to these parameters were not primarily searched for, and might have been referred to very variably within the reviewed studies.

No reference mentioned a decrease of either flood intensity or frequency coupled with an increase of either flood intensity or frequency for the same drainage basin. Nor did any reference in the group of decreasing floods mention quickened basin response.

As for the **relation of high peak changes to other relevant streamflow / lake water level parameters**, no overt patterns could be determined. Only 4 out of 25 references from the category describing increased intensity/frequency of floods also belonged to the group reporting an increase in wet season flow. Also, only 3 out of 25 references from the first category were represented in the group depicting increased annual flow / water levels. It is therefore safe to assume that increased flood parameters mostly appear independent of changes in seasonal or annual streamflow manifestations, even though they likelihood of floods is naturally higher in the rainy season.
For the category describing decreased intensity/frequency of floods, no references belonged to the group mentioning decreased wet season flow, and only 2 out of 9 were among the group reporting decreased annual flow / water levels. However, 6 out of 9 were attributed an artificial regime. Decreasing flood characteristics therefore seem to be strongly linked to the latter trend category.

The pressures attributed to both increased and decreased flood <u>occurrence</u> and <u>intensity</u> were so similar that they are presented jointly in this section .

The **pressures** attributed to **increased flood intensity and frequency** are presented in table 12. The link between land cover changes (and hereby especially the disturbance and removal of natural forest cover) and increased surface runoff as well as other thus related hydrological processes is well established in expert literature [*Calder et al.*, 1995; *Maidment*, 1993; *John F. Mustard et al.*, 2004; *Olang and Fürst*, 2011]. The pressure indicated by the reviewed references fits well into this frame - in all cases, LULCC was stated as the main cause, with *deforestation* and *agricultural expansion* as the most important manifestations. Again, effects were reported to be particularly observable if these processes took place in hillsides. *Gebrehiwot et al.* [2010] poignantly describes how floods in the drainage basin notably increased not during the time of the most massive deforestation, but after a second wave of agricultural expansion had led to the clearing of remaining forests in mountainous parts of the catchment.

Table 12: Increased intensity and frequency of floods in 1970-2010 - Overview of mentions per pressure, manifestation and decade (References = 25)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (56)	Deforestation	8	7	4	2	21
	Agricultural expansion	12	3	4	2	21
	Agricultural mismanagement (overgrazing, soil degradation & poor farming practices)	1	3	3		7
	Urbanization	4	1	2		7
CC/CV (9)	Increasing variability of rainfall	3	1	1	2	7
	Increasing rainfall		2			2
	Total per Decade	*28*	*17*	*14*	*6*	

CC/CV, especially *increased variability of rainfall*, was also stated by a few references as a contributory pressure. Increasingly intense rainfall events, such as massive downpours related to the El Niño phenomenon, were reported in this category as well as a generally increasing uncertainty of quantity and timing of precipitation. The latter could play a role in amplifying effects of poor farming practices, for example if freshly cleared areas or unprepared fields are hit by early, intense rainfall.

Table 13: Quickened basin response time in 1970-2010 - Overview of mentions per pressure, manifestation and decade (References = 9)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
LULCC (20)	Deforestation	4	1	2	1	8
	Agricultural expansion (especially into hillsides & riparian zones)	2	1	3	1	7
	Agricultural mismanagement (overgrazing, soil degradation & poor farming practices)	1		2	1	4
	Urbanization			1		1
CC/CV (2)	Increasing rainfall	2				2
	Total per Decade	*9*	*2*	*8*	*3*	

The attested **pressures** for **quickened basin response** were almost identical to those for increased floods (see table 13). As noted before, the underlying processes are quite similar, and thus the stated main pressure LULCC is a very likely cause for increasing responsiveness of drainage basins to rainfall input. If at the same time rainfall amounts increase, this can further intensify the effects.

Table 14: Decreased intensity and frequency of floods in 1970-2010 - Overview of mentions per pressure, manifestation and decade (References = 9)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
Dams (12)	Hydropower	4	2	1		7
	Irrigation	3	1			4
	Urban water demand	1				1
	Total per Decade	*8*	*3*	*1*	*0*	

In contrast to the other groups, **decreased intensity and frequency of floods** was attributed to one sole **pressure**: the construction / management of dams. The majority of these dams were constructed for *hydropower generation*, and for *irrigation reservoirs*. As already explained in the previous chapters, dams have a massive impact on all manifestations of streamflow / lake level. Apart from their naturally retentive capacities, dams are furthermore often actively used to avoid or reduce floods in downstream areas. It is therefore consistent that references reporting a decrease in floods would mention both decreasing frequency and intensity. The decrease in floods was, by the way, not noted as a positive effect but rather associated with negative impacts of its own kind by half of the respective references. *Snoussi et al.* [2007], *King et al.* [2009a], [*Beilfuss*, 2012] and *Mitchell* [2013] all described massive ecological threats and economic losses in fisheries caused by alterations of salt-water composition in fish and prawns breeding estuaries – the flood water impulses that used to occur during floods proved to be essential elements in a delicate ecosystem.

A short analysis of the **total amount of mentions per decade** among all the tables in this chapter reveals that generally, once more a clear clustering of mentions seems to fall into the 1970s-1980s decade. An interesting exception is quickened basin response time, which is reported most often in the 1970s and then again 1990s.
In respect to the distribution **of mentions per pressure and decade**, the same pattern emerges - all pressures are mentioned more frequently for the 1970s-1980s period, with a slight exception for quickened basin response where agricultural expansion and mismanagement are stated as leading pressures the 1990s rather than earlier decades. A more detailed discussion of possible explanations will be provided in chapters 5.3. and 5.4..

5.2.5 Changes in frequency and duration of no flow

The last considered hydrologic parameter for changes in drainage basins within this review is the frequency and/or duration of no flow. The complete cessation of flow in a river (only rivers were associated with this category) is one of the most visible changes of basin hydrology, and it often has very strong effects for ecosystems and livelihoods of dependent people. No flow is usually strongly connected with the dry season, and can occur as an extreme form of low flow, but it can also appear as an indicator of itself as shown below.
During the review of references, we looked for both mentions on frequency and duration of no flow[53]. However, none of the references stated only one of these independently of the other, so the two will be discussed jointly here.

Changes in no flow characteristics are reported by 22, or a bit less than a fifth, of all reviewed references in the 1970-2010 subset. The overwhelming majority thereby refer to **increases in the frequency and duration of no flow**, only 1 reference describes a **decrease of no flow days[54]**.

The analysis of **links between no flow and other relevant streamflow / lake water level parameters** shows that 16 out of 21 references which describe an increase in no flow also belong to the group stating a decrease in dry season flow. The relation with reduced dry season flow is expectedly obvious. In the same manner, 17 out of 21 references describing increased no flow also report decreasing annual flow trends. Increased no flow is furthermore most frequently mentioned for those drainage basins which show a strong (close to 50% or more) decrease in annual streamflow. The increased occurrence of no flow is therefore a valid indicator for massively altered, and often stressed, basin water balance.
Interestingly, the one drainage basin for which a decrease of no flow was reported also belongs to the group of decreasing dry and annual flow. This rather unusual combination is attributed to dam management and shows how the parameter can appear independently.

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[53] No flow is commonly described in days per hydrological year. An increase in frequency means more days/periods with no flow per year, and an increase in duration means that flow ceases to exist for longer periods of time.
[54] For a detailed overview, please consult Annex 3 and 8.

Table 15: Increased frequency and duration of no flow in 1970-2010 -
Overview of mentions per pressure, manifestation and decade (References = 21)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
WW (41)	Irrigation	4	8	6		18
	Increased domestic demand	3	5	2		10
	Increased urban demand	2	4			6
	Increased livestock numbers		3	2		5
	Industries	2				2
LULCC (17)	Deforestation	1	4	2		7
	Agricultural mismanagement (overgrazing & poor farming practices)		3	4		7
	Urbanization	1				1
	Agricultural expansion	1	1			2
CC/CV (10)	Decreasing rainfall		3	2		5
	Increasing temperature		3			3
	Increasing variability of rainfall		1			1
	Increasing drought occurrence			1		1
Dams (5)	Irrigation		2	1		3
	Urban water demand		1	1		2
	Total per Decade	*14*	*38*	*21*	*0*	

The **pressures** attributed to **increasing frequency and duration of no flow** are similar to the ones for decreased dry season flow, however, in this case the frequency of mentions for WW mirrors the ranked importance as stated by the references (see table 15). WW, and especially abstractions for *irrigation* and increased *domestic and urban demand*, were overwhelmingly named as the leading causes of increased no flow among the reviewed references. In addition, *industries* (industrial water demand – unfortunately no specification of type of industry) were newly stated as a manifestation. The second stated pressure was LULCC, with the same order of manifestations as collated for decreased dry season flow. CC/CV and dams were mentioned as contributory pressures, both with much the same order of manifestations as in decreased dry season flow, except for *decreasing rainfall* and *increasing temperature* which were mentioned a bit more frequently for no flow than low flow.
Given the strong link between no flow and dry season flow, the similarity of attributed pressures only seems logical. It is interesting, though, how much more clearly and directly water abstractions are stated as the main cause for no flow. The references seemed to have little doubt in this regard – maybe because both the effect as well as the cause (irrigated fields, queues at abstraction points) are more visible in the dry season.

Table 16: Decreased frequency and duration of no flow in 1970-2010 -
Overview of mentions per pressure, manifestation and decade (References = 1)

Pressure (Total mentions)	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total
Dams (2)	Irrigation	1				1
	Urban water demand	1				1
	Total per Decade	*2*	*0*	*0*	*0*	

The **pressure** attributed to the single description of **decreased frequency and duration of no flow** is dams (see table 16). As mentioned earlier, the same reference also stated decreasing dry season and annual flows. In this case, the drainage basin was affected by several hundred smaller dams for irrigation in the upper reaches and a few larger dams for urban water demand in the lower reaches of the stream. While the combined effects did not amount to a uniformly regulated artificial regime, it did lead to a reduction of no flow days due to a constant release of small amounts of water from the dams throughout the year. However, the continuous retention and abstractions for irrigation and urban demand with low return rates also caused an overall decline of streamflow towards the lower reaches of the river [*Warburton et al.*, 2012]. This reference renders a good description of how specific factors can affect different regions of drainage basins and also result in cumulative effects that at first seem contrary[55].

Another important assertion is that in respect to dams, operation schemes are the main determinant in regards to the impact on water resources. This becomes clear when we consider that dams were also stated as a cause of increased no flow days just a few sections ago.

A short analysis of the **total amount of mentions per decade** shows that in contrast to the previous chapters, the peak of mentions falls within the 1980s-1990s decade. The same is true for the distribution **of mentions per pressure and decade** – each pressure is mentioned most often in that period of time. A more detailed discussion of possible explanations will be provided in chapters 5.3 and 5.4.

[55] A detailed differentiation of pressures and impacts between up- and lowland reaches of drainage basins was not conducted in frames of this review because not enough references provided the necessary information. However, the few descriptions that did indicated that impacts differ quite strongly depending on where within a basin pressures play out. A closer look at these dynamics would surely constitute another interesting research topic.

5.3 Regional relevance of hydrologic parameter development and attributed pressures

In the following sections, a short excursus will approach the question of spatial patterns in regard to both the occurrence of specific hydrologic parameters and the overall mention of pressures. Annex 4.2 and 5.2 provide an overview of the regional mention of references in relation to annual hydrologic parameters. The spatial location of other parameter mentions can be deducted from the table and drainage basin names provided in Annex 3.

Hydrologic parameters

An overview of the spatial distribution of references per category of streamflow / lake water level development was already briefly presented in chapter 5.1. In the following section, a closer look including the additional hydrologic parameters will be provided. Due to the much higher number of references to Eastern African drainage basins, the number of references per category were related to the total number of references describing each region (see table 17). The resulting percentage allows for a proximate comparison of spatial clusters.

Table 17: Number and percentage of references per hydrologic parameter development category and region, 1970-2010 subset (Eastern Africa references = 79, Southern Africa references = 31)

	Category of hydrological parameter development	Eastern Africa - Count	Eastern Africa - % of n	Southern Africa - Count	Southern Africa - % of n	Total
Annual parameter	No trend in annual flow / water levels	25	31.6	10	32.3	35
	Artificial regime due to dams	3	3.8	4	12.9	7
	Increasing trend of annual flow/water levels	8	10.1	3	9.7	11
	Decreasing trend of annual flow/water levels	43	54.4	14	45.2	57
Additional hydrologic parameters	Decreased dry season flow / water levels	35	44.3	8	25.8	43
	Increased wet season flow	8	10.1			8
	Increased dry season flow	2	2.5	4	12.9	6
	Decreased wet season flow	4	5.1			4
	Increased frequency and/or intensity of floods	24	30.4	1	3.2	25
	Quickened basin response time	10	12.7			10
	Decreased frequency and/or intensity of floods	4	5.1	5	16.1	9
	Increased frequency and duration of no flow	18	22.8	3	9.7	21
	Decreased frequency and duration of no flow			1	3.2	1

(The same reference can describe changes in annual *and* additional parameters, therefore, the total count may exceed the total number of references per region)

The analysis of the above percentages for **annual parameters** shows that in relation, the same proportion of references describe *no trends* and *increasing trends* in both Eastern and Southern Africa. *Decreasing trends* are described by a slightly larger set of references for Eastern Africa, which would be backed by the established impression that water resources are most stressed in that region. However, this difference is most likely not statistically significant given the large variation among the different drainage basins. The one category which shows a clear regional emphasis is *artificial regime*, which was reported by three times as many references in Southern Africa compared to Eastern Africa.

This accumulation of mentions is most likely linked to the larger quantity and storage volume of dams in Southern Africa [*Arthurton et al.*, 2008; *FAO*, 2007; *World Comission on Dams*, 2000].

The regional distribution of references describing changes in **additional hydrologic parameters** is laid out in the lower section of table 17. The major share of changes are all dominantly ascribed to Eastern Africa, with the exception of *increased dry season flow* and *decreased frequency/intensity of floods,* which were mentioned notably more frequently for Southern Africa. Here, a clear pattern related to the primary attributed pressures shows through: those drainage basins with changes in hydrologic parameters primarily attributed to LULCC and WW were predominantly located in Eastern Africa, while those with changes attributed to dams were primarily named in Southern Africa. Once more, the role of dams in Southern Africa is emphasized, as well as the environmental changes and irrigation developments in Eastern Africa. CC/CV was not named as a primary pressure for any hydrologic parameter, but named as important tributary cause especially in Southern Africa.

Attributed Pressures

On the whole, LULCC was by far named most often as a pressure in regard to any of the analyzed hydrological parameters. WW comes in second, with CC/CV at third and dams at fourth position. However, this only pertains to the frequency of mentions – as previously mentioned, pressures may have qualitatively stronger significance for specific parameters (e.g. when ranked, WW has the strongest effect on decreasing annual, seasonal and no flows, while dams have the strongest effect on decreased floods and increased dry season flow despite their comparatively few mentions).

A spatial contemplation of these primary pressures is done here only on a very general level, i.e. by considering the overall mentions of pressures (not separately for each analyzed hydrologic parameter). The number of mentions per pressure is thereby related to the overall number of mentions per region, resulting in a percentage which allows for a coarse comparison (see fig. 33).

As already indicated in the previous section, there seem to be clear differences in the frequency of mentioned pressures per region. LULCC, for example, is brought up more than twice as often as a cause of hydrologic change in Eastern Africa than in Southern Africa. WW is stated as a cause approximately equally often in both regions, while CC/CV and dams are reported up to three times as often for Southern Africa compared to Eastern Africa.

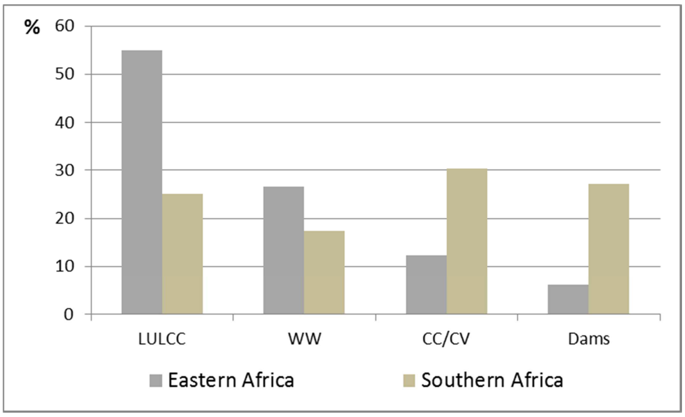

Fig. 33: Percentage of mentions per pressure and region, 1970-2010 subset
(Eastern Africa mentions = 480, Southern Africa mentions = 92)

Table 18: Number and percentage of mentions per pressure-manifestation and region, 1970-2010 subset
(Eastern Africa mentions = 480, Southern Africa mentions = 92)

Pressure (in order of frequency of mentions)	**Pressure - Manifestation**	**Eastern Africa -** Mentions Count	**Eastern Africa -** Mentions as % of n	**Southern Africa -** Mentions Count	**Southern Africa -** Mentions as % of n
LULCC	Deforestation	93	19.4	8	8.7
	Agricultural expansion	80	16.7	6	6.5
	Agricultural mismanagement	59	12.3	1	1.1
	Urbanization	17	3.5	2	2.2
	Afforestation	14	2.9	3	3.3
	Drainage of wetlands			2	2.2
	Return of natural vegetation			1	1.1
	Agricultural intensification	1	0.2		
WW	Irrigation	54	11.3	8	8.7
	Increased domestic demand	37	7.7	7	7.6
	Increased urban demand	17	3.5	1	1.1
	Increased livestock numbers	18	3.8		
	Industries	2	0.4		
CC/CV	Decreasing rainfall	18	3.8	13	14.1
	Increasing variability of rainfall	28	5.8	8	8.7
	Increasing temperature	3	0.6	6	6.5
	Increasing rainfall	7	1.5		
	Increasing drought occurrence	3	0.6	1	1.1
Dams	Irrigation	13	2.7	13	14.1
	Hydropower	9	1.9	9	9.8
	Urban water demand	7	1.5	3	3.3
	Totals	*480*	*100*	*92*	*100*

A more detailed inspection of the reported manifestations reveals some finer spatial distinctions (see table 18).

As has been proven, **LULCC** plays a stronger role in Eastern Africa compared to Southern Africa. This is supported by statistics on agricultural land use and deforestation rates as provided for example by the Food and Agricultural Organization of the United Nations (FAO). These state that changes in said parameters in the past 50 years have been strongest in Eastern Africa, mostly in the Greaft Rift Valley region [*FAO*, 2010; 2014]. Another source displaying this spatial pattern is the "Human Footprint Index" established by the Center for International Earth Science Information Network (CIESIN). As can be seen in fig. 34, only a relatively small area of land has not been modified by anthropogenic activities in Eastern Africa compared to Southern Africa.

It is furthermore conceivable that agricultural expansion in Southern Africa happens on a different level, or encroaches into bushland or dryland rather than into forests such as in Eastern Africa. In Southern Africa, many forests have been replaced by commercial plantations or been designated as nature reserves, which are mostly effectively managed and protected. The comparatively weak enforcement of forest protection in Eastern Africa is indeed a point of criticism in several references.

The prominence of LULCC as a pressure primarily reported for Eastern Africa by the reviewed references is therefore in line with established statistical data. This is especially prominent for *deforestation*, *agricultural expansion,* and *agricultural mismanagement,* which receive considerably more mentions in Eastern Africa. On the other hand, factors such as urbanization as well as afforestation were reported similarly in both regions (the other remaining manifestations were mentioned by too few references to allow valid inferences).

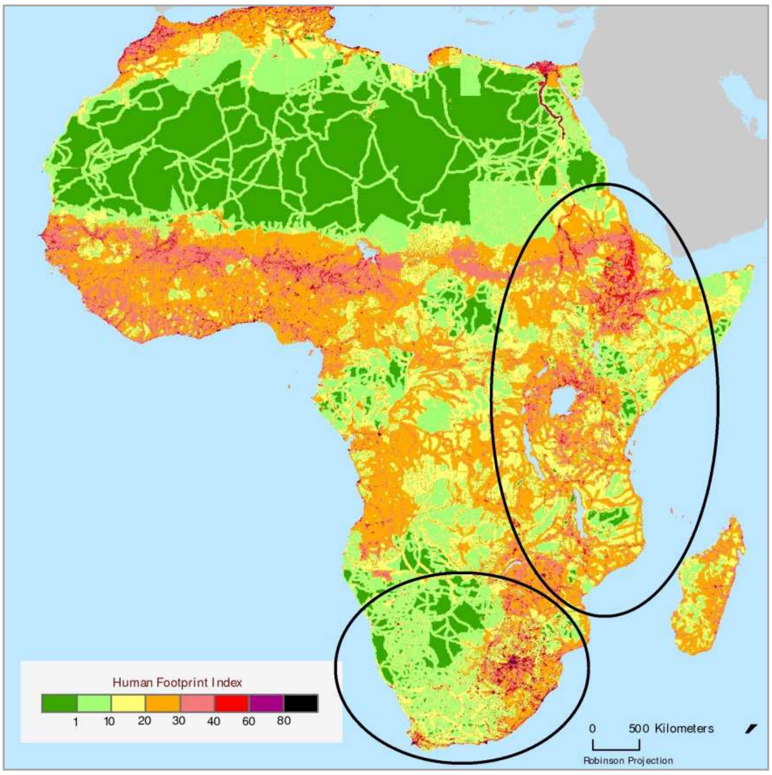

Fig. 34: Africa - Human Footprint Index, 2004 ([*Center for International Earth Science Information Network (CIESIN)*, 2008]) The Human Footprint Index expresses as a percentage the relative human influence in each terrestrial biome. Values range from 1 to 100. A score of 1 represents the least influenced, a score of 100 the most influenced part of a biome. Data used for this map is from 1995-2004. The black circles were added by the author of this review to visualize the respective regions (Eastern Africa = longish circle, Southern Africa = oblong circle).

