Sep 27, 2019

Water resources in Nakuru – assessment and potential

Contribution of Acacia Water to WaterWorX Nakuru project from the mission in June 2019

Final report

Executive summary

Nakuru county, Kenya is facing a number of water-related challenges. To be able to face those challenges, it is vital to understand the water resources of the area; only then can the effect of expected changes be anticipated, and can the best strategies be prioritized. This report aims to do exactly that, in support of the 'Climate resilient water supply program 2050' within the WaterWorX program.

Colophon

Document title	.	Water resources in Nakuru – assessment and potential
Client	.	VEI
Status	.	Final report
Datum	.	Sep 27, 2019
Project number	.	190934
Author(s)	.	R.C. van der Meulen
Peer review	.	A. Gevaert
Reference number		AW_185_RM_190934

Table of contents

List of tables iv

List of figures v

List of acronyms vi

Acknowledgment 1

1 Introduction 2

- 1.1 Project background 2
- 1.2 Outline 3

2 Baseline study 5

- 2.1 Study area 5
- 2.2 Issues and trends 7

3 Water resource assessment 11

- 3.1 Catchment delineation 11
- 3.2 Meteorology 15
- 3.3 River flow 20
- 3.4 Groundwater 21
- 3.5 Water quality 26
- 3.6 Water demand and use 27
- 3.7 Source vulnerability 31
- 3.8 Conclusion 32

4 Implementation 34

- 4.1 Water resource potential and climate change mitigation 34
- 4.2 Nakuru Sponge City 36
- 4.3 Towards sustainable cooperation 38
- 4.4 Financing & investment perspectives 40
- 4.5 Towards climate resilient management of water resources 40

References 43

List of tables

Table 1. Elevations of distinct topographic features around Nakuru county (m asl) 7
Table 2. Area coverage of basins, sub-catchments and remainder areas of Nakuru county 14
Table 3. Summary of meteorological components of the water balance for the different catchments in Nakuru county 19
Table 4. River flow data for major rivers in Nakuru county 21
Table 5. Baseflow/runoff contribution to Naivasha rivers 26
Table 6. Water demand of Nakuru county, current (2019) and future projections (2050) 28
Table 7. Water use of WSPs in Nakuru county, averaged for the last year data was available . 28
Table 8. Purpose of boreholes 30
Table 9. Borehole yield 30
Table 10. Water demand summary 31
Table 11. Water use summary 31
Table 12. Summary water balance catchments of Nakuru county 32

List of figures

Figure 1. Projected population increase in Nakuru county (source: WWX Nakuru assessment) 2
Figure 2. Projected water use increase in Nakuru county (source: WWX Nakuru assessment) .. 3
Figure 3. Coverage of WSPs in Nakuru county (dark green for NAWASSCO, orange for NAIVAWASS, blue for NARUWASCO and light green currently not covered) 5
Figure 4. Topography of Nakuru county. 6
Figure 5. Projected increase in minimum temperature based on a combination of 21 climate change models. 8
Figure 6. Forest reduction in Mau complex (Olang & Kundu, 2011). 9
Figure 7. Catchments of Nakuru county. 12
Figure 8. Full overview of basins, sub-catchments and remainder areas of Nakuru county 14
Figure 9. Average precipitation (mm/y) in Nakuru county. Source: WorldClim2 16
Figure 10. Precipitation data from Naivasha meteorological station (source: https://climexp.knmi.nl/start.cgi) 17
Figure 11. Annual precipitation data from Bahati forest meteorological station (left) and monthly averages (right), where P20-80 indicates the range falling within the 20th and 80th percentiles (source: https://climexp.knmi.nl/start.cgi) 17
Figure 12. Average evapotranspiration (mm/y) in Nakuru county 18
Figure 13. Average net precipitation (mm/y) in Nakuru county. 19
Figure 14. Geological map of Nakuru county area (source: OneGeology) 22
Figure 15. Typical hydrogeological transects for Nakuru county 23
Figure 16. Groundwater levels around Nakuru town 25
Figure 17. Groundwater levels around Naivasha town 25
Figure 18. Fluoride levels in Nakuru county 27
Figure 19. Water infrastructure of Nakuru county 29
Figure 20. Intervention potential map of Northern Kenya 35
Figure 21. Sponge city concept 36
Figure 22. Overview of 3R techniques (replicated from Tuinhof et al., 2012) 46
Figure 23. Some examples of 3R intervention possibilities per category 47
Figure 24. 3R intervention possibilities and water quality of those interventions 49
Figure 25. MAR technology groups: (1) diffuse land surface infiltration, (2) localized land surface infiltration, (3) direct aquifer infiltration, and (4) surface water storage (source: Acacia Water) 54