In respect to **WW**, no clear patterns can be derived from international statistics. Fig. 35 shows the distribution of annual water demand for the whole of Africa. Hot spots of water demand within the relevant regions thereby lie in a more or less even belt spreading from the northern part of South Africa and Zimbabwe throughout the Great Rift Valley to Sudan and Ethiopia.

The minimal differences between manifestations of WW as reported by the reviewed references fits into this picture. Water abstractions for *irrigation, domestic* and *urban demand* seem to be similar in both regions (industries only featured with so low numbers that any inferences must be invalid). Only *increased livestock numbers* were solely mentioned for Eastern Africa. This might be due to the overall fewer livestock numbers in Southern Africa, or less dynamic developments in Southern African livestock systems, which mainly depend on extensive agro-pastoralism, while a multitude of partially intensive livestock systems prevail in Eastern Africa [*Anteneh*, 1984; *FAO*, 2002].

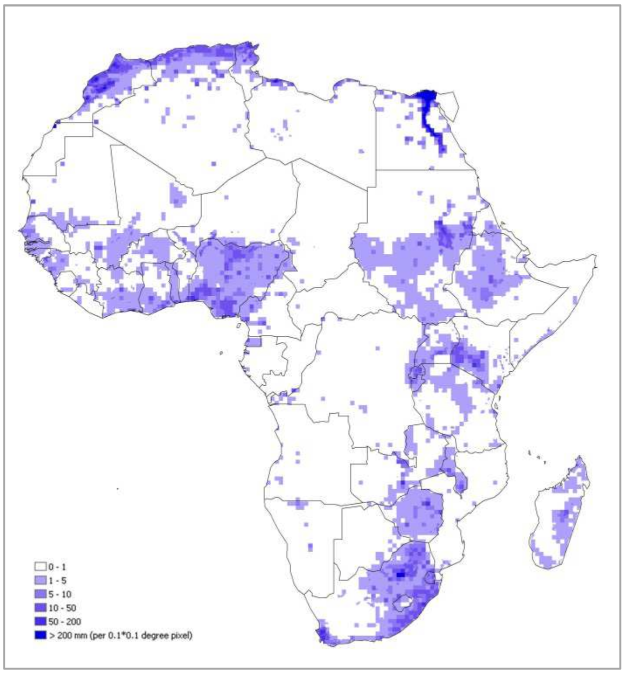

Fig. 35: Water demand (mm/year, all sectors) in Africa, 2000 ([*JRC*, 2012])

The effects of **CC/CV** have been quite diverse in Africa. Most sources state that Equatorial Eastern Africa has received stable rainfalls on a relatively high level since the mid-20th century [*Mango et al.*, 2011; *Spinage*, 2012]. The sub-tropical regions of Eastern Africa, especially in the Greater Horn of Africa, have received decreasing amounts of total rainfall since the 2000s [*Omondi et al.*, 2013]. For Southern Africa, total rainfall trends have been decreasing since 1961, cumulating in an overall negative trend for the 20th century [*Mark R. Jury*, 2012; *Spinage*, 2012].

On the whole, an increase of rainfall variability in time, space and intensity is attributed for both regions [*Githui*, 2008; *Spinage*, 2012], as is an increase in temperatures [*Collins*, 2011; *Mango et al.*, 2011; *Spinage*, 2012; *Todd et al.*, 2011].

The regional distribution of manifestations of CC/CV as reported by the reviewed references mostly match with the above findings. While no regional difference was reported for *increased rainfall variability*, *decreasing rainfall* was mentioned more than three times as often for Southern Africa than for Eastern Africa. However, so was *increased temperatures* – a manifestation that according to other sources occurred throughout both regions in the past 40 years.

Lastly, as has already been established in previous sections, Southern Africa features a significantly larger number of **dams** in proportion to Eastern Africa [*Arthurton et al.*, 2008; *FAO*, 2007; *World Comission on Dams*, 2000]. Although dam construction is increasing also in Eastern Africa, the largest number and largest dams/reservoirs by volume are still mostly found in Southern Africa (see fig. 36). The clear regional emphasis of dams in Southern Africa which was reported by the reviewed references distinctly mirrors this spatial pattern.

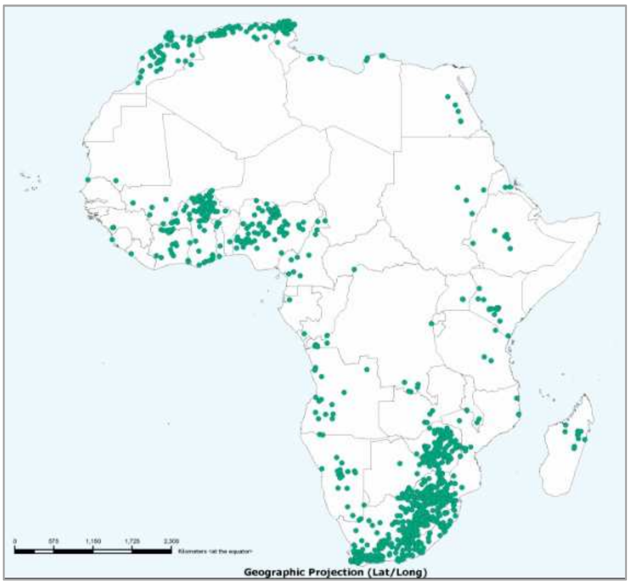

Fig. 36: Distribution of dams in Africa, 2005
(green dot = site of dam, [*FAO*, 2007])

5.4 Temporal relevance of hydrologic parameter development and attributed pressures

In addition to spatial patterns, a short recap of temporal patterns of hydrologic parameter mentions and attributed pressures will be provided in the next passage. The temporal classification is based on change points[56] as indicated in the reviewed references and included as an information in Annex 4.1 to 8.

Hydrologic parameters

The temporal distribution of hydrologic changes is based on the mentions of attributed pressures per hydrologic parameter. Table 19 presents an overview based on the relation between decadal and total mentions (the score in brackets next to the category title shows the number of references belonging to that category).

Table 19: Percentage of decadal mentions per category of hydrological parameter development, 1970-2010 subset (

Category of hydrological parameter development (Nr. of References)	**1970s**	**1980s**	**1990s**	**2000s**
Decreased wet season flow / water levels (4)	100.0			
Decreased frequency and duration of no flow (1)	100.0			
Decreased wet season flow / water levels (4)	100.0			
Artificial regimes (7)	80.0	10.0	10.0	
Increased dry season flow / water levels (6)	71.4	14.3	14.3	
Decreased frequency and/or intensity of floods (9)	66.7	25.0	8.3	
Decreased annual flow / water levels (57)	38.6	42.6	15.3	3.5
Decreased dry season flow / water levels (43)	40.5	35.1	21.6	2.7
Increased frequency and/or intensity of floods (25)	43.1	26.2	21.5	9.2
Increased annual flow / water levels (11)	30.3	21.2	30.3	18.2
Increased wet season flow / water levels (8)	47.4	5.3	47.4	
Increased flashiness / quickened basin response (10)	40.9	9.1	36.4	13.6
Increased frequency and duration of no flow (21)	19.2	52.1	28.8	

There seem to be three broad groups of temporal patterns among the mentioned parameter categories, which can linked to the respective set of attributed pressures. In the first group, the majority of hydrologic changes are attributed to the 1970s and 1980s, a notion that is supported by a

[56] A change point is understood as the point in time were a trend began, or a long-term change in hydrologic parameter was first mentioned. This implies that the "no trend" category will not be included in this part of the analysis. For each change point, respective parameters and attributed pressures were collated and grouped in decades from 1970-2010. These mentions are, however, only proximate: respective changes in parameter may not have been reported earlier, or specific pressures may have been present at earlier stages without causing changes until a certain level was reached, or interactions with additional pressures enhanced the effects.

number of authors ([*Lakhraj-Govender*, 2010; *Mtalo et al.*, 2005; *Mwaura and Moore*, 1991]. The common primary pressures for this group commonly are WW, LULCC, and dams.
Increased frequency and/or intensity of floods is a bit out of line in this group, as it would rather be counted among the hydrologic parameters associated with LULCC and CC/CV. These latter pressures are commonly associated with the second group, which encompasses categories of increased flow parameter and is different in that it is denoted two peaks of mentions – one in the 1970s and one in the 1990s. This group is also the only one which reports noteworthy mentions in the 2000s. However, this in turn could be in line with the described time lag which is associated with the disturbance of vegetation or shift of cultivated crops, and which may cause effects on hydrologic parameters only after 3-10 years [*Kiersch*, 2000; *Zhao et al.*, 2012].
The last group finally pertains to the increase of no flow, which is strongly associated with WW and LULCC and the only group which is attributed a peak in the 1980s.

Attributed pressures
On the whole, two thirds of all mentioned pressures were stated for the 1970s and 1980s, with only about a twentieth of the remaining mentions for the 2000s decade. When looking in more detail at the progression of mentions for each pressure, the same general distribution is visible against a few important variations (see fig. 37). For example, LULCC and CC/CV show a less pronounced decline of mentions after the 1970s/80s than dams, and WW shows a divergent and strong peak in the 1980s.

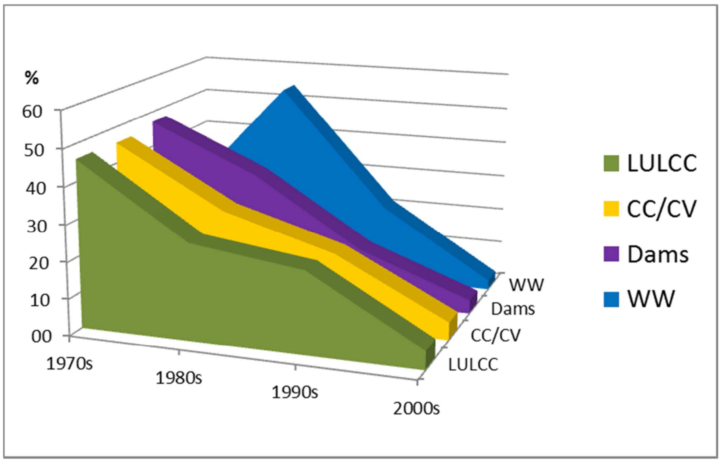

Fig. 37: Percentage of decadal in relation to total mentions of primary pressures, 1970-2010 subset

The low number of mentions for the 2000s – a recurring feature with all pressures, manifestations, and hydrologic parameters - is probably effected by the temporal boundary set by the publication date of the reviewed references. Although the references in the 1970-2010 subset are fairly recent, with publication dates ranging from 1998 to 2013, and a majority of references from the period of 2005 to 2010 with a data timeframe until 2005, this factor surely plays an important role. All conclusions based on mentions for the 2000s decade will therefore only be discussed marginally.

A finer analysis of the frequency of the manifestations of pressures over time reveals how these relate to the broader developments in Eastern and Southern Africa.

<u>Land use/land cover change</u>
Statistical data by the FAO shows that ***deforestation*** in Eastern and Southern Africa has occurred in phases, i.e. peaking in the 1960s-1970s, and then again in the 1990s-2000.

The annual deforestation rate (i.e. the percentage of total forested land that is clear cut each year) in Eastern Africa, for example, lay around -0.81% in 1976-1980 [*FAO*, 1985], but had declined to -0.4% in Eastern Africa and -0.2% in Southern Africa in the period from 1980-1990 [*FAO*, 1995]. Since the 1990s, the rate has risen again to around -0.62% for Eastern and Southern Africa [*FAO*, 2010]. *Mtalo et al.* [2005] describes by reference to the Eastern Arc forests in Tanzania how the then available large stretches of public forests were cleared due to growing population numbers and expanding agricultural land use in the 1970s-80s, and how the rate of deforestation subsequently dwindled mostly due to the fact that little forest remained outside of protected forest areas. The recurring rise of deforestation rates since the 1990s may be explained by the ever-growing demand for energy sources, i.e. mainly charcoal, for growing urban and rural populations [*Madulu*, 2005].

However, developments in individual countries are quite varied. Figure xx exemplarily shows the development of forested area in selected countries over the past decades (no differentiation between natural forest and plantation; earlier data was not available respectively based on such different classifications of forest categories that comparison is not viable).

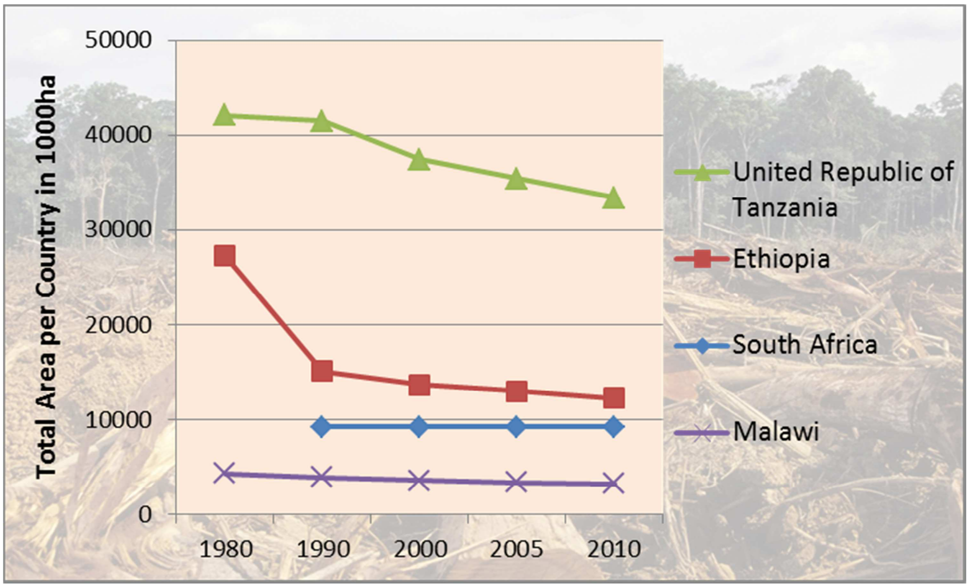

Fig. 38: Development of forested area in selected African countries between 1980 - 2010 (own rendering, based on data by [*FAO*, 1988] and [*FAO*, 2010])

Tanzania and Ethiopia are striking examples of countries with strong reduction of forest cover over different time horizons. In the whole of East Africa, almost 13 million hectares of primary forest were cut down during the last 20 years. The main cause of deforestation here is clearing of land for small-scale agriculture and the consumption of firewood, driven by population growth and economic development. In the recent decades, this has led to an increasing encroachment of remaining remote and steep forest patches in upstream basin drainage areas [*Gebrehiwot et al.*, 2010; *Kassa Tadele*, 2009], as well as the revocation of the protective status of forest lands [*Raini*, 2009] and mounting illegal logging in protected forests [*Mtalo et al.*, 2005]. In Malawi and Southern Africa, on the other hand, forest cover has already experienced a peak of reduction in previous decades, with a large share of remaining natural forests under stable conditions in forest reserves. In addition, both countries experienced a strong increase in commercial plantations triggered by rising domestic demand for mine support and construction timber as well as a growing international pulp market. This increase of managed forest area compensated areal losses from the logging of natural forest [*Biggs and Scholes*, 2002; *FAO*, 2010; 2014; *Mango et al.*, 2011].

In regard to ***afforestation***, the 1960s constitute the main period when alien tree species such as eucalyptus and pine were introduced on larger scales for afforestation and plantation establishment in many African countries [*Bewket and Sterk*, 2005; *Mbano*, 2009; *Scott and Prinsloo*, 2008; *Warburton et al.*, 2012; *Zhao et al.*, 2012]. The strongest effects of afforestation measures on streamflow are reported to occur after ten to twenty years upon planting of the trees, which would coincide with the 1970s to 1980s decade. As mentioned before, these effects possibly level off when full maturity of the trees is reached [*Scott and Prinsloo*, 2008].

The increase of agriculturally used land occurred in similar waves, which were however highly country specific. Figure 39 provides a detailed overview of the development of selected countries from Eastern and Southern Africa. In Tanzania, for example, a phase of steady increase of agricultural land in the 1970s to 1980s alternated with a stagnant period in the 1990s, after which the expansion rose again exponentially. A similar increase in the 2000s can be seen for Ethiopia, although unfortunately no data is available for the years prior to the 1990s. This development closely fits with the deforestation rates of the respective countries. Malawi, on the hand, is an example for continuous but small-scaled increase over time, while in South Africa a peak seems to have been reached in the late 1990s, after which agricultural land is slightly decreasing again.

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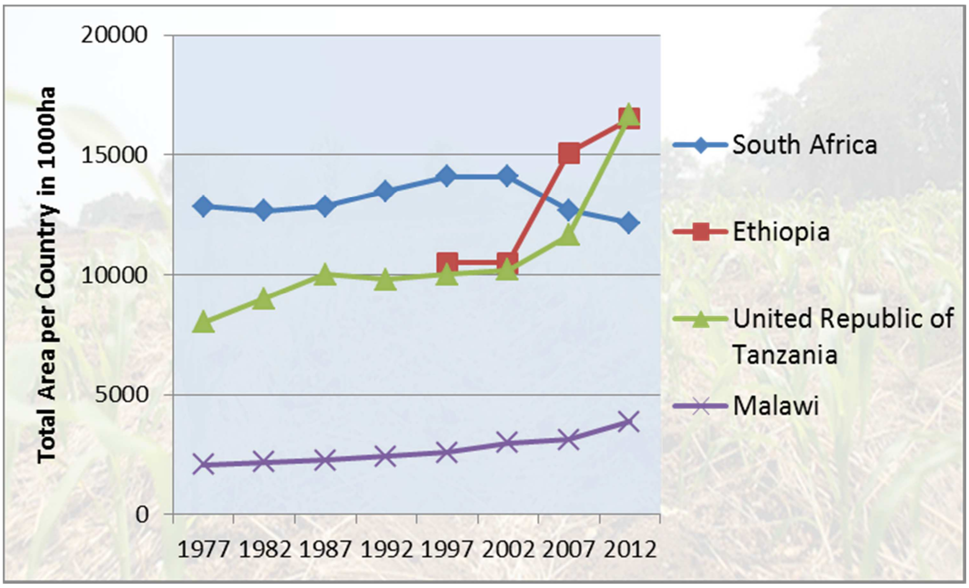

Fig. 39: Development of area under agricultural use in selected African countries from 1977 to 2012 (own rendering, data [*FAO*, 2014]

Interestingly, agricultural expansion is often also driven by political settings: countries like Ethiopia and Tanzania experienced a massive push for the development of previously uncultivated lands through national policies in the 1970s, accompanied by nationwide resettlement schemes in the 1980s ([*Gebrehiwot et al.*, 2013b; *Mtalo et al.*, 2005]. At the same time, agricultural expansion was halted in Angola due to civil war and the consequent prevalence of mines [*Murray-Hudson et al.*, 2006; *Van Langenhove et al.*, 1998]. In Zimbabwe and South Africa, meanwhile, the effects of the strict designation of land for commercial farmers or communal lands for the local population shows long term effects to this day in the sense that regions with commercial farming show very few changes over time in comparison to the increasingly stressed natural resource base in communal lands [*Lørup et al.*, 1998].

<u>The temporal progression of mentions of *deforestation*, *afforestation* and *agricultural expansion* by the reviewed references smoothly reflect the above findings in that a majority of mentions were attributed to the 1970-1980 decade</u> (see table 20).

In addition to the spatial extent of agricultural land use, management practices play an important role respect to hydrologic responses. The type of tillage, plowing, crop and crop rotation as well as livestock systems all have significant effects on runoff generation [*Lørup et al.*, 1998; *Warburton et al.*, 2012]. A detailed summary of these factors would be beyond the scope of this review. However, in the reviewed references, this factor was commonly stated and because it was predominantly mentioned in relation with unfavorable management practices, labeled ***agricultural mismanagement***. The most frequently reported of these were overgrazing, poor farming practices (e.g. tillage, crops) and soil degradation (if not further specified by which cause). It is interesting to see that this manifestation received equal mentions by the reviewed references throughout all decades.

Table 20: Percentage of decadal mentions per pressure-manifestation, 1970-2010 subset

Pressure	Pressure - Manifestation	1970s	1980s	1990s	2000s	Total mentions
LULCC	Deforestation	47.6	26.7	19.0	6.7	105
	Agricultural expansion	48.4	25.3	20.0	6.3	95
	Agricultural mismanagement	32.3	32.3	32.3	3.2	62
	Urbanization	66.7	9.5	23.8	0.0	21
	Afforestation	50.0	30.0	20.0	0.0	10
WW	Irrigation	22.4	41.8	29.9	6.0	67
	Increased domestic demand	23.3	58.1	18.6	0.0	43
	Increased urban demand	21.1	78.9	0.0	0.0	19
	Increased livestock numbers	16.7	61.1	22.2	0.0	18
CC/CV	Increasing variability of rainfall	53.3	17.8	17.8	11.1	45
	Decreasing rainfall	45.2	35.5	19.4	0.0	31
	Increasing temperature	20.0	80.0	0.0	0.0	10
	Increasing rainfall	54.5	27.3	18.2	0.0	11
	Increasing drought occurrence	16.7	0.0	83.3	0.0	6
Dams	Hydropower	56.5	26.1	13.0	4.3	23
	Irrigation	36.4	40.9	18.2	4.5	22
	Urban water demand	50.0	37.5	12.5	0.0	8

(manifestations not included due to too few mentions: natural vegetation, agricultural intensification, drainage of wetlands, industries)

Urbanization in the land use/cover sense of an increased percentage of sealed surfaces is an accelerating trend in Sub-Saharan Africa, but only plays a minor role for this review because we decided to focus on rural drainage basins only. However, urbanization was mentioned as a manifestation of LULCC by quite a number of references who described the impact of growing regional cities and infrastructure (mainly roads) on drainage basins. Here we could not find specific data to evaluate the *pressure* (urbanization trends excluding metropolis), but data is available to assess the attributed *driver* i.e. population growth. Demographic figures show that the annual rate of population change rapidly increased between 1955 and 1965: by 0.2% to the all-time maximum in the 1970s of 2.5% in Southern Africa (current rate is 1.4%), and by 0.6% to 2.8% in Eastern Africa, which reached a peak with 3% population growth in the 1980s (current rate is 2.7) [*UN*, 2012]. The mentions by the reviewed references cannot be viewed as representative due to their overall limited number of mentions, but they do to their extent reflect the observed trends with an unprecedented rapid population increase in the 1970s.