List of acronyms

Acronym	Meaning
3R	Recharge, Retention and Re-use of water
ASAL	Arid or Semi-Arid Land
CBO	Community-Based Organization
CSO	Civil Society Organization
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
m asl	Metres above sea level
MAR	Managed Aquifer Recharge
NAIVAWASS	Naivasha Water, Sewerage and Sanitation company
NARUWASCO	Nakuru Rural Water and Sanitation Company
NAWASSCO	Nakuru Water, Sewerage and Sanitation Company
NEMA	National Environmental Management Agency
NRW	Non-Revenue Water
SWC	Soil and Water Conservation
WASREB	Water Services Regulatory Board
WOP	Water Operators Partnership
WRA	Water Resources Authority
WRUA	Water Resource Users Association
WSP	Water Service Provider
WUA	Water Users Association
WWX	WaterWorX

Acknowledgment

This report is the result of a collaboration between Nakuru Water and Sanitation Services Company (NAWASSCO), Nakuru Rural Water and Sanitation Company (NARUWASCO), Naivasha Water Sewerage and Sanitation Company (NAIVAWASS), VEI and Acacia Water through the WaterWorX program and the Water Resources Authority (WRA) Rift-Valley Regional and Naivasha Sub-Regional Office as well as the County Government of Nakuru.

1 Introduction

1.1 Project background

This report has been made in service of the WaterWorX project, aiming to increase sustainable access to drinking water to ten million people in 2030 through Water Operator Partnerships (WOPs) between Dutch and local water companies. One of these WOPs is being executed with the three water utilities in Nakuru County. The population in Nakuru County is approximately two million and projected to increase to over five million by 2050 (Figure 1). With this population increase, water demand is expected to increase as well, from 50,000 m^3/day to 350,000 m^3/day. Meanwhile, based on figures from October 2017, the water coverage in the county is 59% and the sanitation coverage is 65%. This means that 820,000 people do not have access to improved water facilities and 700,000 people do not have access to improved sanitation services.

This goal of this WOP is to increase the improved water and improved sanitation services in Nakuru County in line with the sustainable development goals. To do this in an efficient and effective way, the water utilities need to look beyond their area of jurisdiction. The three water utilities have the same shareholder, Nakuru County. The county promotes the collaboration between the utilities, to provide better services for the residents of Nakuru County.