Water withdrawal

The availability of data on water withdrawal is very limited for the decades up to around 1980.
The existing data on agricultural water abstractions (which is chiefly used for ***irrigation***) compiled by the FAO after 1980 shows that the ratio of abstractions for agricultural water use lay at around 40-90% of total water withdrawals in most of the reviewed countries in the 1980s-1990s. In the following years, the volume of agricultural water abstractions generally increased while the ratio to total water abstractions often decreased (that is, a higher percentage of water was abstracted for other purposes, and/or more efficient use was made of agriculturally used water – the latter may be supported by the observation that the extent of irrigated areas has increased steadily in all countries since the 1990s). An interesting exception are South Africa and Zambia, were the volume of agricultural water abstractions has decreased steadily after a peak in the 1980s. In Kenya, too, agricultural abstraction volumes decreased until 2000 but have since then been increasing again strongly [*FAO*, 2014; *The World Bank*, 2008].

Water abstractions ***for domestic demand*** in this context refer to an increase of water use based on growing population numbers, the temporal dimension of which has already been outlined in the previous section. ***Urban demand*** refers to an increase of water use per capita due to rising living standards and to urban population agglomerations. The data for municipal water abstractions indicates a steady increase for all reviewed countries since the 1980s, with strong increments of up to 50% in the 2000 decade. Per capita water use has increased in all countries except for South Africa and Zambia, were a decrease sets in after the 1980s – however, the latest data in this regard is from 2002, therefore newer developments cannot be incorporated [*FAO*, 2014].

With regard to ***water demand for livestock***[57], no direct data is available on water abstractions but there are statistics on the development of livestock numbers. Data by the International Livestock Research Institute (ILRI) for example shows that while populations in Eastern and Southern Africa have generally been increasing since the 1960s, the growth is not very intense (e.g. at around 2.1% annual growth rate between 1990-2007) and often disrupted by strong periodic decreases. The 1980s for example saw a massive reduction of the annual growth rate to 1.4% from previously 3.6% in the 1970s in Eastern Africa. The reasons for these developments are closely linked to the prevalent extensive agro-pastoralist farming systems and the available natural resource base in the respective countries. Severe droughts such as experienced in the Sahel, parts of Eastern Africa, and Zimbabwe up to the 1990s, as well as increasing conflicts over water resources and grazing land lead to a natural restriction of livestock numbers. In addition, poor nutrition heightens the susceptibility for major diseases and infertility [*Anteneh*, 1984; *ILRI*, 2014; *Lørup et al.*, 1998].

The temporal pattern of mentions for *irrigation, increased domestic* and *urban water demand,* as well as *increased water abstractions for livestock* by the reviewed references generally fit with the data describing a peak for most of these factors in the 1980s.

[57] Livestock here encompasses cattle, sheep, goats and camels.

Climate change and climate variability

The development of ***climatic conditions*** in the reviewed countries over the 1970-2010 period is less consistent temporally than spatially and has already been described in the previous chapter. Broadly speaking, rainfalls seem to have been stable on a relatively high level for the past 40 years in equatorial Eastern Africa [*Mango et al.*, 2011; *Spinage*, 2012], while the sub-tropical regions of Eastern Africa, especially in the Greater Horn of Africa, have received decreasing amounts of total rainfall [*Omondi et al.*, 2013]. In Southern Africa, total rainfall trends have been decreasing since the 1960s [*Mark R. Jury*, 2012; *Spinage*, 2012].

On the whole, an increase of rainfall variability in time, space and intensity and related extreme events such as floods and droughts as well as an increase in temperatures and potential evapotranspiration is attributed for both regions for the past decades [*Collins*, 2011; *Conway et al.*, 2009; *Githui*, 2008; *Mango et al.*, 2011; *Shu and Villholth*, 2012; *Spinage*, 2012; *Todd et al.*, 2011].

An important additional aspect in the temporal context is the mention of **climatic cyclicity**. Both annual rainfall trends and, even to a greater extent, the occurrence of extreme events, are reportedly linked to large-scale atmospheric constellations such as the El Niño-Southern Oscillation (ENSO) and the Atlantic Multi-Decadal Oscillation (AMO). These events recur periodically in consistent intervals, with respective effects on regional climatic conditions. In Southern Africa, a number of authors for example describe short term patterns of recurring dry phases in 3- to 5-year intervals affecting the Limpopo and Zambezi river basins, which seems to further be embedded in a long term cycle of 17 to 20 or even 48.5 years [*Beilfuss*, 2012; *Mark R. Jury*, 2013; *Love et al.*, 2010; *Wolski et al.*, 2012]. Similar findings are reported for the neighboring Okavango delta and Lake Ngami basins [*Shaw*, 1983; *Wolski et al.*, 2012] as well as the Orange river basin [*Sene et al.*, 1998]. In Eastern Africa, cyclic climate conditions were mentioned for the Lake Tana basin [*Kebede et al.*, 2006], the Great Ruaha river basin [*Tanzanian Ministry of Water*, 2012] and the Lake Malawi basin [*Mark R. Jury*, 2013; *Mbano*, 2009; *Neuland*, 1984].

The manifestations of *increased or decreased rainfall* trends as reported by the reviewed references are predominantly spatially relevant and therefore an evaluation without geographic consideration is not meaningful. In regard to the mentions of *increased temperatures, drought occurrence* and *rainfall variability* it would have been expected that mentions were more evenly distributed across the decades, with a possibly higher proportion of the 2000s since these factors seem to be progressing and have received growing consideration in research over the past years.

In this respect it is also noteworthy to mention that quite a number of references explicitly stated a "decoupling" of drainage basin developments from climatic factors over the course of time. Most often, hydrologic parameters were described to closely relate to rainfall patterns until the 1960s to 1980s, after which changes in the basin could not be explained by rainfall events anymore (i.e., decreasing streamflow despite of increasing rainfall trends). Commonly, a shift from natural to anthropogenic driven pressures was described [*Gichuki*, 2004; *Liniger et al.*, 2005; *McHugh et al.*, 2007; *Nicholson*, 1998; *Notter et al.*, 2007; *Stoof-Leichsenring et al.*, 2011; *K. Tadele and Förch*, 2007].

Dams

The bulk of dams in Sub-Saharan Africa was constructed in the 1960s to 1980s, without any clearly distinguishable phases pertaining to the primary dam purpose [*Arthurton et al.*, 2008; *International Rivers*, 2010; *Schulze*, 2004]. The obvious timely with the date of construction must be supplemented with a link to the matter of dam operation. In the early era of dam construction in Africa, little regard was given to ecological and social issues related to the downstream changes invoked by dams. With time and growing experience (as well as protests from affected stakeholders), natural flow requirements and reserve flows were increasingly allowed for in dam operation schemes. In the last decade, even further reaching plans were introduced: the operators of dams in the Tana river in Ethiopia and the Zambezi river in Zambia are planning to re-introduce a controlled version of the former bi-annual flood patterns to ensure the sustainability of downstream ecosystems and maintain important fish breeding grounds [*Mitchell*, 2013; *Snoussi et al.*, 2007].

The temporal pattern of mentions for *dams (for all purposes)* stated by the reviewed references fits well with the above described era of major dam construction in the 1960s to 1980s, as well as changes in operation schemes later on.

In summary it can be said that the described progresses of hydrologic parameters can be ascribed regional and temporal patterns, which can for the larger part be related to documented temporal and spatial developments in the analyzed regions.

5.5 Relation of basin size to reported hydrologic parameters and attributed pressures

As mentioned before, the **spatial extent** of drainage basins plays an important role for all hydrological processes. For better handling of the analysis in this review, all references were categorized according to the size of the described drainage basins[58]. This chapter will now briefly investigate whether there are any discernible relations between the categories of drainage basin size and reported changes in hydrologic parameters or attributed pressures.

Hydrologic parameters

To enhance comparability of the findings, the number of mentions per hydrological parameter development were put in relation with the total number of references in the respective size group.

Table 21: Frequency of mentions per hydrological parameter development group and drainage basin size group, 1970-2010 subset

Category of hydrological parameter development (Nr. of References)	**XS (10)** <100km²	**S (22)** 100 - 999km²	**M (25)** 1000-10,000km²	**L (31)** 10,000-100,000km²	**XL (21)** >100,000km²
No trend (35)	0.4	0.2	0.2	0.4	0.4
Increased wet season flow / water levels (8)	0.0	0.3	0.1	0.1	0.2
Decreased wet season flow / water levels (4)	0.0	0.3	0.0	0.2	0.0
Increased flashiness/quickened basin response (10)	0.0	0.3	0.2	0.2	0.2
Decreased annual flow / water levels (57)	3.5	1.5	2.1	1.3	1.0
Decreased dry season flow / water levels (43)	2.4	2.0	1.0	1.5	0.4
Increased frequency and duration of no flow (21)	1.6	0.4	0.6	1.1	0.0
Increased annual flow / lake water levels (11)	0.2	0.8	0.3	0.0	0.3
Increased frequency and/or intensity of floods (25)	1.1	0.5	0.9	0.4	0.4
Artificial regime (7)	0.0	0.0	0.1	0.1	0.0
Increased dry season flow (6)	0.0	0.0	0.2	0.0	0.1
Decreased frequency and/or intensity of floods (9)	0.0	0.0	0.2	0.1	0.1
Decreased frequency and duration of no flow (1)	0.0	0.0	0.1	0.0	0.0

(The score in above table is derived by dividing the total number of mentions per parameter per size group by the total number of references of the respective size group (indicated in brackets below the size group name). For example for the "no trend" category, 4 mentions were made within the "XS" group, this figure was then divided by 10 which is the total number of references describing "XS" groups The resulting figure gives an indication of how often, proportionally, any size group was mentioned per hydrologic change. The number of total references per hydrological parameter group as stated in the left column is provided for means of a better relational comparison of categories).

The result in respect to reported parameters can be broadly divided into three groups. For the first group (see uppermost segment in table 21), no patterns can be detected. This is somewhat surprising for the *no trend* group, because it would have been expected that trends were more difficult to determine in spatially extensive basins, therefore biasing the number of mentions towards large and very large basins. This can, however, not be attested from the herein reviewed references.

[58] For more details on these categories, please see chapter 4.1, and for consultation of drainage basins sizes Annex 1.

The second group (see middle segment of above table) shows a more or less pronounced emphasis towards smaller drainage basin sizes. This corresponds with the established hydrological experience that in general, impacts of changes in drainage basins can become harder to measure at larger scales due to offsetting effects (e.g. larger number of inflowing rivers with potentially very different flow regimes, de-synchronisation of floods, differing storage capacity and of the river bed). This is especially true for effects from highly localized pressures, such as LULCC and WW, which happen to be the primary pressures attributed to the middle group of hydrologic parameters [*Kiersch*, 2000].

The last group finally displays a not very strong but perceivable emphasis on large to very large drainage basins. Once more the attributed pressure could be the factor best explaining this pattern. The respective hydrologic parameters are all primarily influenced by the construction of dams, which directly alter stream flows and naturally present a factor with a much larger scale of reach.

Attributed pressures

For the analysis of links between pressures and basin size, the total mentions per pressure were aggregated[59] and put in relation to the total number of references per size group. The results showed some quite expressive coherences (see fig. 40).

Firstly, LULCC and WW were both notably more often mentioned in respect to smaller drainage basins than to large ones. This matches very neatly with the observations that localized interventions such as caused by above pressures tend to be more easily detected and cumulate faster in smaller drainage basins because of the lower number of potentially offsetting factors [*Gebrehiwot et al.*, 2013a; *Kiersch*, 2000; *Warburton et al.*, 2012]. Given the high prevalence of LULCC and WW it is reasonable to assume that these pressures are present everywhere and not only in smaller drainage basins.

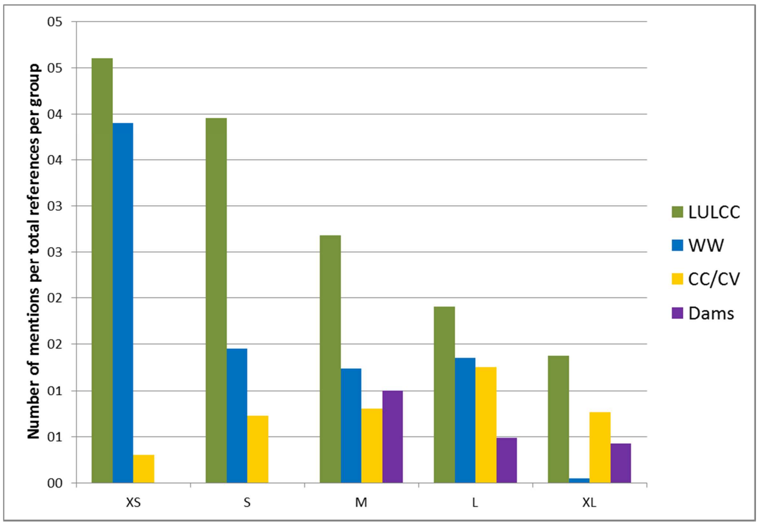

Fig. 40: Frequency of mentions per pressure and drainage basin size group, 1970-2010 subset

Secondly, dams were only mentioned for medium to large drainage basins. As explained in the previous section, this is probably linked to the fact that dams have far-reaching and relatively easily measurable consequences which remain distinguishable even in large drainage basins [*Beilfuss*, 2012]. However, it is also conceivable that large drainage basins predominantly conform to large rivers, and that large rivers attract higher shares of damming activities due to the higher capacities and return benefits of construction and maintenance costs.

CC/CV, finally, was mentioned for all size groups. This fits well with the given high complexity and spatial variability of climate in the African context [*Legesse et al.*, 2003; *Spinage*, 2012]. A possible explanation of the small tendency towards larger basins could be that climatic impacts seem to be a major offsetting (or aggravating) factor of localized pressures, and therefore take more effect at larger scales [*Awange et al.*, 2008; *Gebrehiwot et al.*, 2013b; *Legesse et al.*, 2003; *Tekleab et al.*, 2013; *Warburton et al.*, 2012].

[59] In this case we decided to aggregate the findings per pressure and forego the individual manifestations because it showed that useful insights were nil without including details on e.g. how much of a basin was affected by a pressure.

6. SUMMARY AND OUTLOOK

6.1 Summary of review findings

The aim of the present report was to gain a comprehensive and systematic understanding of hydrological changes and attributed causes in Eastern and Southern Africa within the past hundred years. For that purpose, an extensive literature search was conducted and 85 publications which met a set of predefined criteria were employed for a quantitative and qualitative analysis. A total of 132 references to 75 river and 17 lake drainage were assessed for mentions of changes in the ***hydrologic parameters*** **annual streamflow / lake water levels, seasonal flow composition, flood parameters,** and **no flow.** In addition, detailed notes were taken on the specific causes mentioned for the described changes. The analysis focused on four main questions: which changes and possibly overall trends were described, which were the commonly attributed pressures to which change, and could regional, and/or temporal, relations be established?

The hereby collated database constitutes the source for the findings presented in the previous chapters, drawing a detailed picture about the trends and causes of hydrologic change in the reviewed drainage basins in Eastern and Southern Africa.

In regard to the first question, the picture conveys that water resources in Eastern and Southern Africa are commonly affected by high annual and inter-annual variability [*Shahin*, 2002], but also that in the past decades, a **growing number of drainage basins reportedly display decreasing long-term trends in annual streamflow or lake water levels** [*Conway et al.*, 2009; *Gebrehiwot et al.*, 2013a; *Mitchell*, 2013; *Rajabu et al.*, 2005; *Snoussi et al.*, 2007]. Figure 41 exemplarily shows Lake Naivasha, Kenya.

On an aggregated level, decreased annual streamflow or lake water levels were reported for 11 out of 22 meta-basins in Eastern and Southern Africa between 1900 to 2010. 8 meta-basins were attested opposing trends, while only 3 meta-basins showed no trends.

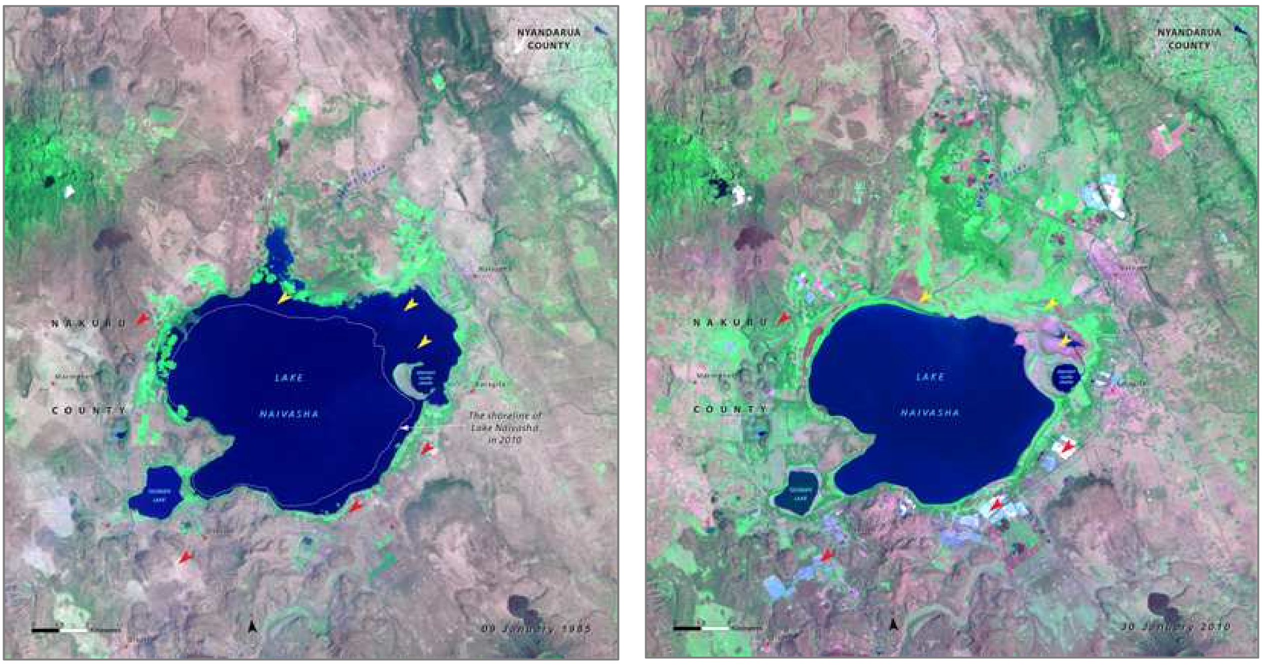

Fig. 41 Comparison of satellite images of Lake Naivasha, Kenya, from 1985 and 2010 Note the marked decrease of lake surface, and increase of irrigated land as well as buildings around the shore [*UNEP*, 2012].

The analysis on drainage basin level was narrowed down to the years between 1970 to 2010 in order to ensure a better comparability of findings. For this time span, 57 respectively 52% of all references described decreased trends in annual streamflow or lake water levels in Eastern and Southern Africa. 35, or 32%, described no trends (including 2 references to drainage basins with mixed trends, and 9 references to drainage basins that did not provide enough detail on annual parameters but did for other parameters). 11, or 10%, of all references described increased annual streamflow or lake water levels. 7 respective 6% of references fell into a special category named artificial regime, comprising river drainage basins whose flow regime had been altered by the construction of dams in such a way that the natural flow regime had been completely replaced by a human operated flow scheme.

Because altered states in drainage basins are not only measurable by changes in annual flow or lake water levels, a number of ***additional hydrologic parameters*** reflecting seasonal flow composition and basin reactivity were evaluated for this review. In fact, 9 references described changes in such parameters without effects on annual flow values. The large majority of drainage basins, though, were reported to display annual and in addition seasonal changes.
The most frequently named of these additional changes was *decreased dry season flow* (also known as low flow), which was stated by 43 respectively 39% references. *Increased dry season flow* was mentioned by 6 respective 5% of the references. An *increase in wet season flow* was reported by 8 respective 7%, and a *decrease in wet season* flow by 4 respective 4%.
The second largest group encompasses flood parameters. *Increased intensity and/or frequency of floods* was stated by 25 or 23% of references, a *decrease in the same parameter* by 9 respective 8% of references. *Quickened basin response time* describes a reduction of the timespan which elapses between a change in input in a drainage basin (e.g., onset of rainfall event) and a measurable change in affected drainage basin parameters (e.g., streamflow). This phenomenon was described by 10 or 9% of references.

Ultimately, all changes in the above mentioned hydrologic parameters are indicators of modified in- and output-steering parameters in drainage basins. These can pertain to changes in water input (e.g. climate, water transfers), water storage capacity (e.g. soil and runoff properties, vegetative interception) and water output (e.g. discharge, evapotranspiration, groundwater movements, abstractions). The grade of change can give some indication of the extent of these modifications, however since there are usually several modifications interacting simultaneously, a clear attribution is sometimes complicated [*Yanda and Munishi*, 2007].

The results show that the **majority of drainage basins in Eastern and Southern Africa are experiencing massive, long-dated changes in hydrologic parameters** which are effected by modifications in the drainage basins. This tendency corresponds with similarly reported trends on a global scale. *Dai et al.* [2009] for example analyzed stream flow of the world's largest rivers from 1948 to 2004 and found that a third of these displayed significant changes, mostly relating to decreases, over time.

Concerning the second question, the reviewed references often offered a description of the investigated and/or attributed causes of the described hydrologic change(s). Following the applied modified DPSI(R) model, these proximate causes of change are termed ***pressures*** throughout the report. Wherever pressures were stated, these were noted and later grouped in five categories: **climate change / variability, land use and land cover change, water withdrawal, dams, and tectonic activity**. Of these, climate and tectonic activity can be seen as natural factors, while all other factors in this context are human induced. For each category, consistent terminology was used to describe sub-groups (e.g. climate = increased rainfall, decreased rainfall, increased variability of rainfall, increased drought occurrence, increased temperatures).

The relation between stated pressures and hydrologic changes was evaluated by frequency and qualitative analysis. On the whole, human induced factors were mentioned seven times more often than natural factors.
The most powerful pressure stated was *water withdrawal*, chiefly related to the irrigation of cash crops and the provision of increased human and livestock populations. This pressure was closely linked to decreased annual and dry season flow as well as increased no flow by most references.
Land use and land cover change, primarily through deforestation and agricultural expansion, was the most frequently stated pressure and attributed to the just named parameters as a secondary cause. It was also quoted as the leading cause for increased annual flow, increased and decreased wet season flow, as well as increased floods and quickened basin response time.
Climate change was stated as a contributory factor to almost all parameters except for increased dry season flow, decreased floods and no flow, and artificial regime - which were all solely attributed to the construction of *dams*. Dams were built primarily for irrigation water supply and hydropower generation. The subsidiary role of climate as a pressure was somewhat surprising, given the ongoing debates and indisputable climatic changes in Africa.

All in all, the mentioned pressures as well as established relations with reported hydrologic changes match with the expectations set by expert literature. This even pertains to the described contradictory effects of land use and land cover change, which was mentioned e.g. as a cause for both increased and decreased wet season flow, and which has been similarly described in other studies before. In reality, the attribution of specific pressures to specific changes is highly complicated because so much depends on the precise location, extent and timing of pressures as well as the interaction with other factors. The established findings are therefore meant to be seen as a broad outline.

With regard to the third question, an overarching ***regional clustering*** of described changes could be identified. Hereby, the two main regions with the strongest mention of changes seem to be the central to northern Rift Valley area in Ethiopia, as well as the Lake Victoria and southern Rift Valley region in Kenya towards the Indian Ocean coast. In addition, it could be established that hydrologic changes related to land use and land cover change as well as water withdrawal were more commonly mentioned as pressures in Eastern Africa, while those primarily attributed to dams were more frequently mentioned in Southern Africa. Impacts attributed primarily to climate change/variability were very rare, but by tendency, these were mentioned a bit more frequently in Southern Africa.

In the same vein, the fourth question revealed distinctive ***temporal patterns*** of observed changes and pressures. The main outcome is that the majority of described changes among the reviewed references were located in the 1970s and 1980s. The exception were hydrologic parameters which were primarily related to land use and land cover change, which were mentioned most often in the 1970s and 1990s, and also those parameters chiefly associated with water withdrawal, which were prominently stated in the 1980s.

The thereby established regional and temporal patterns were critically compared with publicly available statistical data on the progression of pressures in the respective area or decade. By this means, it could be confirmed that there are indeed causal links which ultimately affect the observed changes in hydrologic parameters.

These processes were also related to the main ***driving forces*** behind the reported pressures and changes. In frames of this report we did not evaluate drivers, but where named they were recorded. The most frequently cited d*riving forces* among the reviewed references were population growth, agricultural sector development, and global warming respective global atmospheric patterns.

In the past 60 years, the total population in Eastern Africa increased fivefold to about 350 million people, while Southern Africa's population quadrupled to about 60 million people [*UN*, 2012]. This prominent driving force was thematized by the overwhelming majority of references.

The second important driving force was agricultural sector development and growth (including livestock), which was mentioned by about two thirds of the references. The percentage of agriculturally used land to total country area has doubled, in some cases tripled, in the past 50 years in Eastern and Southern Africa [*FAO*, 2014]. Furthermore, agricultural intensification in terms of irrigation and commercial production of cash-crops and timber has increased notably [*Awange et al.*, 2013; *FAO*, 2014; *Kashaigili*, 2008; *Liniger et al.*, 2005; *Lloyd*, 2010; *Mitchell*, 2013; *Warburton et al.*, 2012]. These latter can also be understood as implications of global trade and economics, since a large share of the newly introduced cash-crops are produced for international markets.

Thirdly, global warming respectively global climate change was stated by a bit more than a third of all references as a driving force. Global atmospheric patterns such as the El Niño-Southern Oscillation (ENSO) and the Atlantic Multi-Decadal Oscillation (AMO) were explicitly mentioned by a few references [*Beilfuss*, 2012; *Mark R. Jury*, 2013; *Kebede et al.*, 2006; *Love et al.*, 2010; *Wolski et al.*, 2012]. Urbanization, political framework, global economics and trade as well as lithospheric processes were also named but only be a handful of few references.

The ***implications*** of the described hydrologic changes in Eastern and Southern Africa were manifold. Since this issue was not particularly evaluated within this review, a short overview shall be included at this point.

Problems with erosion and siltation but also an increased washing out of agricultural pollutants were mentioned in relation to increased flow and quickened basin response time by several references [*Mwakalila*, 2011]. The loss of homesteads, valuable farmland, and infrastructure were also quoted as negative impacts of floods and rising water levels. Dams evidently reduced flood risks and associated dangers for livelihoods, and also provided socioeconomic benefits at national scales [*Snoussi et al.*, 2007]. On catchment scale, however, dams were also reported to bring about other problems when not operated sustainably. A common impact for example was increasing water scarcity downstream of dams in the dry season. Less obvious but also mentioned by a number of references was the issue of collapsing fisheries due to the cessation of annual flood peaks, which were required by the highly specialized ecosystem to maintain the brackish water in sensitive fish breeding estuaries. With the construction of dams, traversing freshwater pulses were cut off, and an increased intrusion of saline seawater caused a massive decline in fish and prawns population. The consequences of hydrologic change can thereore also be massive for ecosystems and wildlife [*Acreman*, 1996; *Beilfuss*, 2012; *Snoussi et al.*, 2007].

The impacts of decreased streamflow or lake water levels can be even more severe for local people and their livelihoods. In many cases, surface water resources are over-allocated even at best times. A further decline of water availability then often induces water scarcity, which poses limitations for agricultural production and livestock keeping and can infuse conflicts over the dwindling resource.

Such concrete water conflicts were mentioned by 4 out of the total 57 references in this category, but water shortages were commonly reported. Other impacts not resulting in conflicts yet but causing distress to local people included reduced groundwater tables, declining yields of springs and boreholes, and declining water quality due to salinization and siltation. The consequences of decreased water resources therefore can affect livelihoods both directly (water availability & quality) and indirectly (conflicts, power shortage, economic losses).

Finally, the most important ***limitations*** that became apparent during the completion of this report shall briefly be shared.

Two major issues encountered with the **analysis of data** set were those of scale and time. Many hydrologic processes are very site specific and show different effects at different scales. Even though the reference value was always a drainage basin, these can vary in size from a few to several hundred thousand square kilometers. Obviously, different processes and patterns will become apparent at such diverging scales, and contradictory trends even within small spatial distances can occur [*Tekleab et al.*, 2013]. Furthermore, comparison of findings becomes really difficult. We tried to alleviate the problem by introducing size classes, aggregating findings at meta-basin level where appropriate, and actively including the question of basin size in the analysis process.

This was not as easily done with time, because it is less easy to classify. The introduction of a timespan requirement with a minimum joint coverage of the years from 1970 to 2010 was an attempt at a respective harmonization. However, the results in regard to both the described development of hydrological parameters as well as attributed pressures will depend greatly on the period of time considered (Gebremicael et al 2013). This is especially relevant in light of time lags between drainage basin modifications and impacts on flow characteristics (for example, changes in vegetation cover can take about 3-10 years to be reflected in hydrologic parameters [*Zhao et al.*, 2012]) and recurring patterns of long-termed cyclicity (e.g. 30 - 100 year rainfall cycles in Lake Malawi and East African lakes region [*Neuland*, 1984; *Nicholson*, 1998]). A comprehensive background assessment is the only way to counter these difficulties, but is itself constrained due to the scarcity of reliable data [*Conway et al.*, 2009].

Another more primal uncertainty remained unsolved within the scope of this work. As mentioned earlier, a relatively larger proportion of references report decreasing trends for the late 20th and 21st century compared to the overall timespan. While the circumstantial evidence hints at an ever-increasing impact of human actions on drainage basins in the past decades, it must also be noted that the focus of scientific research as well as state and non-governmental projects has shifted massively over the years, thus introducing a bias or at least chicken-egg-problem. It suggests itself that many of the reviewed studies were written precisely because changes had been observed in the respective drainage basin. Drainage basins with little changes in remote areas, on the other hand, may be underrepresented, thus resulting in a biased sample.

In comparison amongst the whole sample group, **quality of publications** even from peer reviewed sources varied considerably. A common notation pertains to the often not fully explored investigation of potential causes, and the sometimes lacking evaluation of relations to larger spatial contexts (especially for drainage basin of very small size). Obviously, different authors were following different objectives at the time of research, all of which were brought together in this review under the common denominator of described hydrologic changes in drainage basins. This criticism can therefore only be of very general nature. That said, a number of publications particularly stood out for their thorough analysis of individual drainage basin components and relations, namely *Mwaura and Moore* [1991], *Gichuki* [2004], *Bewket and Sterk* [2005], *Liniger et al.* [2005], *Legesse and Ayenew* [2006], *Kashaigili* [2008], *Melesse et al.* [2008], *Ngigi et al.* [2008], *Beilfuss* [2012], *Shu and Villholth* [2012], *Gebrehiwot et al.* [2013a], *Gebremicael et al.* [2013] and *Tekleab et al.* [2013].

On the whole, the statements of all reviewed references constitute a solid description of causal links and qualitative relations between described changes and attributed pressures in general. What is covered remarkably less extensively is the description of quantitative relations. This is reportedly due to limited data availability, and also at least to some extent to the complications arising from identifying the impact of specific pressures on individual hydrologic parameter components. However, it remains one of the main **knowledge gaps** identified in frames of the present literature review. Other issues which have not received much attention so far but are of growing importance in light of the ongoing and expected developments concern the more detailed understanding of particular processes: how does the impact of intensified land use on drainage basin processes differ from the impact of the previously dominating change in land cover? To what extent will projected temperature increases alter already investigated dynamics? And what are possible feedback patterns arising from the observed manifestations – for example, where is the water going that is being abstracted for irrigation and which increasingly evaporates from reservoir surfaces? Among the reviewed publications, these issues very hardly investigated, but explanations would greatly improve the understanding and representation of drainage basin dynamics in hydrologic modelling.

In summary it can be said that the review was successful in meeting its objective and providing a comprehensive overview of hydrologic parameter development and inter-linkages with attributed pressures in Eastern and Southern Africa. The results show that the observed pressures display both regionally and temporally differentiated progresses, which in turn lead to regionally and temporally differentiated developments of the analyzed hydrologic parameters. The first are documented by statistics on pressures and/or drivers; the second become apparent by the descriptions of the reviewed references. These findings support our assumption that causal links exist between pressures and hydrologic changes, and that these can be described to a certain extent.

Many of the described developments can be interpreted as processes ultimately resulting in harming peoples food security and livelihood by compromising basic natural resources. Water in this sense is a key resource, because without it no other resources, natural or human, can be sustained. But it is also a finite resource, which is increasingly in danger of over-exploitation in many of the described drainage basins [*Rajabu*, 2005]. Agriculture plays a main role in this regard because it is a driving force for both land use changes, as well as water abstractions and dam construction. It is therefore crucial that any consideration of agricultural development must consider the sustainable use of both land and water resources.

6.2 Outlook on expected future development

The described developments of hydrologic parameters and attributed pressures in Eastern and Southern Africa took place before a backdrop of surging population growth, expansion of agricultural land, the beginning intensification and commercialization of agricultural production, and climatic changes. Given the strong link between water resources trends and anthropogenic influence, especially that of agricultural growth, it can be assumed that future developments will be linked to the same factors. In the following section, therefore, a short outlook will be provided on the expected future development of the underlying *driving forces* and, where appropriate, respective consequences for the main pressures.

Population growth

Population growth was the most important driving force of all anthropogenic modifications in Sub-Saharan Africa in the 20th century. The unparalleled surge in population numbers is set to continue for the better part of the next hundred years, however, marked regional differences apply.

In Eastern Africa, the annual rate of population change will remain well above 2 until the year 2045, when it will first drop below that threshold (a lowering to less than 1 is expected at the end of the century). This means that the number of people living in East Africa will increase by 475 million heads over the next 35 years – a doubling of the current numbers [*UN*, 2012].

In Southern Africa, on the other hand, population growth has already passed its zenith. The annual rate of population change currently lies at 0.9, which is comparable to Europe, and is steadily decreasing (negative rates are expected by the end of the century). This means that the number of people living in Southern Africa will only increase by 13 million heads over the next 35 years [*UN*, 2012].

In addition to these prospects of quantitative changes, qualitative changes have to be taken into consideration when assessing the impact of population numbers. The most important issue in this regard is that increasing living standards are expected to be achieved by growing shares of the population in the future, which typically translates into higher shares of natural resource use per capita.[*John F. Mustard et al.*, 2004].

Agricultural sector growth

The agricultural sector is an important determinant because it involves the majority of people in Eastern and Southern Africa. Agricultural GDP growth rate per capita has risen exponentially since the 2000s, and is expected to continue to do so in the coming decades with increasing shares of international investments. Importantly, the fastest growing markets are expected for nontraditional exports geared towards international trade, e.g. horticulture, flowers, organic coffee or aquaculture. Additionally, an increased and intensified production of staple crops is expected to cover the ever-growing food requirements in Sub-Saharan Africa [*Chimtengo et al.*, 2013; *The World Bank*, 2008].

Global warming

Depending on the applied models and assumptions, predictions of the effect of global warming on regional climate in Africa in the 21st century vary. However, all scenarios agree that global warming will effect Sub-Saharan-Africa foremost through an increase of temperatures (which will presumably be even stronger than the global annual mean increase), and that drier subtropical regions will be more affected than moist equatorial regions [*Getnet et al.*, 2014; *Todd et al.*, 2011].

For **Eastern Africa**, a common overlap pertains to the projections of a modest increases of rainfall (with a pronounced spatial variability), which is accompanied by increased evapotranspiration rates primarily caused by increasing temperatures. Depending on local conditions, these two factors are expected to commonly counterbalance one another, or, in extreme cases, even lead to a reduction of runoff [*Cook and Vizy*, 2013; *Mango et al.*, 2011; *Todd et al.*, 2011].

For ***Southern Africa***, predictions are more homogenous and suggest a progressive shift towards drier climate, with especially reduced winter precipitation and increased temperatures. In addition, multi-decadal cycles of extreme precipitation events as observed in the 20th century are expected to repeat themselves [*Todd et al.*, 2011; *Wolski et al.*, 2012].

In sum this means that increased temperatures and associated evapotranspiration rates may, if not counterbalanced by increased precipitation, cumulate into negative runoff trends. In addition, extreme weather events are expected to recur regularly on a cyclic basis.

The described future developments of driving forces are expected to translate into the following **consequences for the remaining pressures:**

Water withdrawal

A continuous increase of water withdrawals is expected to occur to satisfy the growing demands for population needs and agricultural production [*Githui*, 2008; *Vörösmarty et al.*, 2000]. Figure 42 shows the scope of anticipated freshwater stress and scarcity in the next decades. Intensified production of staple crops incl. irrigation measures is being promoted by some governments as a strategy to improve local food production [*Chimtengo et al.*, 2013]. On the other hand, irrigation of high-value cash crops for export markets are becoming increasingly important [*Kassa Tadele*, 2009; *The World Bank*, 2008]. In the Ethiopian Central Rift Valley region, for example, water demand for the irrigation of horticulture has increased more than tenfold between 2002 and 2009, and the increased area is being expanded continually [*Getnet et al.*, 2014]. In the same way, the strong decline of water levels at Lake Naivasha in Kenya markedly coincides with the onset of the flower industry, which grew rapidly in the 2000s and by now produces a third of the flower imports of the European Union. In addition to the mounting water abstractions for agricultural production, the flower industry is dependent on a large workforce of 500,000 people, many of which have recently migrated to the region and add further stress to the water resources [*Awange et al.*, 2013].

Fig. 42: Expected freshwater stress and scarcity in Africa in 2025 [*UNECA*, 2000]

Land use and land cover change

In regard to LULCC, a continuous expansion of agricultural area and the removal of natural vegetation are expected to take place at least until the turn of the century [*John F. Mustard et al.*, 2004]. At the same time, changes in land use will increasingly occur. This pertains to changes in crop types (e.g. higher input cash crops) as well as management practices (e.g. irrigation, mechanization). Under the expected temperature increases, large scale LULCC is also more likely to affect regional climate through changes in evapotranspiration and albedo [*Githui*, 2008; *Snoussi et al.*, 2007; *Kassa Tadele*, 2009; *The World Bank*, 2008].

Dams

Increasing demands for energy, irrigation water, and domestic/urban water supply will likely lead to a recurring rise of dam constructions in many of the described countries. Along Zambezi river, for example, a number of additional dam sites have been assessed (see fig. 43). Another frequently mentioned concern for dams in the future is the increased siltation due to LULCC in the drainage basins, as it reduces the water storage capacity and dam lifespan. In addition, increased evaporation from the open water sources of is feared in light of the predicted temperature increases. In the Zambezi river basin, already 11% of the mean annual flow of the river is calculated to evaporate from the large reservoirs [*Beilfuss*, 2012; *International Rivers*, 2010; *McCartney and Arranz*, 2009; *McCartney et al.*, 2004; *Snoussi et al.*, 2007].

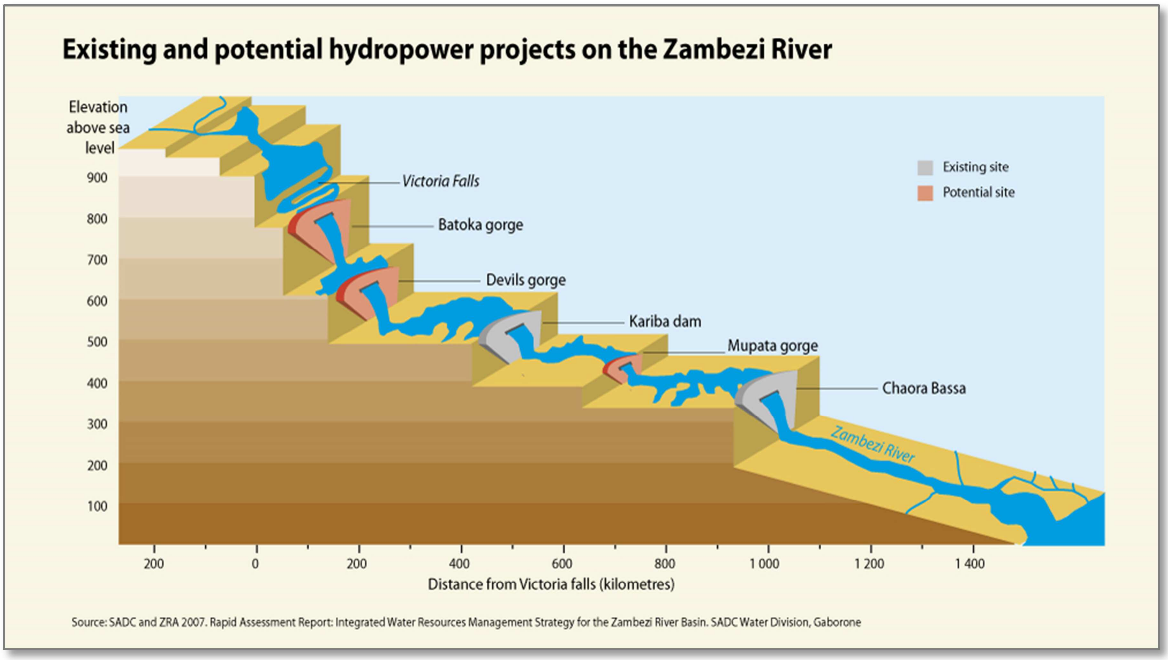

Fig. 43: Map of existing and potential dams for hydropower generation on the Zambezi River
[*GRID-Arendal*, 2013]

In summary, it can be said that

a) Rising water demands mainly from agricultural sector developments but also associated population concentrations will lead to increased pressure on drainage basin water resources, possibly resulting in growing water scarcity, i.e. decreased annual and seasonal flows, increased no flow.

b) Continuous removal of forests and inappropriate agricultural practices will likely further lead to augmented annual and seasonal flow and flood parameters. The expected progressive shift towards changes in agricultural management practices (e.g. crop changes, agricultural intensification, but also more sustainable and efficient soil and water use technologies) will probably introduce new intrinsic effects which would merit future research.

c) A new era of increased dam construction is likely. This encompasses both large-volume dam projects for hydropower and urban demand as well as agglomerations of smaller dams for irrigation water storage. The effect of these dams on for example low flow, no flow, and flood parameters will highly depend on the density (small dams) and the operation schemes (large dams) of the structures.

d) The role of climate will be highly variable. In general, increased temperatures may impact negatively on runoff rates if rainfall does not increase at the same time. Warmer and/or drier conditions are also likely to cause problems for dam operation (e.g. low water levels, increased evaporation) as well as augment water demand for irrigation purposes. The increase or periodic return of extreme weather events will very likely affect flood parameters, especially if interactions with land cover changes arise.