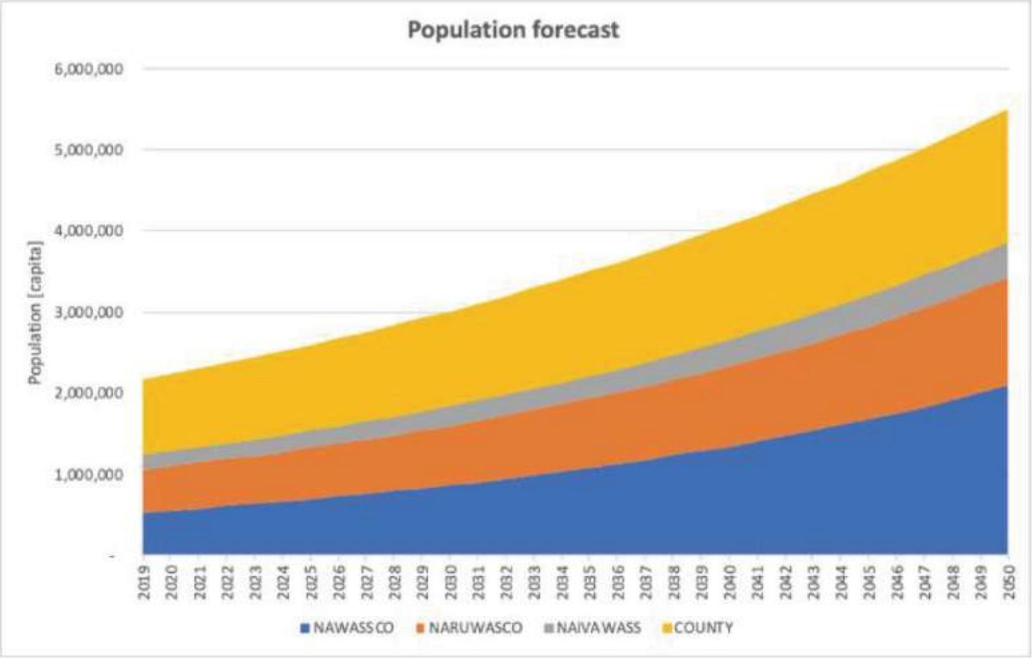


Figure 1. Projected population increase in Nakuru county (source: WWX Nakuru assessment)

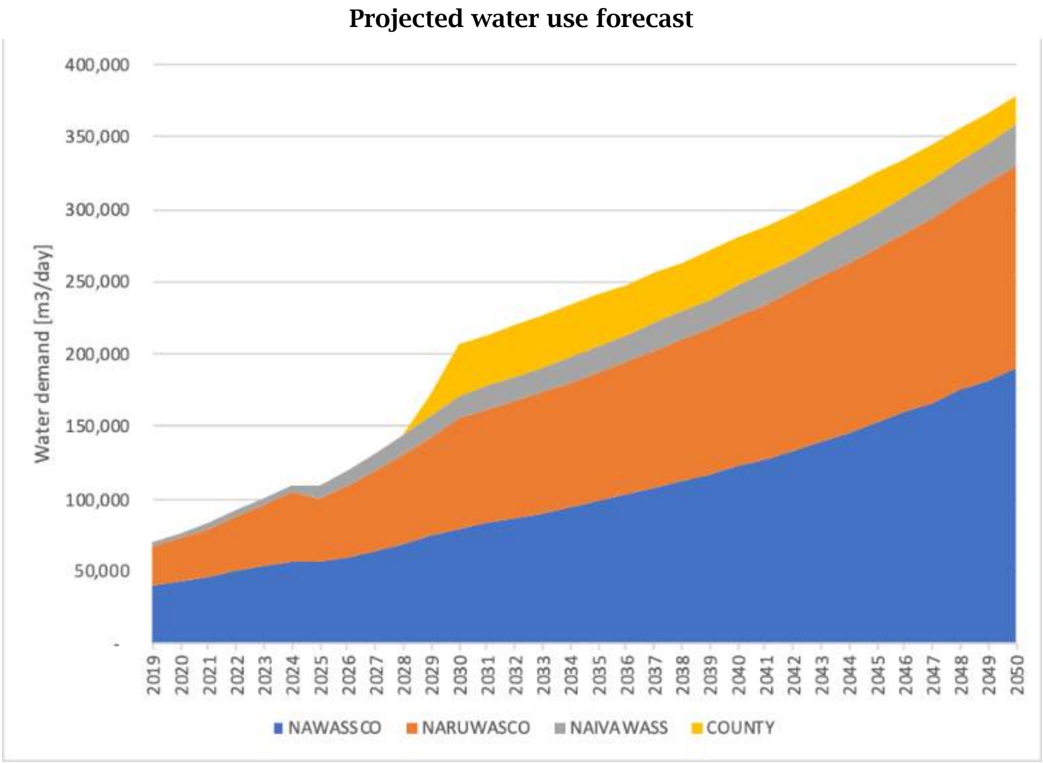


Figure 2. Projected water use increase in Nakuru county (source: WWX Nakuru assessment)

Within this joint effort between the international and local partners it is crucial to ensure that water resources, infrastructure, water supply and demand are balanced under current and future conditions. Climate change, demographic growth and economic development scenarios are key components to look at within this framework. The development of a stakeholder engagement strategy, the setting up of a stakeholder platform, the design of a hydrologic monitoring plan, and ultimately the implementation of a 'Climate resilient water supply program 2050' are intrinsic elements to accomplish that water demand is met sustainably, now and in the future.

1.2 Outline

The 'Climate resilient water supply program 2050' of WaterWorX aims to produce a variety of outputs, a number of which were addressed in this assignment. Due to the limited involvement of the advisor in the program, it was decided to produce all specific sub-outputs of the advisor in one stand-alone report, instead of being incorporated into the relevant outputs directly. This way, the contribution of the advisor can be assessed directly, and specific parts can be incorporated into specific outputs at a later date. As such, this report should be seen as an amalgamation of sub-outputs for the 'Climate resilient water supply program 2050'.