The developments will, very importantly, be highly dependent on the region. Pressure on natural resources is expected to be much higher in Eastern compared to Southern Africa due to the larger population numbers and increase rates [*Love et al.*, 2010; *John F. Mustard and Fisher*, 2004; *Todd et al.*, 2011]. Also, agricultural sector development is just taking off in Eastern Africa, whereas it has already reached a steady level in Southern Africa. Climatic changes, on the other hand, are expected to be less favorable in Southern Africa. On the whole, conflicts about water resources are expected to occur more frequently [*Gichuki*, 2004; *Liniger et al.*, 2005]. However, not all drainage basins are equally vulnerable to water shortage, even under the expected growing demands [*Githui*, 2008; *M. R. Jury and Gwazantini*, 2002].

6.3 Relevance and scope for Trans-SEC project

The present report was compiled in frames of 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. These strategies are primarily geared to small-scale agricultural production, on which the majority of people living in Tanzania still depend for their livelihood.
Research for the Trans-SEC project is implemented by a large consortium of experts from a range of political, social, economic and natural resources backgrounds to cover the complex realities of agricultural production in rural Tanzania. The task of the hydrologic work group is to provide an assessment of the state of water resources and expected future developments, and to evaluate the potential impacts of large-scale application of upgrading strategies on water resources in the project region. This includes hydrologic modelling and the definition of future scenarios.

To that effect, the conducted literature review and subsequent analysis of statements substantially contributes to a more comprehensive understanding of the processes affecting water resources on drainage basin and regional scale in Eastern and Southern Africa. It also provides the frames for placing observed changes and pressures within a larger regional and temporal context, which is especially important for the assessment of future developments and also recommendations of action.

On a work group level, the obtained results by this review will be applied for the refinement of applied models and the definition of future scenarios (including potential upscaling of upgrading strategies) for the next phase of the project. The most important insights hereby comprise the better understanding of links between hydrologic changes and pressures (as well as drivers), a well-founded assessments of future developments, and a number of specific insights on factors which are highly relevant for hydrologic modelling and have been repeatedly named for the region (e.g., the importance of rising temperatures and evapotranspiration rates, or the increase of no flow days).

On the project level, the compiled statements will provide important information on the background of natural resources change against which Trans-SEC is operating. As it became apparent, 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. The Wami-Ruvu drainage basin, which is the site of the project field trials in Tanzania, is no exception to this case. Since climatic factors, population density, and agricultural/industrial activities differ greatly across the basin, precise statements can only be made on sub-basin scale, but increased water scarcity due to these drivers has already been reported for a number of sub-basins. In the future, a further increase and intensification of agricultural activities is to be expected given the governmental agricultural growth plans (e.g. SAGCOT[60]). Trend scenarios by the water basin authorities already indicate that under increasing temperature, the amount of demanded water will exceed the amount of usable water resources by the year 2025 [*JICA*, 2013].

These developments show that there will be increasingly competing demands for water use in Tanzania and the whole Eastern African region in the coming decades. With continuously high population growth figures, water demands as well as impacts from land use and land cover change as well as damming of streams will advance. The majority of subsistence farmers rely on rain-fed agriculture, but with the projected increase in temperatures and evaporation rates, a larger share of crops might need to be irrigated to steady yields. On the other hand, large amounts of water will continued to be abstracted for the irrigation of cash crops which are primarily geared for export, and whose economic returns only benefit a small portion of the population. In addition, the growing variability of rainfall timing and intensity combined with increased runoff due to land use and cover changes heightens the risk of floods, and might therefore result in additional crop losses in rain-fed agricultural systems where planting commonly occurs before the onset of the rainy season. Obviously, such danger grows further when agricultural land is expanded into riparian zones as was described by a number of references in this review. Therefore, food security might be significantly compromised from several angles [*Baker and Miller*, 2013; *FAO*, 2007; *Gebrehiwot et al.*, 2013a; *Love et al.*, 2010].

In light of these prospects, agricultural development and upgrading strategies for the Wami-Ruvu basin in particular but very likely also for Tanzania in general must factor in limitations of total and/or seasonal water availability. As the Trans-SEC project primarily aims at smallholder farmers, strategies to counter these limitations need to be considered which can be implemented locally, without high investment coasts, by either individual farmers or small collective groups. These strategies should follow two important claims.
Firstly, the efficiency of the use of available water needs to be increased in all respects [*Rajabu et al.*, 2005; *Tanzanian Ministry of Water*, 2012; *The World Bank*, 2008; *Van Niekerk and Du Pisani*, 2006].

Secondly, water needs to be used more specifically to combat potential shortages during sensitive cropping periods [*Rajabu et al.*, 2005; *Rockström et al.*, 2002; *Valimba*, 2008]. Both of these options will increase overall production and contribute to ensured food security.

[60] SAGCOT stands for "Southern Agricultural Growth Corridor of Tanzania" and is a major development concept pertaining to the encouragement of private sector investments in agriculture incl. agricultural industry and infrastructure in Southern Tanzania in the next decade. The Wami-Ruvu basin lies partly within the targeted growth corridor and will most likely be affected in some ways by the expected developments ERM (2012), Southern Agricultural Growth Corridor of Tanzania (SAGCOT): Strategic Regional Environmental and Social Assessment (Interim Report)*Rep.*, 144 pp, Environmental Resources Management Consultancy (on behalf of Government of Tanzania), London..

One such strategy 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 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 reportedly positive effects and potential for stabilized or even increased crop productivity are encouraging [*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].

Of course, such measures develop their full potential only if climatic factors are not highly unfavorable, and they also require a strict implementation of designated protected forest and riparian areas and a good regulation of water abstractions. The latter are aspects that would generally be beneficial for drainage basin management in Tanzania and other African countries, but which are beyond the scope of the project at the time [*Le Maitre et al.*, 2009; *Yanda and Munishi*, 2007]. In addition, it remains to be investigated whether the described benefits of SWMP will persist in the long term, or may cumulate to other un-intended negative effects at some other point over time or within the drainage basin.

However, a SWMP component (i.e., in situ rainwater harvesting) has recently been selected as one promising upgrading strategy within the Trans-SEC project and will be tested with a set of other strategies for applicability, effects and limitations in field trials in the Wami basin over the next years. While the primary aim of the strategy is to ensure food security through stabilized yields, it must also be ensured that no negative consequences will arrive from its potentially large-scaled application. The compiled insights from the present literature review will thereby serve as a basis to develop a sound hydrologic model which strives at covering all essential connections between the influencing factors, and developing reliable scenarios which will consider the upscaling of rainwater harvesting in the context of all known interactive pressures.

ANNEX 1 - Reference Background and Drainage Basin Information for All Reviewed References

Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
1	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Abbay River Basin**	200,000	500-4400m	bimodal (June-Sep, March-May)	800-2200mm	1960-2004	*Gebrehiwot et al.* [2013]
2	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Abbay River Basin**	200,000	480-4200m	bimodal (June-Oct, March-May)	1000-2000mm	1970-2009	*Gebremicael et al.* [2013]
3	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Abbay River Basin**	200,000		bimodal (June-Oct, March-May)	1200-1800mm	1964-2003	*Tesemma et al.* [2010]
4	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Birr River Basin**	980			1569mm	1960-2004	*Gebrehiwot et al.* [2013]
5	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Chemoga River Basin**	364	2420-4000m	bimodal (June-Sep, March-May)	1300mm	1957-1999	*Bewket and Sterk* [2005]
6	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Gilgel Abbay River Basin**	1,660			1483mm	1960-2004	*Gebrehiwot et al.* [2013]
7	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Hara River Basin**	48	1460-1730m	bimodal (July-Sep,March-May)	830mm	1955-2003	*McHugh et al.* [2007]
8	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Jedeb River Basin**	296	2171-4000m		1326-1434mm	1973-2010	*Tekleab et al.* [2013]
9	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Koga River Basin**	266	1800-3000m	unimodal (June-Sep)	1560mm	1960-2002	*Gebrehiwot et al.* [2010]
10	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Koga River Basin**	260			1510mm	1960-2004	*Gebrehiwot et al.* [2013]
11	Yes²	River	Ethiopia	Nile Basin	Blue Nile Basin	**Lake Tana Basin**	16,500	1786-4110m		1326mm	1959-2006	*McCartney et al* . [2010]
12	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Upper-Didesa River Basin**	1,806			1995mm	1960-2004	*Gebrehiwot et al.* [2013]
13	Yes	River	Ethiopia	Nile Basin	Blue Nile Basin	**Upper-Gilgel Abbay River Basin**	1,656	1934-3528m	bimodal (June-Sep, March-May)	1500-1600mm	1973-2005	*Rientjes et al.* [2011]
14	Yes	Lake	Ethiopia	Nile Basin	Lake Tana Basin	**Lake Tana**	16,500	1786-4110m	unimodal (June-Sep)		1960-1992	*Kebede et al.* [2006]
15	Yes	River	Ethiopia	Rift Valley Basin	Lake Abaya Basin	**Hare River Basin**	167	1180-3480m		890-1430mm	1980-2005	*Tadele and Förch* [2007]
16	Yes	Lake	Ethiopia	Rift Valley Basin	Lake Abiyata Basin	**Lake Abiyata**	1,100	1600-4000m		700-1200mm	1970-1995	*Legesse and Ayenew* [2006]
17	Yes	Lake	Ethiopia	Rift Valley Basin	Lake Basaka Basin	**Lake Basaka**	402	755-1940m	bimodal (July-Sep,March-May)	544mm	1960-2010	*Dinka* [2012]
18	-	Lake	Ethiopia	Rift Valley Basin	Lake Chew Bahir Basin	**Lake Chew Bahir (formerly: Lake Stefanie)**				200-800mm	1800-1980	*Nicholson* [1998]
19	Yes	Lake	Ethiopia	Rift Valley Basin	Lake Langano Basin	**Lake Langano**	1,750	1600-4000m		700-1200mm	1970-1995	*Legesse and Ayenew* [2006]
20	Yes	Lake	Ethiopia	Rift Valley Basin	Lake Shala Basin	**Lake Shala**	3,280	1600-4000m		700-1200mm	1970-1995	*Legesse and Ayenew* [2006]

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Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
21	Yes	Lake	Ethiopia	Rift Valley Basin	Lake Ziway Basin	**Lake Ziway**	6,834	1600-4000m		700-1200mm	1970-1995	*Legesse and Ayenew* [2006]
22	-	River	Transboundary E (Ethiopia, Sudan)	Nile Basin	Blue Nile Basin	**Blue Nile Basin**	195,000			1224mm	1945-1984	*Conway and Hulme* [1993]
23	-	Lake	Transboundary E (Kenya, Ethiopia)	Rift Valley Basin	Lake Turkana Basin	**Lake Turkana**	8,860			200-800mm	1800-1980	*Nicholson* [1998]
24	Yes	River	Kenya	Athi-Galana-Sabaki River Basin		**Athi-Sabaki River Basin**	70,000				1982-2007	*Snoussi et al* [2007]
25	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Burguret River Basin**	18				1960-2002	*Liniger et al.* [2005]
26	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Burguret River Basin**	99	1700-4000m	bimodal (March-June, Sep-Dec)	600-1600mm	1987-2005	*Notter et al.* [2007]
27	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Likii River Basin**	33				1960-2002	*Liniger et al.* [2005]
28	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Nanyuki River Basin**	69	1700-4000m	bimodal (March-June, Sep-Dec)	600-1600mm	1987-2005	*Notter et al.* [2007]
29	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Naro Moru River Basin**	173	1800-5000m			1960-2004	*Aeschbacher et al.* [2005]
30	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Naro Moru River Basin**	173	1800-5200m	bimodal (April-June, Nov-Dec)	500-1500mm	1960-2005	*Ngigi et al.* [2008]
31	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Naro Moru River Basin**	173	1700-4000m	bimodal (March-June, Sep-Dec)	600-1600mm	1987-2005	*Notter et al.* [2007]
32	Yes	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Timau River Basin**	11				1960-2004	*Liniger et al.* [2005]
33	Yes[1]	River	Kenya	Jubba River Basin	Upper Ewaso Ng'iro Basin	**Upper Ewaso Ng'iro North River Basin**	15,200		bimodal	300-1500mm	1960-2000	*Gichuki* [2004]
34	Yes[1]	River	Kenya	Nile Basin	Lake Victoria Basin	**Nyando River Basin**	3,550	1934-3528m	bimodal (April-June, Sep-Dec)	1300mm	1973-2000	*Olang and Fürst* [2011]
35	-	River	Kenya	Nile Basin	Lake Victoria Basin	**Nzoia River Basin**	12,709	1100-2300m	bimodal (March-May, Oct-Dec)	1076-2235mm	1962 - 2004	*Githui* [2008]
36	-	Lake	Kenya	Rift Valley Basin	Lake Elmenteita Basin	**Lake Elmenteita**	335	1850-2540m			1958-1987	*Murimi* [1994]
37	-	Lake	Kenya	Rift Valley Basin	Lake Elmenteita Basin	**Lake Elmenteita**	335	1800-2600m		733-1066mm	1962-1984	*Mwaura and Moore* [1991]
38	-	River	Kenya	Rift Valley Basin	Lake Elmenteita Basin	**Lake Elmenteita Basin**	335	1850-2540m			1958-1987	*Murimi* [1994]
39	-	River	Kenya	Rift Valley Basin	Lake Elmenteita Basin	**Lake Elmenteita Basin**	335	1800-2600m		733-1066mm	1962-1984	*Mwaura and Moore* [1991]
40	Yes	Lake	Kenya	Rift Valley Basin	Lake Naivasha Basin	**Lake Naivasha**	3,400	1890-3906m	bimodal (April-June, Oct-Nov)	600-1720mm	1989-2010	*Awange et al.* [2013]
41	Yes	Lake	Kenya	Rift Valley Basin	Lake Naivasha Basin	**Lake Naivasha**	3,400	1890-3906m		600mm	1932-1992	*Becht and Harper* [2002]
42	-	Lake	Kenya	Rift Valley Basin	Lake Naivasha Basin	**Lake Naivasha**	3,400			600-900mm	1800-1980	*Nicholson* [1998]

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Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
43	Yes	Lake	Kenya	Rift Valley Basin	Lake Nakuru Basin	**Lake Nakuru**	1,800			876mm	1968-2002	*Raini* [2009]
44	Yes	River	Kenya	Rift Valley Basin	Lake Nakuru Basin	**Lake Nakuru Basin**	1,800			876mm	1968-2002	*Raini* [2009]
45	Yes[2]	River	Kenya	Rift Valley Basin	Lake Nakuru Basin	**Njoro River Basin**	272	1759-3000m	bimodal (April-May, Nov-Dec)	939mm	1986-2003	*Baker and Miller* [2013]
46	Yes	River	Kenya	Tana River Basin		**Tana River Basin**	126,000				1982-2007	*Snoussi et al* [2007]
47	Yes	Lake	Transboundary E (Kenya, Uganda, Tanzania, Rwanda, Burundi)	Nile Basin	Lake Victoria Basin	**Lake Victoria**	184,000				1961-2000 (2005)	*Awange et al.* [2008]
48	-	Lake	Transboundary E (Kenya, Uganda, Tanzania, Rwanda, Burundi)	Nile Basin	Lake Victoria Basin	**Lake Victoria**	184,000			1200-1600mm	1800-1980	*Nicholson* [1998]
49	Yes	Lake& River	Transboundary E (Kenya, Uganda, Tanzania, Rwanda, Burundi)	Nile Basin	Lake Victoria Basin	**Lake Victoria**	184,000				1930-2004	*UNEP* [2006]
50	Yes	River	Trans-Boundary E (Uganda, Kenya, Tanzania, Rwanda, DR Congo, Burundi)	Nile Basin	Lake Victoria Basin	**Lake Victoria Basin**	184,000	1135-4000m	bimodal (March-May, Oct-Dec)		1960-2006	*Mbungu et al.* [2012]
51	Yes[1]	River& Lake	Trans-Boundary E (Uganda, Kenya, Tanzania, Rwanda, DR Congo, Burundi)	Nile Basin	Lake Victoria Basin	**Lake Victoria Basin**	184,000				1930-2004	*UNEP* [2006]
52	Yes[1]	River	Trans-Boundary E (Kenya, Tanzania)	Nile Basin	Lake Victoria Basin	**Mara River Basin**	13,750	1134-2932m	bimodal (April-Sep, Nov-Dec)	700-1750mm	1973-2002?	*Mati et al.* [2008]
53	Yes[1]	River	Trans-Boundary E (Kenya, Tanzania)	Nile Basin	Lake Victoria Basin	**Mara River Basin**	13,750	1134-2920m	bimodal (March-April, Aug-Oct)	700-1400mm	1962-2002	*Melesse et al.* [2008]
54	Yes[1]	River	Trans-Boundary E (Kenya, Tanzania)	Nile Basin	Lake Victoria Basin	**Nyangores River Basin**	696	1100-3000m			1996-2008	*Mango et al.* [2011]
55	-	River	Uganda	Nile Basin	White Nile Basin	**White Nile Basin**	911,000			935-1356mm	1945-1984	*Conway and Hulme* [1993]
56	Yes	River	Uganda	Nile Basin	White Nile Basin (Lake Kyoga Basin)	**Upper-Ssezibwa River Basin**	175	1122-1353m	bimodal (March-May, Oct-Dec)	1600-2000mm	1960-2006	*Nyenje and Batelaan* [2009]
57	Yes	River	Tanzania	Pangani River Basin		**Luengera River Basin**	800	500-1800m	bimodal (March-May, Oct-Dec)		1968-1990	*Mtalo et al.* [2005]
58	-	River	Tanzania	Pangani River Basin		**Mkomazi River Basin**	3,341	500-1800m	bimodal (March-May, Oct-Dec)		1962-1984	*Mtalo et al.* [2005]
59	Yes[1]	River	Tanzania	Pangani River Basin		**Pangani River Basin**	43,650		bimodal (March-June, Oct-Nov)		1952-2005	*Valimba* [2008]
60	Yes[2]	River	Tanzania	Pangani River Basin		**Sigi River Basin**	705	900m	bimodal (March-May, Oct-Dec)		1957-1989	*Mtalo et al.* [2005]

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Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
61	Yes[1]	River	Tanzania	Pangani River Basin		**Sigi River Basin**	705		bimodal (March-June, Oct-Nov)		1952-2005	*Valimba* [2008]
62	Yes[2]	River	Tanzania	Pangani River Basin		**Sigi River Basin**	705		bimodal (March-May, Oct-Dec)	1650mm	1970-1989	*Yanda and Munishi* [2007]
63	Yes[1]	River	Tanzania	Pangani River Basin		**Umba River Basin**	8,070		bimodal (March-June, Oct-Nov)		1952-2005	*Valimba* [2008]
64	Yes	Lake	Tanzania	Rift Valley Basin	Lake Rukwa Basin	**Lake Rukwa**	88,000		unimodal (Oct-April)	650-2500mm	1971-2010	*Ministry of Water, TZ* [2012]
65	Yes	Lake	Tanzania	Rift Valley Basin	Lake Rukwa Basin	**Lake Rukwa**	88,000			800-1200mm	1972-1992	*Nicholson* [1999]
66	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Great Ruaha River Basin**	68,000				1950 - 2011	*Mitchell* [2013]
67	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Great Ruaha River Basin**	68,000		unimodal (Nov-April)	500-1200mm	1965-2000	*Mwakalila* [2005]
68	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Great Ruaha River Basin**	68,000		unimodal (Nov-April)	500-1200mm	1965-2000	*Mwakalila* [2011]
69	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Mkoji River Basin**	3,400		unimodal (Nov-Aprl)	617-1039mm	1980-2004	*Rajabu et al.* [2005]
70	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Usangu River Basin**	20,800	1100-2000m	unimodal (Dec-April)	700-2000mm	1965-1999	*Ministry of Water, TZ* [2001]
71	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Usangu River Basin**	20,800	1100-2000m	unimodal (Dec-May)	500-1600mm	1960-2009	*Shu and Villholth* [2012]
72	Yes	River	Tanzania	Rufiji River Basin	Great Ruaha River Basin	**Usangu Wetland Basin**	1,800	1100-3000m			1948-2004	*Kashaigili* [2008]
73	-	River	Tanzania	Rufiji River Basin		**Kilombero River Basin**	14,136	420-1860m	unimodal (Nov-May)		1962-1983	*Mtalo et al.* [2005]
74	Yes	River	Tanzania	Rufiji River Basin		**Rufiji River Basin**	177,429				1982-2007	*Snoussi et al* [2007]
75	Yes	River	Tanzania	Ruvu River Basin		**Ngerengere River Basin**	2,780	100-2250m	bimodal (March-May, Oct-Dec)	800-1500mm	1970-2010	*Natkhin et al.* [2013]
76	Yes	River	Tanzania	Ruvu River Basin		**Ruvu River Basin**	11,789	0-2260m	mixed (inland - unimodal (Oct-Feb), rest - bimodal (March-May, Oct-Dec)	600-2500mm	1960-2010	*JICA* [2013]
77	Yes	River	Tanzania	Ruvu River Basin		**Ruvu River Basin**	19,190	200-1300m	transition unimodal-bimodal (Oct-May, reduced rains in Jan-Feb)		1959-1987	*Mtalo et al.* [2005]
78	Yes	River	Tanzania	Ruvu River Basin		**Ruvu River Basin**	19,190			350-2300mm	1952-2005	*Yanda and Munishi* [2007]
79	Yes	River	Tanzania	Wami River Basin		**Wami River Basin**	40,000	0-2260m	mixed (inland - unimodal (Oct-Feb), rest - bimodal (March-May, Oct-Dec)	600-2500mm	1960-2010	*JICA* [2013]
80	Yes	River	Tanzania	Wami River Basin		**Wami River Basin**	40,000	200-1120m	transition unimodal-bimodal (Oct-May, reduced rains in Jan-Feb)		1960-1983	*Mtalo et al.* [2005]
81	Yes	River	Tanzania	Wami River Basin		**Wami River Basin**	40,000	0-2260m	bimodal (March-June, Nov-Dec)	550-1000mm	1974-2000	*Nobert and Jeremiah* [2012]
82	Yes	River	Tanzania	Zambezi River Basin	Lake Malawi Basin	**Ruhudji River Basin**	500	600-1500m		600-1600mm	1959-1994	*Atwitye* [1999]

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Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
83	Yes	Lake	Transboundary E (Tanzania, Kenya)	Pangani River Basin	Lake Jipe Basin	**Lake Jipe**		900-5895m	bimodal (March-June, Nov-Dec)	500-2000mm	1961-2007	*King et al.* [2009]
84	Yes	River	Transboundary E (Tanzania, Kenya)	Pangani River Basin		**Pangani River Basin**	43,650	900-5895m	bimodal (March-June, Nov-Dec)	500-2000mm	1961-2007	*King et al.* [2009]
85	Yes	River	Transboundary E (Tanzania, Kenya)	Pangani River Basin		**Pangani River Basin**	43,650	900-5895m	bimodal (March-June, Nov-Dec)	500-2000mm	1975-2007	*PBWO/IUCN* [2007]
86	Yes	Lake	Transboundary E (Tanzania, DR Congo, Burundi, Zambia)	Congo Basin	Lake Tanganyika Basin	**Lake Tanganyika**	198,400	770-1750m		800-1400mm	1922-1992	*Nicholson* [1999]
87	Yes	River	Malawi	Lake Chilwa Basin		**Mulunguzi River Basin**	19	1800m		2000mm	1954-1993	*Mbano et al* . [2009]
88	Yes	River	Malawi	Lake Chilwa Basin		**Namadzi River Basin**	27			997mm	1952-1999	*Mbano et al.* [2009]
89	-	River	Malawi	Zambezi River Basin	Lake Malawi Basin	**Luchelemu River Basin**	13		unimodal (December-April)	1300mm	1961-1978	*Mwendera* [1994]
90	Yes	River	Malawi	Zambezi River Basin	Shire River Basin	**Rivirivi River Basin**	748		bimodal (Nov-April, May-Oct)	1000mm	1963-2004	*Chimtengo et al.* [2013]
91	Yes	River	Malawi	Zambezi River Basin	Shire River Basin	**Upper-Shire River Basin**	4,500		unimodal (October-April)	950mm	1976-2006	*Palamuleni et al.* [2011]
92	Yes	Lake	Transboundary E (Malawi, Tanzania, Mozambique)	Zambezi River Basin	Lake Malawi Basin	**Lake Malawi**	126,500				1896-1994	*Calder et al.* [1995]
93	-	Lake	Transboundary E (Malawi, Tanzania, Mozambique)	Zambezi River Basin	Lake Malawi Basin	**Lake Malawi**	126,500		unimodal (Sep-Feb)	1300mm	1900-1980	*Drayton* [1984]
94	Yes	Lake	Transboundary E (Malawi, Tanzania, Mozambique)	Zambezi River Basin	Lake Malawi Basin	**Lake Malawi**	126,500			600-2500mm	1937-1995	*Jury and Gwazantini* [2002]
95	-	Lake	Transboundary E (Malawi, Tanzania, Mozambique)	Zambezi River Basin	Lake Malawi Basin	**Lake Malawi**	126,500		unimodal (Sep-Feb)	1300mm	1900-1980	*Neuland* [1984]
96	Yes	River	Transboundary S (Angola, Botswana, DR Congo, Malawi, Zambia, Zimbabwe, Mozambique, Namibia, Tanzania)	Zambezi River Basin		**Zambezi River Basin**	1,400,000		unimodal (Nov-March)	550-1600mm	1907-2006	*Beilfuss* [2012]
97	Yes	River	Zambia	Zambezi River Basin		**Kafue Flats Basin**	6,500				1940-2010	*Mitchell* [2013]
98	Yes	River	Zambia	Zambezi River Basin		**Kafue River Basin**	6,500		unimodal (October-April)	800mm	1978-2000	*Mumba and Thompson* [2005]
99	Yes[2]	River	Transboundary S (Zambia,Botswana)	Zambezi River Basin		**Zambezi River Basin**	1,400,000				1995-2010	*Jury* [2013]
100	Yes	River	Transboundary S (Zambia,Botswana)	Zambezi River Basin		**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	360,638			857mm	1907-1990	*Conway et al* . [2009]

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Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
101	Yes	River	Transboundary S (Zambia,Botswana)	Zambezi River Basin		**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	360,638			450-560mm	1924-2004	*Mazvimavi and Wolski* [2006]
102	Yes	River	Transboundary S (Angola, Zambia,Botswana)	Zambezi River Basin		**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	360,638				1925-1996	*van Langenhove et al.* [1998]
103	-	Lake	Botswana	Lake Ngami Basin		**Lake Ngami**	3,000				1849-1981	*Shaw* [1983]
104	Yes	River	Botswana	Okavango River Basin		**Okavango Delta Basin**	13,000			450-560mm	1934-2011	*Wolski et al.* [2012]
105	Yes	River	Transboundary S (Angola, Namibia)	Okavango River Basin		**Cubango-Okavango River Basin**	120,000		unimodal (Dec-March)		1950-2005	*Jury* [2010]
106	Yes	River	Transboundary S (Angola, Botswana, Namibia)	Okavango River Basin		**Okavango River Basin**	238,700			739mm	1933-1999	*Conway et al.* [2009]
107	Yes	River	Zimbabwe	Limpopo River Basin		**Insiza River Basin**	3,401	1100-1500m	unimodal (Nov-March)	480mm	1960s-2005 (?)	*Kileshye Onema et al.* [2006]
108	Yes	River	Zimbabwe	Limpopo River Basin		**Mzingwane River Basin**	15,695		unimodal (Nov-March)	360-630mm	1950-2000	*Love et al.* [2010]
109	Yes	River	Zimbabwe	Limpopo River Basin		**Shashe River Basin**	18,991		unimodal (Nov-March)	360-630mm	1950-2000	*Love et al.* [2010]
110	-	River	Zimbabwe	Sabi/Save River Basin	Mtilikwe River Basin	**Mshagashi River Basin**	541				1962-1992	*Lorup et al.* [1998]
111	-	River	Zimbabwe	Sabi/Save River Basin	Mtilikwe River Basin	**Popotekwe River Basin**	1,010				1962-1992	*Lorup et al.* [1998]
112	Yes	River	Zimbabwe	Sabi/Save River Basin	Mtilikwe River Basin	**Roswa River Basin**	197				1962-1992	*Lorup et al.* [1998]
113	Yes	River	Zimbabwe	Sabi/Save River Basin	Mtilikwe River Basin	**Turgwe River Basin**	223				1962-1992	*Lorup et al.* [1998]
114	-	River	Zimbabwe	Sabi/Save River Basin		**Upper-Sabi River Basin**	165			600mm	1955-1978	*du Toit* [1985]
115	-	River	Zimbabwe	Zambezi River Basin		**Nyatsime River Basin**	500				1962-1992	*Lorup et al.* [1998]
116	Yes[2]	River	Lesotho	Orange River Basin		**Lesotho Highland Basin**	30,344	1500-3500m	unimodal (Oct-March)	500-1600mm	1975-1990	*Sene et al.* [1998]
117	Yes	River	South Africa	Berg River Basin	Jonkershoek Valley Basin	**Tierkloof River Basin**	16	280-1530m	unimodal (April-October)	1360-1390mm	1938-2004	*Scott and Prinsloo* [2008]
118	Yes	River	South Africa	Breede River Basin		**Breede River Basin**	12,600				1923-2008	*Lakhraj-Govender* [2010]
119	Yes	River	South Africa	Breede River Basin		**Breede River Basin**	17,951				1950-2009	*Lloyd* [2010]
120	Yes	River	South Africa	Breede River Basin		**Upper-Breede River Basin**	2,046			400-600mm	1960-1999	*Warburton et al.* [2012]
121	Yes[2]	River	South Africa	Limpopo River Basin	Mohlapetsi River Basin	**B71C Quarternary Mohlapetsi Basin**	263	760-2000m	unimodal (October-April)	500-1000mm	1970-2005	*Troy et al.* [2007]

Yes[1] = annual streamflow/water levels referred to but details of change only on other hydrological parameters Yes² = references from otherwise high quality publications with a data record of close to two decades

Ref. Nr.	In 1970-2010 sub set?	Type	Country	Metabasin	Mesobasin	Basin/Lake	Area (km²)	Elevation (masl)	Rainfall Pattern (bimodal = long, short rainy season)	Mean annual precipitation (mm)	Timeframe of study	Reference
122	Yes	River	South Africa	Limpopo River Basin		**Luvuvhu River Basin**	5,940	200-1500m		608mm	1931-2001	*Odiyo* [2011]
123	Yes	River	South Africa	Limpopo River Basin		**Luvuvhu River Basin**	5,940			400-800mm	1960-1999	*Warburton et al.* [2012]
124	Yes	River	South Africa	Limpopo River Basin		**Olifants River Basin**	54,475		unimodal (Nov-March)	630mm	1948-2000	*McCartney et al.* [2004]
125	Yes	River	South Africa	Limpopo River Basin		**Westfalia-D River Basin**	4	280-1530m	unimodal (April-October)	1360-1390mm	1938-2004	*Scott and Prinsloo* [2008]
126	Yes	River	South Africa	Mgeni River Basin		**Mgeni River Basin**	4,349				1951-2008	*Lakhraj-Govender* [2010]
127	Yes	River	South Africa	Mgeni River Basin		**Mgeni River Basin**	4,349			800-1200mm	1960-1999	*Warburton et al.* [2012]
128	Yes	River	South Africa	Orange River Basin		**Vaal River Basin**	196,438				1940-2008	*Lakhraj-Govender* [2010]
129	Yes[2]	River	South Africa	Orange River Basin		**Harts River Basin**	13,127	930-1500m	unimodal (Oct-April)		1990-2010	*Kabanda and Palamuleni* [2013]
130	Yes	River	South Africa	Orange River Basin		**Orange River Basin**	973,000				1927-2008	*Lakhraj-Govender* [2010]
131	-	River	South Africa	Tugela River Basin		**Cathedral Peak Basin**	1		unimodal (October-April)	1519mm	1952-1980	*Zhao et al.* [2012]
132	Yes	River	South Africa	Tugela River Basin		**Tugela River Basin**	29,100				1927-2008	*Lakhraj-Govender* [2010]

ANNEX 2 - Described Hydrological Developments and Attributed Pressures for All Reviewed References

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
1	River	**Abbay River Basin**	+- (mixed, both + and - at different sub-basins)	+- (mixed, both + and - at different sub-basins)		Increased runoff coefficient (1996)	- LoF (1996)	LULCC; CV	LULCC - Deforestation; Agr. Expansion; Degradation through overgrazing (since 1980s) CV - Increased rainfall variability (since 1990s)
2	River	**Abbay River Basin**	+	+	1990s		- LoF (1990s)	LULCC	LULCC - Deforestation; Agr. Expansion; Degradation of land (241% increase of barren land!); Increase of grazing land
3	River	**Abbay River Basin**	+-	+-		+ I (2000) QB (2000)	- LoF (1990s, in lower parts of river)	(Floods, QB: LULCC; LoF: Dams)	(LULCC - Degradation of soils (since 1990s) Dams - Construction of weir at Lake Tana outflow (for irrigation, 1996))
4	River	**Birr River Basin**	-	+	1960s / 1970s			LULCC; CV	LULCC - Deforestation, Degradation by overgrazing (1990s) CV - Period of decreased rainfall (1970s)
5	River	**Chemoga River Basin**	-	-	1960s		- LoF (1960s)	LULCC; WW; CV	LULCC - Agr. Expansion, Land degradation through overgrazing, Afforestation (eucalyptus plantations) WW - Mainly dry season/year abstraction for domestic use and lifestock CV - Decreasing rainfall from 1960s til 1980s, increasing since then
6	River	**Gilgel Abbay River Basin**	+-	+-					
7	River	**Hara River Basin**	+	+	1980s	+ I (1980s)		LULCC	LULCC - Urbanization (since 1970s); Deforestation (intensified since 1980s)
8	River	**Jedeb River Basin**	-	-	1980s (2000)	+ I (1990s) QB (1990s)	- LoF (since 1980s)	LULCC; WW	LULCC - Agr. Expansion (incl. into sensitive hillside zones), Degradation through poor farming practices; Small scale afforestation with eucalyptus (mostly til 1990s) WW - Agr. Intensification (Irrigation, since late 1990s)
9	River	**Koga River Basin**	+-	+-		+ O (1960s)	- LoF (1960s, upper part of river)	LULCC; CC	LULCC - Agr.Expansion (incl. into sensitive hillside zones), Deforestation (since 1960s) CC - Decreasing rainfall (since 1975)
10	River	**Koga River Basin**	+	+	1960s			LULCC; CV	LULCC - Agr. Expansion, Deforestation (1960s), Soil degradation by overgrazing (1990s) CV - Period of decreased rainfall (1970s)
11	River	**Lake Tana Basin**	+- / (≈)	+- / (≈)	1996 (≈)	- I, O (1996)	+ LoF (1996)	Dams	Dams - Hydropower (1996)
12	River	**Upper-Didesa River Basin**	-	-	1990s			LULCC; CV	LULCC - Deforestation, Degradation by overgrazing (1990s) CV - Period of decreased rainfall (1970s)
13	River	**Upper-Gilgel Abbay River Basin**	-	-	1973 (2000s)	+ I (1982)	- LoF (1982 / 2000)	LULCC, CC	LULCC - Deforestation, Agr. Expansion, Degradation through overgrazing and poor farming practices CC - Decreasing rainfall (since 1973)
14	Lake	**Lake Tana**	+-	+-				CV	CV - Rainfall variability
15	River	**Hare River Basin**	-	-	1990s		- LoF (1990s)	WW; LULCC	WW - Agr. Expansion & Intensification (Irrigation of apple orchards); Population increase LULCC - Agr. Expansion, Deforestation (since 1980s)
16	Lake	**Lake Abiyata**	-	-	1970s			WW	WW - Agr. Intensification (Irrigation); Soda-Ash industry

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
17	Lake	**Lake Basaka**	+	+	1970s (2007)			LULCC; Tectonic	LULCC - Agr. Expansion & Intensification (excess water of irrigation projects discharges into lake); Deforestation Tectonic - Recent earthquakes, lava flows, emergence of underground hot springs affect basin hydrology
18	Lake	**Lake Chew Bahir (formerly: Lake Stefanie)**	-	n.a. (data ends 1980, from 1970 to 1980 +-)	1970s			CV	CV - Rainfall variability
19	Lake	**Lake Langano**	-	-	1970s			WW; Tectonic	WW - Agr. Intensification (Irrigation) Tectonic - Balancing abstractions though underground springs
20	Lake	**Lake Shala**	-	-	1970s			WW	WW - Agr. Intensification (Irrigation); Soda-Ash industry
21	Lake	**Lake Ziway**	+-	+-				WW	WW - Agr. Intensification (Irrigation) - both large-scale abstractions & excess irrigation leading to capillary rise
22	River	**Blue Nile Basin**	-	n.a. (data ends 1984)	1960s			CC	CC - Decreasing rainfall (not significant, since 1960s)
23	Lake	**Lake Turkana**	+-	n.a. (data ends 1980, from 1970 to 1980 -)				CV	CV - Rainfall variability
24	River	**Athi-Sabaki River Basin**	+-	+-		+ O (1987)		CV (floods: LULCC; CC)	CV - Increased variability of rainfall (LULCC - Agr.Expansion, Deforestation (since 1950s, marked increase in 1980s) CC - Increased rainfall (since late 1980s))
25	River	**Burguret River Basin**	-	-	1970s	+ O (1980s, since 1995 again slightly reduced)	- LoF (1995) + NoF (1990s, tributary rivers)	WW; LULCC	WW - Population increase (since 1960s); Agr. Intensification (Irrigation for commercial horticulture, since 1995) LULCC - Agr. Expansion, Deforestation, Urbanization (since 1960s)
26	River	**Burguret River Basin**	-	-	1980s		- LoF (1980s) + NoF (tributary rivers)	WW; LULCC	WW - Agr. Intensification, Population increase, Increased urban demand, Increased lifestock numbers LULCC - Agr. Expansion; Degradation through overgrazing
27	River	**Likii River Basin**	-	+-	1970s	+ O (1980s)	- LoF (1980s, since 1990 slight increase) + NoF (1980s, tributary rivers)	WW; LULCC	WW - Population increase (since 1960s); Agr. Intensification (Irrigation for commercial horticulture, since 1995) LULCC - Agr. Expansion, Deforestation, Urbanization (since 1960s)
28	River	**Nanyuki River Basin**	-	-	1980s		- LoF (1980s) + NoF (tributary rivers)	WW; LULCC	WW - Agr. Intensification, Population increase, Increased urban demand, Increased lifestock numbers LULCC - Agr. Expansion; Degradation through overgrazing
29	River	**Naro Moru River Basin**	+-	+-			- LoF (1980s) + NoF (1990s, lower reaches of main river)	WW; LULCC	WW - Agr. Intensification (Irrigation), Population increase LULCC - Agr. Expansion & Intensification
30	River	**Naro Moru River Basin**	-	-	1960s		+ NoF (1960s, lower reaches of main river)	WW; LULCC	WW - Agr. Expansion & Intensification (incl. Commercial horticulture); Increased domestic demand LULCC - Agr. Expansion

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
31	River	**Naro Moru River Basin**	-	-	1980s		- LoF (1980s) + NoF (tributary rivers)	WW; LULCC	WW - Agr. Intensification, Population increase, Increased urban demand, Increased lifestock numbers LULCC - Agr. Expansion; Degradation through overgrazing
32	River	**Timau River Basin**	-	-	1960s (1990s)	+ O (1995)	- LoF (1995)	WW; LULCC	WW - Population increase (since 1960s); Agr. Intensification (Irrigation for commercial horticulture, since 1995) LULCC - Agr. Expansion, Deforestation, Urbanization (since 1960s)
33	River	**Upper Ewaso Ng'iro North River Basin**	no details on annual flow	no details on annual flow			- LoF (1979)	LULCC; WW; CV	LULCC - Agr. Expansion (since 1960s); Degradation through overgrazing, Sand mining (since 1970s) WW - Agr. Intensification (Irrigation), Population increase, Increase of lifestock numbers (since 1970s) CV - Rainfall variability
34	River	**Nyando River Basin**	no details on annual flow	no details on annual flow		+ I (2000s) QB (2000s)		LULCC; CV	LULCC - Agr. Expansion, Deforestation CV - Variability of rainfaill
35	River	**Nzoia River Basin**	-	n.a. (data ends 1985)	1966			LULCC; CV; WW	LULCC - Agr. Expansion, Deforestation CV - High rainfall variability, no significant trend but upland slight increase, lowland slight decrease WW - Population increase
36	Lake	**Lake Elmenteita**	-	n.a. (data ends 1987, from 1970 to 1987 -)	1963		- LoF (1970s, inflowing rivers) + NoF (1970s, inflowing river)	LULCC; WW; Dams	LULCC - Agr. Expansion; Deforestation WW - Population growth; Increased livestock numbers Dams - Damming of inflowing rivers (reduced flow)
37	Lake	**Lake Elmenteita**	-	n.a. (data ends 1984, from 1970 to 1984 -)	1970		+ NoF (1970s, inflowing rivers)	LULCC; CV	LULCC - Deforestation & Agr. Expansion; Population growth CV - Increasing temperatures & Decreasing Rainfall
38	River	**Lake Elmenteita Basin**	-	n.a. (data ends 1987)	1960s		- LoF (1970s, tributary rivers)	WW; LULCC; Dams; CC	WW - Population increase, Increased lifestock numbers (since 1960s) LULCC - Agr. Expansion, Deforestation (since 1960s) Dams - Construction of many small dams along tributaries (since 1960s) CC - Increase of temperature by 3°C since 1960, statistically not significant decreasing rainfall trend
39	River	**Lake Elmenteita Basin**	-	n.a. (data ends 1980)	1960s		+ NoF (tributary rivers)	CC; LULCC	WW - Population increase, Agr. Expansion, Increased lifestock numbers (since 1960s) LULCC - Agr. Expansion, Deforestation (since 1960s) Dams - Construction of many small dams and reservoirs in tributaries (since 1960s) CC - Increasing temperatures; Decreasing rainfall (not significant) (since 1960s)
40	Lake	**Lake Naivasha**	-	-	1980s (2000)			WW; CC	WW - Agr. Intensification (Irrigation, commercial horticulture & flowers); Population growth CC - Decreasing rainfall (since 1960s)
41	Lake	**Lake Naivasha**	-	-	1905 (1983)			WW	WW - Agr. Intensification (Irrigation); Population growth
42	Lake	**Lake Naivasha**	+-	n.a. (data ends 1980, from 1970 to 1980 -)				CV	CV - Rainfall variability
43	Lake	**Lake Nakuru**	-	-	1970s	+ I (1970s)	- LoF	LULCC; WW	LULCC - Deforestation; Agr.Expansion; Urbanization WW - Increased urban water demand
44	River	**Lake Nakuru Basin**	-	-	1970s	+ I (1970s)	- LoF	LULCC; WW	LULCC - Agr. Expansion, Deforestation (since 1970s) WW - Population increase / Urban water demand (since 1985)