In the second chapter, the baseline study is described, and issues and trends are identified. The water resources assessment is presented in chapter 3. This includes description and elaboration of various components of the water balance, as well as a description and elaboration of water demand and water use in the study area. In chapter 4, potential adaptation and mitigation strategies and other recommendations are presented. An important part of this strategy concerns sustainable cooperation.

Specific outputs for the 'Climate resilient water supply program 2050' can be found in the following chapters:

Conduct a baseline study in which the relevant issues and trends concerning environmental, socio-economic, political and policy aspects are described and their possible impact on water resources and water demand identified for the time horizon 2050: **Chapter 2.2, only parts relevant to water resources are considered here**;
Conduct a source vulnerability assessment, which includes the mapping of water resources, and the quantity and quality of these resources in light of the changing conditions: **Chapter 3.8**;
Prioritize adaptation and mitigation strategies in collaboration with stakeholders to secure water resources availability, and the financial and technical sustainability of the infrastructure: **Chapter 4, limited to considerations from a water resource perspective**;
Regional water resources assessment: Inventory made of water sources (quality and quantity), including mapping of hydrogeological conditions: **Chapter 3**;
Opportunity scenarios for Nakuru to improve living conditions in town by incorporating principles of a sponge city: **Chapter 4.2**.

2 Baseline study

2.1 Study area

Nakuru county is located in the Rift Valley area in Kenya and is home to about two million people (number to be updated by the 2019 census). The county has a total area of 7,495 km^2 and consists of 11 sub-counties and 55 wards. Thirteen urban conurbations are located within Nakuru county, namely Nakuru Town, Naivasha, Mai Mahiu, Molo, Mau Narok, Olenguruoni, Njoro, Rongai, Salgaa, Dundori, Bahati, Subukia, and Gilgil.

The area is home to three WSPs:

- Nakuru Water and Sanitation Services Company (NAWASSCO);
- Naivasha Water, Sewerage and Sanitation Company (NAIVAWASS); and
- Nakuru Rural Water and Sanitation Company (NARUWASCO).

NAWASSCO is responsible for Nakuru town (~500,000 people), NAIVAWASS is responsible for Naivasha town (~175,000 people) and NARUWASCO and the county are responsible for the rest of Nakuru county (~1,460,000 people). Current coverage of NAWASCO extends to about 500,000 people. The extent of WSP coverage is shown in Figure 3.

Figure 3. Coverage of WSPs in Nakuru county (dark green for NAWASSCO, orange for NAIVAWASS, blue for NARUWASCO and light green currently not covered)

Nakuru county (Figure 4) is located in middle of the Rift Valley area of Kenya, bordering the counties of Baringo to the north, Laikipia to the northeast, Nyandarua to the east, Kiambu and Kajiado to the southeast, Narok to the south, and Bomet and Kericho to the west. Its capital is Nakuru town, with a population of approximately 500,000. Other larger towns include Naivasha, Gilgil and Njoro.