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
45	River	**Njoro River Basin**	(+)	(+)	1980s	QB		LULCC	LULCC - Deforestation, Agr. Expansion
46	River	**Tana River Basin**	-	-	1980s	- O, I (1988, below dam)	+ LoF (1988, below dam)	Dams, WW, LULCC	Dams - Two large dams for hydropower (1968, 1988) WW - Urban water demand (= Water transfers to Athi-Sabaki Basin) LULCC - Agr. Expansion (inc. into sensitive zones), Deforestation (since 1960s)
47	Lake	**Lake Victoria**	-	-	1965 (2000)			CC; Dams	CC - Decreasing rainfall Dams - Damming of inflowing rivers (irrigation, hydropower)
48	Lake	**Lake Victoria**	+-	n.a. (data ends 1980, from 1960 to 1980 +)				CV	CV - Rainfall variability
49	Lake&River	**Lake Victoria**	-	-	1960s / 1970s	+ O (1990s)		LULCC; CC	LULCC - Deforestation; Agr. Expansion; Urbanization CC - Increased temperatures & Increased variability of rainfall
50	River	**Lake Victoria Basin**	+	+	1990s			CC	CC - Increasing rainfall (since mid-1980s); Increased rainfall variability (since 1990s)
51	River&Lake	**Lake Victoria Basin**	no details on annual flow	no details on annual flow		+ O, I (1970s)		LULCC	LULCC - Agr.Expansion, Deforestation, Urbanization
52	River	**Mara River Basin**	no details on annual flow	no details on annual flow		+ O, I (1970s) QB (1970s)		LULCC	LULCC - Agr.Expansion, Deforestation, Degradation through overgrazing (since 1970s)
53	River	**Mara River Basin**	no details on annual flow	no details on annual flow		+ I (2000s, in sub-basins)	- LoF (2000s)	LULCC; CV	LULCC - Agr.Expansion, Deforestation CV - High rainfall variability; Decreasing rainfall (not significant); Increasing short rainy season rainfall (since 1990s)
54	River	**Nyangores River Basin**	no details on annual flow	no details on annual flow		+ I (1990s)	- LoF (1990s)	LULCC	LULCC - Agr. Expansion, Deforestation
55	River	**White Nile Basin**	+	n.a. (data ends 1984, from 1970 to 1984 a slight decline at some stations)	1950s			CV, Dams	CV - Continous flow increase 1950s-1966s correlates with period of increased rainfall (no general trend for longer period) Dams - Afterwards stabilization of flow on high level most likely caused by dams constructed for irrigation in 1960s (dams constructed in 1920s didn't show effect on flow)
56	River	**Upper-Ssezibwa River Basin**	-	-	1990s			CV	CC - Increasing temperatures Other causes not considered
57	River	**Luengera River Basin**	-	-	1970s		- LoF (1970s)	CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1970s, since 1980s illegal logging in forest reserves); Agr. Expansion (encroaching sensitive riparian zones and hillsides); Degradation through poor farming practices (since 1980s)
58	River	**Mkomazi River Basin**	+	n.a. (data ends 1984, from 1970 to 1984 continued slight increase)	1970s		- LoF (1970s)	CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1970s, since 1980s illegal logging in forest reserves); Agr. Expansion (encroaching sensitive riparian zones and hillsides); Degradation through poor farming practices (since 1980s)
59	River	**Pangani River Basin**	no details on annual flow	no details on annual flow	1960s / 1970s	+ I (1970s)	- LoF (1970s)	CV; LULCC	CV - Decadal variability of rainfall, with high rainfall years in late 1970s/1980s LULCC - Agr. Expansion, Deforestation (since 1970s)

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
60	River	**Sigi River Basin**	(-)	(-)	1970s		- LoF (1970s)	CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1970s, since 1980s illegal logging in forest reserves); Agr. Expansion (encroaching sensitive riparian zones and hillsides); Degradation through poor farming practices (since 1980s)
61	River	**Sigi River Basin**	no details on annual flow	no details on annual flow	1960s / 1970s	+ I (1970s)	- LoF (1970s)	CV; LULCC	CV - Decadal variability of rainfall, with high rainfall years in late 1970s/1980s LULCC - Agr. Expansion, Deforestation (since 1970s)
62	River	**Sigi River Basin**	(-)	(-)	1960s	QB (1970s)	- LoF (1960s)	LULCC; CC	LULCC - Deforestation; Agr. Expansion (encroachment of sensitive riparian zones and hillsides, mainly 1960/70s, 1995 -2000) CC - Increasing rainfall (not significant, since 1965)
63	River	**Umba River Basin**	no details on annual flow	no details on annual flow		+ I (1970s)	- LoF (1970s)	CV; LULCC	CV - Decadal variability of rainfall, with high rainfall years in late 1970s/1980s LULCC - Agr. Expansion, Deforestation (since 1970s)
64	Lake	**Lake Rukwa**	+-	+-					
65	Lake	**Lake Rukwa**	+-	+-				CV	CV - Rainfall variability
66	River	**Great Ruaha River Basin**	-	-			+ NoF (1993, cessation of main river)	WW	WW - Agr.Expansion & Intensification (commercial wet-rice agriculture, since 1990s)
67	River	**Great Ruaha River Basin**	-	-			+ NoF (1990s, cessation of tributaries and main river)	WW	WW - Agr.Expansion & Intensification (commercial wet-rice agriculture, since 1990s)
68	River	**Great Ruaha River Basin**	-	-			- LoF (1970, tributary rivers) + NoF (1990s, cessation of tributaries and main river)	WW; LULCC	WW - Agr.Expansion & Intensification (commercial wet-rice agriculture, since 1990s) LULCC - Agr. Expansion, Degradation through overgrazing and poor agr.practices (in upper parts of catchment)
69	River	**Mkoji River Basin**	-	-	1980s (2002)		- LoF (1980s) + NoF (1980s, cessation of tributaries and main river)	WW	WW - Agr. Expansion (since 1980s); Agr. Intensification (Irrigation, improved irrigation schemes with concrete canals since 2002)
70	River	**Usangu River Basin**	-	-	1980s	+ I (1980s)	+ NoF (1994, cessation of main river)	WW; LULCC; CC	WW - Agr. Intensification (wet-rice agriculture, increased dry-season irrigation of other crops) LULCC - Degradation through overgrazing CC - Slightly decreasing rainfall (not significant)
71	River	**Usangu River Basin**	-	-	1989		- LoF (1989) + NoF (1993, cessation of main river)	WW; LULCC; CC	WW - Agr. Intensification (wet-rice agriculture, irrigation in dry season), Population increase, Increased lifestock numbers (since 1990s) LULCC - Agr. Expansion, Deforestation, Degradation through overgrazing CC - Slightly decreasing rainfall; Increased dry spells and longer dry season; Increased rainfall variability (all since 1990s)
72	River	**Usangu Wetland Basin**	-	-	1980s	+ I (1985)	- LoF (1960s) + NoF (1993, cessation of main river)	WW; LULCC	WW - Agr. Expansion & Intensification (wet-rice agriculture); Population growth; Increased lifestock numbers LULCC - Agr. Expansion, Deforestation, Degradation through overgrazing

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
73	River	**Kilombero River Basin**	+- (mixed, both + and - at different sub-basins)	n.a. (data ends in 1983)				CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1950s); Fires; Agr. Expansion (encroaching sensitive riparian zones and hillsides)
74	River	**Rufiji River Basin**	-	-	1980s	+ O (1980s, above dam)		Dams; LULCC; CC	Dams - Three larger dams for hydropower (in 1980s) LULCC - Deforestation; Agr. Expansion CC - Increased rainfall trend over upper basin region
75	River	**Ngerengere River Basin**	-	-	1990s	- O, I (1983)	- LoF + NoF (increased cessation of main river, below dam)	CC; Dam; LULCC	CC - Increased length of dry spells Dams - For urban water demand (1983) LULCC - Deforestation; Agr. Expansion
76	River	**Ruvu River Basin**	-	-	1980s		- LoF (1970s) + NoF (1980s, increased cessation of main river)	LULCC; CC; Dams; WW	LULCC - Deforestation; Agr. Expansion (since 1960s) CC - Slightly decreasing rainfll (not significant), Increasing temperatures Dams - Construction of large dam (for urban water supply, in 1983) WW - (Illegal) abstraction for irrigation CV - Increased rainfall variability (both temporal and spatial), insignificantly decreased rainfall trend and slightly increased temperature since 1965
77	River	**Ruvu River Basin**	-	-	1960s		- LoF (1970s)	CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1970s, since 1980s illegal logging in forest reserves); Agr. Expansion (encroaching sensitive riparian zones and hillsides); Degradation through poor farming practices (since 1980s)
78	River	**Ruvu River Basin**	-	-	1960s	QB (1970s)	- LoF (1970s)	LULCC; CC	LULCC - Deforestation; Agr. Expansion (encroachment of sensitive riparian zones and hillsides, mainly 1960/70s, 1995 -2000) CC - Increasing rainfall (not significant, since 1965)
79	River	**Wami River Basin**	+-	+-					
80	River	**Wami River Basin**	-	-	1960s		- LoF (1970s)	CV; LULCC	CV - Increased rainfall variability LULCC - Deforestation (large extent in 1970s, since 1980s illegal logging in forest reserves); Agr. Expansion (encroaching sensitive riparian zones and hillsides); Degradation through poor farming practices (since 1980s)
81	River	**Wami River Basin**	-	-	1980s	Increased runoff coefficient		LULCC	LULCC - Deforestation; Agr. Expansion; Urbanization
82	River	**Ruhudji River Basin**	+-	+-					
83	Lake	**Lake Jipe**	-	-	1970s		- LoF	WW	WW - Agr. Expansion & Intensification (Irrigation), Population growth
84	River	**Pangani River Basin**	≈ (- = upstream of dam, ≈ downstream of dam)	≈ (- = upstream of dam, ≈ downstream of dam)	1965 / 1970s	- O, I (1965)	+ NoF (1970s, tributary rivers)	Dams; WW	Dams - Two large dams constructed in 1957/65 for hydropower and irrigation WW - Agr. Expansion & Intensification, Population increase, Increased urban & industrial water demand, Water abstraction for power generation (Hale Falls - no dam but abstraction)

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
85	River	**Pangani River Basin**	≈ (- = upstream of dam, ≈ downstream of dam)	≈ (- = upstream of dam, ≈ downstream of dam)	1970s		+ NoF (1970s, tributary rivers)	WW; Dams; LULCC; CC	WW - Agr. Expansion & Intensification, Population increase, Increased urban & industrial water demand, Water abstraction for power generation (Hale Falls - no dam but abstraction) Dams - Two large dams constructed in 1957/65 for hydropower and irrigation LULCC - Agr. Expansion, Deforestation, Urbanization CC - Decreasing rainfall; Increasing temperatures (since 1960s)
86	Lake	**Lake Tanganyika**	+-	+-				CV	CV - Rainfall variability
87	River	**Mulunguzi River Basin**	-	-	1950s (1980s)		- LoF (1990)	CC; LULCC	CC - Decreasing rainfall LULCC - Afforestation (Commercial pine plantations, in 1960s)
88	River	**Namadzi River Basin**	-	-	1950s (1990s)			LULCC; CC	LULCC - Afforestation (Commercial pine & eucalyptus plantations, mainly in 1960s but massive increase of area in 1990s) CC - Decreasing rainfall (trend not significat)
89	River	**Luchelemu River Basin**	(+-)	n.a. (data ends in 1978)			- LoF (1969)	LULCC	LULCC - Agr. Expansion, Deforestation (since 1960s)
90	River	**Rivirivi River Basin**	-	-	1980s (2000)	+ O, I (1980s)	- LoF (1980s) + NoF (1980s)	LULCC; WW	LULCC - Agr.Expansion, Deforestation (since 1990s) WW - Agr. Expansion & Intensification, Increased urban water demand (Ntcheu Town) (since 1970s); Abstraction for irrigation storage reservoir (established 1994), especially since introduced improved pumps and canals (2000)
91	River	**Upper-Shire River Basin**	+	+	1980s	QB (1990s)		LULCC, CV	LULCC - Deforestation, Agr. Expansion, Urbanization, Population increase CV - Variability of rainfall
92	Lake	**Lake Malawi**	+	+-	1905	QB (1990s)		CC; LULCC	CC - Increasing rainfall LULCC - Deforestation
93	Lake	**Lake Malawi**	+	n.a. (data ends in 1980, from 1970 to 1980 massive +)	1915	QB (1970s, inflowing rivers)		CC; CV	CC - Increased rainfall CV - Sporadic seasons with exceptionally high rainfall
94	Lake	**Lake Malawi**	+-	+-				CV	CV - Rainfall variability
95	Lake	**Lake Malawi**	+-	n.a. (data ends 1980, from 1970 to 1980 +)				CC	CC - Increasing rainfall
96	River	**Zambezi River Basin**	≈ (mixed both increasing and decreasing 20-year periods) = upstream of dams, ≈ = downstream of dams)	≈ (- = upstream of dam, ≈ downstream of dams)	1958 (1980s)	- O, I (1958)	+ LoF (1958, below dam)	Dams, CV	Dams - Construction of three large dams for hydropower in 1950s-1980s CV - Long term variability of rainfall
97	River	**Kafue Flats Basin**	≈ (- = upstream of dam, ≈ downstream of dam)	≈ (- = upstream of dam, ≈ downstream of dam)	1970s	- O, I (1978)		Dams; CC	Dams - Construction of three large dams (for hydropower, in 1959, 1971, 1978) CC - Decreased rainfall trend in upper river basin (since 1970s - headwaters for Kafue river are outside of this basin)

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
98	River	**Kafue River Basin**	≈ (gauge is downstream of dams)	≈ (gauge is downstream of dams)	1978	- O, I (1978)	+ LoF (1978)	Dams	Dams - Construction of two large dams (for hydropower, 1971/78)
99	River	**Zambezi River Basin**	(+) (gauge upstream of dams)	(+) (gauge upstream of dams)	2000			CV	CV - Increasing rainfall
100	River	**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	+- (gauge is upstream of dam)	+- (gauge is upstream of dam)					
101	River	**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	+- (mixed - both increasing and decreasing 20-year periods, gauge is upstream of dam)	- (gauge is upstream of dam)			- LoF (1979)	CV	CV - Long term variability of rainfall (17.5, respective 40/48 year cycle)
102	River	**Zambezi River Basin (Upstream Dam = Victoria Falls Gauge)**	+- (mixed - both increasing and decreasing 20-year periods, gauge is upstream of dam)	- (gauge is upstream of dam)	1980s			LULCC; CC	LULCC - Abandonment of agriculture and return of indigenous land cover due to civil war (1975) CC - Indications of large-scale climatic pattern of decreasing rainfall (no validation possible because of limited data availability due to civil war)
103	Lake	**Lake Ngami**	+-	n.a. (data ends 1981, from 1970 to 1981 +-)				CV	CV - Rainfall variability
104	River	**Okavango Delta Basin**	+-	+-			- LoF (1979)	CV	CV - Variability of rainfall
105	River	**Cubango-Okavango River Basin**	-	-	1950s			CC; CV	CC - Declining precipitation over headwater basins CV - Large-scale rainfall variability (ENSO)
106	River	**Okavango River Basin**	+	-					(Probably CV plus LULCC, but data not sufficient to establish significant assertions)
107	River	**Insiza River Basin**	≈	≈	1966	- O (1966)	+ LoF (1966)	Dams	Dams - Construction of three larger dams/reservoirs for irrigation in 1966, 1967 and 1973
108	River	**Mzingwane River Basin**	-	-	1980s		- LoF (1980s) + NoF (1980, tributary rivers)	CC; WW; Dams; LULCC	CC - Decreasing rainfall; Increasing temperatures WW - Population growth; Agr. Extension Dams - Small-scale dams for irrigation along tribuaties LULCC - Deforestation; Agr. Expansion
109	River	**Shashe River Basin**	-	-	1980s		- LoF (1980s) + NoF (1980, tributary rivers)	CC; WW; Dams; LULCC	CC - Decreasing rainfall; Increasing temperatures WW - Population growth; Agr. Extension Dams - Small-scale dams for irrigation along tribuaties LULCC - Deforestation; Agr. Expansion
110	River	**Mshagashi River Basin**	+-	n.a. (no detailed details comparing 1970-1991)					
111	River	**Popotekwe River Basin**	+	n.a. (no detailed details comparing 1970-1991)	1970s			LULCC	LULCC - Deforestation; Agr. Expansion

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
112	River	**Roswa River Basin**	-	-	1980s			WW	WW - Population increase
113	River	**Turgwe River Basin**	-	-	1980s			LULCC	LULCC - Drainage of swamps/wetlands; Deforestation; Agr. Expansion
114	River	**Upper-Sabi River Basin**	+-	n.a. (data ends 1978, since late 1960s to 1978 -)		+ I (early 1970s)		(Floods: LULCC)	(LULCC - Deforestation, Agr. Expansion, Increasing livestock numbers (all since 1940s already, increasing towards 1980s))
115	River	**Nyatsime River Basin**	-	n.a. (no detailed details comparing 1970-1991)	1970s			WW; LULCC	WW - Population growth LULCC - Drainage of wetlands; Agr. Expansion
116	River	**Lesotho Highland Basin**	(+-)	(+-)				CV	CV - Climatic variability
117	River	**Tierkloof River Basin**	+-	+-			(+ NoF (period in 1960-70s))	(NoF: LULCC)	(LULCC - Afforestation of 40-100 % of basin in 1956 (commercial pine & eucalyptus plantations))
118	River	**Breede River Basin**	-	-	1970s			WW; CC	WW - Not specified CC - Despite Increasing rainfall
119	River	**Breede River Basin**	+-	+-				WW; Dams; CC	WW - Agr.Expansion & Intensification (grape industry) Dams - Construction of two large dams in 1960s, and many smaller dams since then CC - Significant increase in temperature and not significant increase in rainfall (since 1960s)
120	River	**Upper-Breede River Basin**	-	-	1960s			WW, LULCC	WW - Agr. Intensification (commercial orchards and vineyards) LULCC - Agr. Expansion(especially in middle reach of basin)
121	River	**B71C Quarternary Mohlapetsi Basin**	(+)	(+)	1990s			LULCC; CV	LULCC - Agr.Expansion, Drainage of wetlands, Urbanization (since 1996) CV - Extreme high rainfall in 2000, possibly causing recharge of regional water table and thus changed hydrological regime
122	River	**Luvuvhu River Basin**	+- (mixed, both + and - at different gauges)	+- (mixed, both + and - at different gauges)		+ O (1970s / 1990s)	'- LoF (1970s / 1990s)	CC; LULCC; Dams	CC - Decreasing rainfall trend since 1960s; Increased drought occurence LULCC - Upland Afforestation, Agr. Expansion, Degradation through overgrazing Dams - Several small dams/reservoirs were built along tributaries in the basin since the 1960s
123	River	**Luvuvhu River Basin**	+-	+-			- LoF (upper reaches of main river)	(Lof: LULCC)	(LULCC - Afforestation (commercial plantations in upland); probably compensated further downstream by increased runoff through overgrazing and agr. Expansion)
124	River	**Olifants River Basin**	+-	+-					
125	River	**Westfalia-D River Basin**	+-	+-			'(+ NoF (period in 1960-70s))		
126	River	**Mgeni River Basin**	-	-	1950s (1970s)			CC	CC - Decreasing rainfall WW - Not specified Dams - Not specified

Ref. Nr.	Type	Basin/Lake	Trend in annual flow / water level within entire study time frame (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Trend in annual flow / water level in 1970-2010 (+ = increase - = decrease +- = no trend ≈ = artificial regime)	Change Point / Decade (brackets = further marked amplification of trend)	Flood Occurrence, Flood Intensity and Basin Response (O = flood occurrence, I = flood intensity, QB = quicker basin response, + = increase, - = decrease, change point)	Low Flow and No Flow (LoF = low flow, NoF = no flow, + = increase, - = decrease, change point)	Attributed Pressures (CC = climate change, CV = climate variability, LULCC = land use land cover change, WW = water withdrawal, D = dams)	Details on Manifestation of Pressure
127	River	**Mgeni River Basin**	-	-	1960s	- O, I (1960s, below dams)	+ LoF (below dams) - NoF (below dams)	WW; LULCC; Dams	WW - Agr. Intensification (commercial sugarcane schemes), Urban water demand (since 1960s) LULCC - Afforestation (pine plantations), Urbanization (Durban) (since 1950s) Dams - Four large dams for urban water supply, several hundred small dams for irrigation (since 1960s)
128	River	**Vaal River Basin**	-	-	1940s (1970s)			CC; WW; Dams	CC - Decreasing rainfall WW - Not specified Dams - Not specified
129	River	**Harts River Basin**	(+)	(+)	2000			LULCC; CV	LULCC - Agr. Expansion, Deforestation, Massive increase of barren land (since 2000s) CV - Statistically not significant increase of precipitation (since 1990s)
130	River	**Orange River Basin**	+	+-	1930s			CC	CC - Increasing rainfall
131	River	**Cathedral Peak Basin**	-	n.a. (data ends 1980)	1966			LULCC	LULCC - Afforestation of 80% of basin area (commercial pine plantation, in 1958)
132	River	**Tugela River Basin**	-	-	1930s			CC; WW; Dams	CC - Decreasing rainfall WW - Transfer scheme Dams - Not specified

ANNEX 3 - Overview of Selected Developments in Hydrological Parameters and Associated Drainage Basins

(1970-2010 subset)

Parameter	Development	Magnitude / Category	Count of References	River Basin Names (in sequential order of Ref.Nr.)	Rivers by Reference Numbers	Lake Names (in sequential order of Ref.Nr.)	Lakes by Reference Numbers
annual discharge / lake water level	no details on annual discharge	-	**9**	**Upper Ewaso Ng'iro North, Nyando, Lake Victoria, Mara, Mara, Nyangores, Pangani, Sigi, Umba**	**33, 34, 51, 52, 53, 54, 59, 61, 63**		
	no trend	-	**26**	**Abbay, Abbay, Gilgel Abbay, Koga, Athi-Sabaki, Likii, Naro Moru, Wami, Ruhudji, Zambezi, Okavango Delta, Lesotho Highland, Tierkloof, Breede, Luvuvhu, Luvuvhu, Olifants, Westfalia-D, Orange**	**1, 3, 6, 9, 24, 27, 29, 79, 82, 100, 104, 116, 117, 119, 122, 123, 124, 125, 139**	**Lake Tana, Lake Ziway, Lake Rukwa, Lake Rukwa, Lake Tanganyika, Lake Malawi. Lake Malawi**	**14,21, 64, 65, 86, 92, 94**
	artificial regime	-	**7**	**Lake Tana, Pangani, Pangani, Zambezi, Kafue Flats, Kafue River, Insiza**	**11, 84, 85, 96, 97, 98, 107**		
	increased annual flow / water level	< 10%	**1**	**Njoro**	**45**		
		10 - 49 %	**3**	**Abba, Birr, Koga**	**2, 4, 10**		
		50-100%	**2**	**Zambezi, B71C Mohlapetsi**	**99, 121**		
		> 100 %	**1**			**Lake Basaka**	**17 (366%)**
		no details	**4**	**Hara Swamp, Lake Victoria, Upper-Shire, Harts**	**7, 50, 91, 129**		
		TOTAL	***11***				
	decreased annual flow / water level	< 10%	**3**	**Wami**	**81**	**Lake Naivasha, Lake Victoria**	**41, 49**
		10 - 49 %	**22**	**Chemoga, Upper-Didesa, Upper-Gilgel Abbay, Burguret, Naro Moru, Timau, Upper-Ssezibwa, Great Ruaha, Usangu Wetland, Ngerengere, Ruvu, Zambezi, Cubango-Okavango, Okavango, Turgwell, Breede, Upper-Breede, Mgeni, Tugela**	**5, 12, 13, 25, 30, 32, 56, 66, 72, 75, 78, 101, 105, 106, 113, 118, 120, 127, 132**	**Lake Abiyata, Lake Langano, Lake Shala**	**16, 19, 20**
		50-100%	**9**	**Great Ruaha, Great Ruaha, Usangu River, Usangu River, Roswa, Mgeni, Vaal**	**67, 68, 70, 71, 112, 126, 128**	**Lake Nakuru, Lake Jipe**	**43, 83**
		> 100 %	**1**			**Lake Naivasha**	**40 (130%)**
		no details	**22**	**Jedeb, Hare, Burguret, Nanyuki, Nanyuki, Naro Moru, Lake Nakuru, Tana, Luengera, Sigi, Sigi, Mkoji, Rufiji, Ruvu, Ruvu, Wami, Mulunguzi, Namadzi, Rivirivi, Zambezi, Mzingwane, Shashe**	**8, 15, 26, 28, 31, 44, 46, 57, 60, 62, 69, 74, 76, 77, 80, 87, 88, 90, 102, 108, 109**	**Lake Victoria**	**47**
		TOTAL	***57***				

ANNEX 4.1 - Temporal Distribution of Pressures Attributed to Increased Annual Flow / Water Levels
(1970-2010 subset)

Increased annual flow / water level (11 References)		1970s			1980s			1990s			2000s			TOTAL COUNT
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (24)	Agricultural expansion	**17**	**10**	**2**		**45, 91**	**2**		**2, 121**	**2**		**129**	**1**	**7**
	Agricultural intensification + Type	**17sugarcane**		**1**										**1**
	Agricultural mismanagement + Type	**17excess irrigation water from nearby**	**4og**	**2**					**2og, 10og**	**2**	**17excess irrigation water from nearby**		**1**	**5**
	Deforestation	**17**	**4, 10**	**2**		**7, 45, 91**	**3**		**2**	**1**		**129**	**1**	**7**
	Afforestation													
	Drainage of wetlands								**121**	**1**				**1**
	Urbanization		**7**	**1**		**91**	**1**		**121**	**1**				**3**
	Industries + Type!													
CC/CV (9)	Increased rainfall								**50**	**1**				**1**
	Decreased rainfall													
	Increased variability of rainfall		**4, 10**	**2**		**91**	**1**		**50, 121**	**2**		**99, 121, 129**	**3**	**8**
	Increased temperature													

Key to abbreviations: og = overgrazing

WW or **Dams** were not reported as an attributed pressure for increasing annual flow/water levels by any reference

ANNEX 4.2 - Spatial Distribution of Pressures Attributed to Increased Annual Flow / Water Levels
(1970-2010 subset)

Increased annual flow / water level (11 References)		Eastern Africa (n=79)			Southern Africa (n=31)		
Pressure	**Pressure - Manifestation**	**Lakes & Rivers by Ref. Nr.**	Ref. - **COUNT**	Ref. - **% of n**	**Rivers by Ref. Nr.***	Ref. - **COUNT**	Ref. - **% of n**
LULCC	Agricultural expansion	**2, 10, 17, 45, 91**	**5**	**6**	**121, 129**	**2**	**6**
	Agricultural intensification + Type	**17**	**1**	**1**			
	Agricultural mismanagement + Type	**2og, 4og, 10og, 17excessirrigation**	**4**	**5**			
	Deforestation	**2, 4, 7, 10, 17, 45, 91**	**7**	**9**	**129**	**1**	**3**
	Drainage of wetlands				**121**	**1**	**3**
	Urbanization	**7, 91**	**2**	**3**	**121**	**1**	**3**
CC/CV	Increased rainfall	**50**	**1**	**1**			
	Increased variability of rainfall	**4, 10, 50, 91**	**4**	**5**	**99, 121, 129**	**3**	**10**

Key to abbreviations: og = overgrazing

WW or **Dams** were not reported as an attributed pressure for increasing annual flow/water levels by any reference

* No lakes were mentioned for Southern Africa

ANNEX 5.1 - Temporal Distribution of Pressures Attributed to Decreased Annual Flow / Water Levels

(1970-2010 subset)

Decreased annual flow / water level (57 References)		1970s			1980s			1990s			2000s			TOTAL COUNT
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (91)	Agricultural expansion	43, 49	5, 13, 25, 30, 32, 44, 46, 57h&rip, 60h&rip, 62, 77h&rip, 78h&rip, 80h&rip, 81, 120	17		5, 8h, 26, 28, 31, 72, 74, 76, 90, 108, 109, 113	12		15, 68, 71, 75	4		62h&rip	1	34
	Agricultural intensification + Type													0
	Agricultural mismanagement + Type		13pf, 77pf, 80pf, 60pf	4		5og, 8pf, 26og, 28og, 31og, 57pf, 70og, 72og	8		12og, 68og&pf, 71og	3				15
	Deforestation	43, 49	13, 25, 32, 44, 46, 57h&rip, 60, 62, 77, 78, 80, 81	14		15, 72, 74, 76, 90, 108, 109, 113	6	43	12, 71, 75, 88	4		13, 62	2	26
	Afforestation		87pine, 88pine, 127pine	3		5eucalyptus, 8eucalyptus	2		88pine	1				6
	Drainage of wetlands					113	1							1
	Urbanization	43, 49	25, 32, 81, 127	6										6
	Return of natural vegetation		102	1		102	1							2
WW (62)	Irrigation + Crop	16, 19, 20, 83	30hor, 120orchard&vines, 127sugarcane	7	40hor&flowers, 41hor&flowers	26, 28, 31, 70rice&other, 72rice, 76illegalirr, 90, 108, 109	11		8, 15apples, 25hor, 32hor, 66rice, 67rice, 68rice, 71rice	8	40flowers (new boom)	90improvedirrigationcanals	2	28
	Increased livestock numbers					5, 26, 28, 31, 72	5		71	1				6
	Increased domestic demand	83	25	2	40, 43	5, 26, 28, 31, 44, 72, 88, 109, 109, 112	12	41	15, 71	3				17
	Increased urban demand		32, 127	2		26, 28, 31, 44, 46wtransfer, 90	6							8
	Industries + Type				16sodaash, 20sodaash		2							2
CC/CV (37)	Increased rainfall		78	1		74	1							2
	Decreased rainfall	40, 47	13, 88, 102, 105, 126, 128, 132	9		5, 70, 76, 87, 108, 109	6		71	1				16
	Increased variability of rainfall	49	12, 57, 60, 77, 80, 105	7		76, 101	2		56, 71	2				11
	Increased drought occurence								71, 75	2				2
	Increased temperature	49		1		76, 108, 109	3							4
Dams (15)	Hydropower		132wtransfer	1	47 (on inflowing rivers)	46, 74	3				47 (on inflowing rivers)		1	5
	Irrigation		127, 132wtransfer	2	47 (on inflowing rivers)	108, 109	3		75	1	47 (on inflowing rivers)		1	7
	Urban water demand		127	1		75, 76	2							3

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside, rip = riparian zones, hor = horticulture, illegalirr = illegal irrigation, wtransfer = water transfer

ANNEX 5.2 - Spatial Distribution of Pressures Attributed to Decreased Annual Flow / Water Levels
(1970-2010 subset)

Decreased annual flow / water level (57 References)		Eastern Africa (n=79)			Southern Africa (n=31)		
Pressure	**Pressure - Manifestation**	**Lakes & Rivers by Ref. Nr.**	Ref. - **COUNT**	Ref. - **% of n**	**Rivers by Ref. Nr.***	Ref. - **COUNT**	Ref. - **% of n**
LULCC	Agricultural expansion	**5, 8, 13, 15, 25, 28, 29, 30, 31, 32, 43, 44, 57h&rip, 60h&rip, 62, 68, 72, 74, 75, 76, 77h&rip, 78h&rip, 80h&rip, 81, 90**	**25**	**32**	**108, 113**	**2**	**6**
	Agricultural mismanagement + Type	**5og, 8pf, 12og, 13pf, 28og, 29og, 31og, 57og, 60pf, 68pf&og, 70og, 71og, 72og, 77pf, 80pf**	**15**	**19**			
	Deforestation	**13, 15, 25, 32, 43, 44, 57h&rip, 60, 62, 71, 72, 74, 75, 76, 77, 78, 80, 81, 90**	**19**	**24**	**108, 109, 113**	**3**	**10**
	Afforestation	**5eucalyptus, 8eucalyptus, 87pine, 88pine**	**4**	**5**	**127pine**	**1**	**3**
	Drainage of wetlands				**113**	**1**	**3**
	Urbanization	**25, 32, 43, 81**	**4**	**5**	**127**	**1**	**3**
	Return of natural vegetation				**102**	**1**	**3**
WW	Irrigation + Crop	**8, 12, 15apples, 16, 19, 20, 25hor, 28, 29, 30hor, 31, 32, 40hor&flowers, 41hor&flowers, 66rice, 67rice, 68rice, 70rice&other, 71rice, 72rice, 76illegalirr, 83, 90**	**23**	**29**	**108, 109, 120orchard&vines, 127sugarcane**	**4**	**13**
	Increased livestock numbers	**5, 28, 29, 31, 71, 72**	**6**	**8**			
	Increased domestic demand	**5, 15, 25, 28, 29, 31, 32, 40, 41, 43, 44, 71, 72, 83**	**14**	**18**	**108, 109, 112**	**3**	**10**
	Increased urban demand	**28, 29, 31, 44, 46, 90**	**6**	**8**	**127**	**1**	**3**
	Industries + Type	**16sodaash, 20sodaash**	**2**	**3**			
CC/CV	Decreased rainfall	**5, 13, 40, 47, 70, 71, 76, 87, 88**	**9**	**11**	**102, 105, 108, 109, 126, 128, 132**	**7**	**23**
	Increased variability of rainfall	**12, 49, 57, 60, 71, 76, 77, 80**	**8**	**10**	**56, 101, 105**	**3**	**10**
	Increased drought occurence	**71, 75**	**2**	**3**			
	Increased temperature	**49, 76**	**2**	**3**	**108, 109**	**2**	**6**
Dams	Hydropower	**46, 47 (on inflowing rivers), 74**	**3**	**4**	**132**	**1**	**3**
	Irrigation	**47 (on inflowing rivers), 75**	**2**	**3**	**108, 109, 127**	**3**	**10**
	Urban water demand	**75**	**1**	**1**	**127**	**1**	**3**

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside, rip = riparian zones, hor = horticulture, illegalirr = illegal irrigation, wtransfer = water transfer

* No lakes were mentioned for Southern Africa

ANNEX 6 - Temporal Distribution of Pressures Attributed to Changes in Seasonal Flow / Water Levels

(1970-2010 subset)

DECREASED dry season flow / water level (43 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (64)	Agricultural expansion	43	3, 9h, 59, 61,62h&rip, 63	7		8h, 13, 15, 25, 29	5		1, 25, 54	3		53	1	16
	Agricultural mismanagement + Type		3og, 33og, 57og, 60og, 68og&pf, 72og, 77pf, 80pf	8		8pf, 13pf&og, 25og, 28og, 31og, 71og	6		1og, 2og, 3soildegradation	3				17
	Deforestation	43	9h, 27, 44, 57, 59, 60, 62, 72, 76, 77, 78, 80	13		13, 15, 71, 90, 108, 109	6	43	1, 2, 25, 54	5		53	1	25
	Afforestation		3eucalyptus, 122	2		8eucalyptus	1		87pine	1				4
	Urbanization		27	1					25	1				2
WW (49)	Irrigation	83	33, 72rice, 76illegalirr	4		26, 28, 29, 31, 69, 71rice, 90improvedpumps, 108, 109	9		8, 15apple, 25hor, 27hor, 32hor, 68rice	6		8, 69improvedirrigation canals	2	21
	Increased livestock numbers	33	3, 72	3		26, 28, 31	3		71	1				7
	Increased domestic demand	83	3, 27, 33, 72	5	43	26, 28, 29, 31, 44, 108, 109	8		15, 25, 71	3				16
	Increased urban demand					26, 28, 31, 44, 90	5							5
CC/CV (29)	Increased rainfall			0										0
	Decreased rainfall		3, 9, 13, 76, 122	8		108, 109	2		53, 71, 87	3				13
	Increased rainfall variability		33, 57, 60, 76, 77, 80, 101, 104	1		59, 61, 63	3		53, 122	2				6
	Increased drought occurence		122	1					71, 122	2				3
	Increased temperature		76			108, 109	2							2
Dams (6)	Hydropower													0
	Irrigation		122	1		108, 109	2		3, 75	2				5
	Urban water demand		76	1										1

DECREASED wet season flow (4 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (12)	Agricultural expansion		57, 60	2										2
	Agricultural mismanagement + Type		57og, 60pf, 77pf, 80pf	4										4
	Deforestation		57, 60, 77, 80, 81	5										5
	Urbanization		81	1										1
CC/CV (4)	Increased variability of rainfall		57, 60, 77, 80	4										4

WW or **Dams** were not reported as an attributed pressure for decreased dry season flow/water levels by any reference

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside, rip = riparian zones, hor = horticulture, illegalirr = illegal irrigation, wtransfer = water transfer

Continued - Temporal Distribution of Pressures Attributed to Changes in Seasonal Flow / Water Levels
(1970-2010 subset)

INCREASED wet season flow (8 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (14)	Agricultural expansion		**59, 61, 63**	**3**					**2, 8h, 15**	**3**				**6**
	Agricultural mismanagement + Type								**2og, 3soildegradation, 8pf**	**3**				**3**
	Deforestation		**59, 61, 63**	**3**		**15**	**1**		**2**	**1**				**5**
CC/CV (5)	Increased rainfall		**59, 61, 63**	**3**					**50**	**1**				**4**
	Increased variability of rainfall								**50**	**1**				**1**

WW or **Dams** were not reported as an attributed pressure for increased wet season flow/water levels by any reference

INCREASED dry season flow (6 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
Dams (7)	Hydropower		**96, 98**	**2**					**11**	**1**				**3**
	Irrigation		**107, 127**	**2**		**46**	**1**							**3**
	Urban water demand		**127**	**1**										**1**

LULCC, WW or **CC/CV** were not reported as an attributed pressure for increased dry season flow/water levels by any reference

Artificial regime (inter-annual flow variations leveld by dams, 7 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
Dams (10)	Hydropower		**84, 85, 96, 97, 98**	**5**		**96**	**1**		**11**	**1**				**7**
	Irrigation		**84, 85, 107**	**3**										**3**
	Urban water demand													**0**

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside

ANNEX 7 - Temporal Distribution of Pressures Attributed to Increased Frequency and/or Intensity of Floods (1970-2010 subset)

INCREASED frequency and/or intensity of floods (25 References)		1970s			1980s			1990s			2000s			TOTAL COUNT
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (56)	Deforestation	43, 49	9, 25, 27, 44, 51, 52	8		7, 13, 24, 45, 72, 74, 90	7	43	32, 54, 91	4		34, 53	2	21
	Agricultural expansion	43, 49	9, 25, 27, 44, 51, 52, 59, 61, 63, 122	12		13, 24, 45	3		8h, 32, 54, 91	4		34, 53	2	21
	Agricultural mismanagement + Type		52og	1		13og&pf, 70og, 72og	3		3soildegradation, 8og, 122og	3				7
	Urbanization	43, 49	25, 51	4		7	1		32, 91	2				7
CC/CV (9)	Increased rainfall					24, 74	2							2
	Increased variability of rainfall		59, 61, 63	3		24	1	49 (El Nino)		1		34, 53	2	7

WW or **Dams** were not reported as an attributed pressure for increased frequency and/or intensity of floods by any reference

QUICKENED basin response time (10 References)		1970s			1980s			1990s			2000s			TOTAL COUNT
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
LULCC (20)	Deforestation	92	52, 62, 78	4		45	1		1, 91	2		34	1	8
	Agricultural expansion		52, 62h&rip	2		45	1		1, 8h, 91	3		34	1	7
	Agricultural mismanagement + Type		52og	1					1og, 8pf	2		3soildegradation	1	4
	Urbanization								91	1				1
CC/CV (2)	Increased rainfall		62, 78	2										2

WW or **Dams** were not reported as an attributed pressure for increased flashiness / quicker basin response by any reference

Decreased flashiness / basin response time was not reported by any reference.

DECREASED frequency and/or intensity of floods (9 References)		1970s			1980s			1990s			2000s			TOTAL COUNT
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
Dams (12)	Hydropower		84, 96, 97, 98	4		46, 96	2		11	1				7
	Irrigation		84, 107, 127	3		75	1							4
	Urban water demand		127	1										1

CC/CV was not reported as an attributed pressure for decreased frequency and/or intensity of floods by any reference

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside, rip = riparian zones

ANNEX 8 - Temporal Distribution of Pressures Attributed to Increased Frequency and Duration of No Flow (1970-2010 subset)

INCREASED frequency and duration of no flow (21 References)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
WW (41)	Irrigation		25hor, 30hor, 84, 85	4		26, 28, 31, 69, 76illegalirr, 90, 108, 109	8		66rice, 67rice, 68rice, 70rice, 71rice, 72rice	6				18
	Increased livestock numbers					26, 28, 31	3		71, 72	2				5
	Increased domestic demand		25, 84, 85	3		26, 28, 31, 108, 109	5		71, 72	2				10
	Increased urban demand		84, 85	2		26, 28, 31, 90	4							6
	Industries (type not specified)		84, 85	2										2
LULCC (17)	Agricultural expansion		25	1		26	1							2
	Agricultural intensification													
	Agricultural mismanagement					26og, 28og, 31og	3		68og&pf, 70og, 71og, 72og	4				7
	Deforestation		25	1		76, 90, 108, 109	4		71, 72	2				7
	Afforestation													0
	Urbanization		25	1										
	Industries + Type													
CC/CV (10)	Increased rainfall													0
	Decreased rainfall					76, 108, 109	3		70, 71	2				5
	Increased drought occurence								71	1				1
	Rainfall variability					76	1							1
	Increased temperature					76, 108, 109	3							3
Dams (5)	Hydropower													0
	Irrigation					108, 109	2		75	1				3
	Urban water demand					76	1		75	1				2

DECREASED frequency and duration of no flow (1 Reference)		**1970s**			**1980s**			**1990s**			**2000s**			**TOTAL COUNT**
Pressure (Total mentions)	**Pressure - Manifestation**	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	**Lakes by Ref. Nr.**	**Rivers by Ref. Nr.**	**COUNT** (L&R)	(L&R 1970s-2000s)
Dams (2)	Irrigation		127	1										1
	Urban water demand		127	1										1

Key to abbreviations: og = overgrazing, pf = poor farming practices, h = hillside, rip = riparian zones, hor = horticulture, illegalirr = illegal irrigation

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Source of GIS input data

The input data used for the GIS generated maps in this review originate from the following sources:

JICA [2013]	= Shapefiles of Wami-Ruvu Basin and Tanzanian region/district borders
WWF [2014]	= Shapefiles of African lakes and wetlands
Natural Earth [2014]	= Shapefiles of African rivers, lakes, and countries
FAO [2009]	= Shapefile of hydrobasins i.e. meta-basins delineated from HydroSHED Project