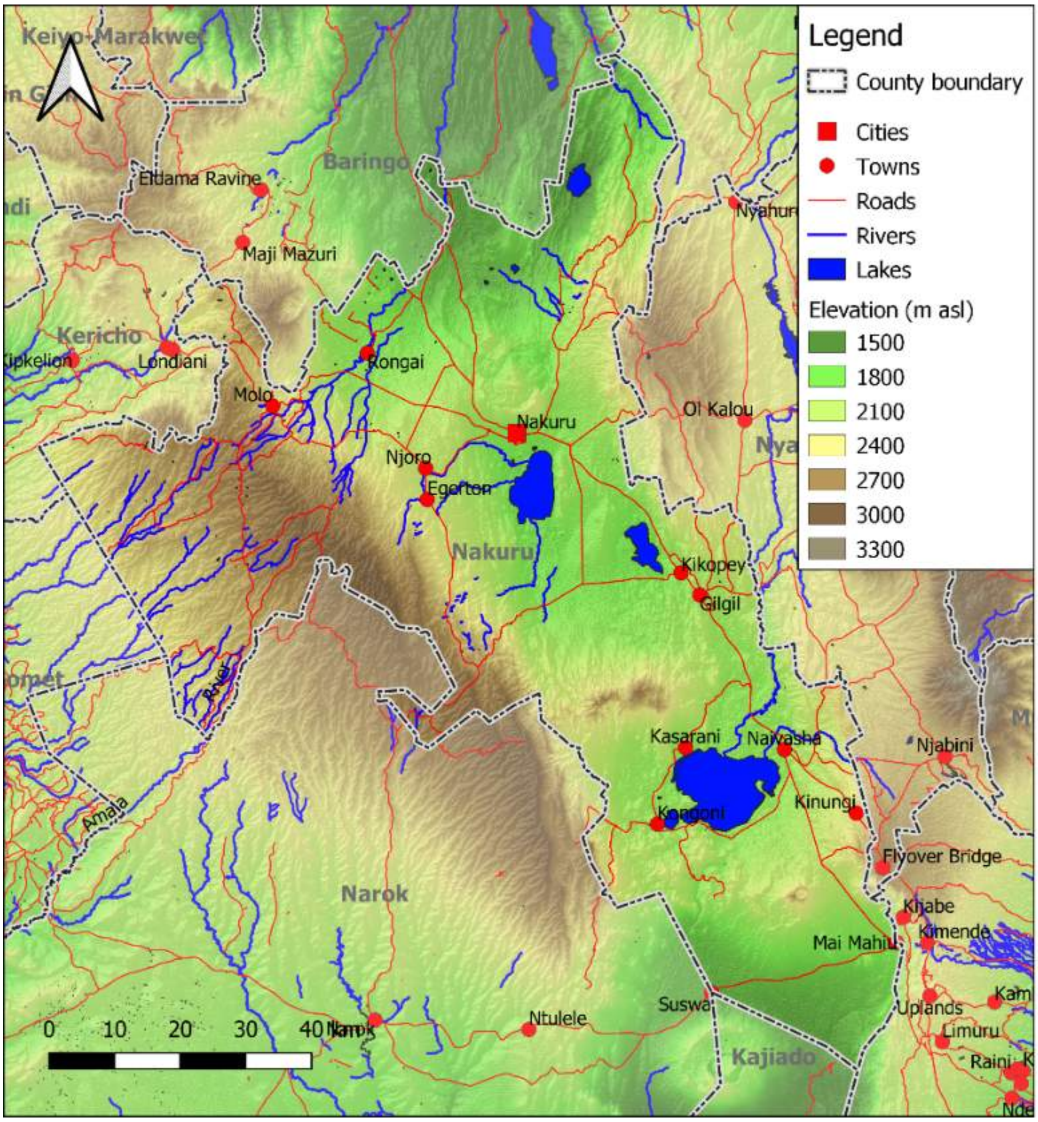


Figure 4. Topography of Nakuru county.

Several Rift Valley lakes are located within the county: Lake Nakuru, Lake Elementaita, Lake Naivasha and the lesser known Lake Solai, while Lake Bogoria lies just beyond the northern boundary of the catchment. Nakuru county is situated between the Mau escarpment to the west and the Kinangop plateau to the east. The Mau escarpment shows the highest elevations in the county, going up to 3,000 m asl (above sea level). A few volcanic craters are dotted along the Rift Valley floor, with Menengai Crater near Nakuru town, Ol Doinyo Eburru northwest of Lake Naivasha, Mount Longonot south of Naivasha town, and Mount Suswa just south of the county. An overview of the elevations of lakes and volcanic peaks is presented in Table 1.

Table 1. Elevations of distinct topographic features around Nakuru county (m asl[1])

Lakes	Nakuru	Elementaita	Naivasha	Solai	Bogoria
	1,755	1,774	1,881	1,510	990
Volcanic peaks	Menengai Crater	Ol Doinyo Eburru	Mount Longonot	Mount Suswa	
	2,278	2,586	2,776	2,356	

2.2 Issues and trends

Nakuru county is experiencing changes related to demographics and the environment such as population growth, climate change and landcover change, and a number of issues, like flooding and water quality, while also experiencing institutional challenges. In this chapter, issues and trends related to water resources are discussed.

2.2.1 Population growth and urbanisation

The population in Kenya has been rapidly increasing for decades now, and the same is true for Nakuru county. Population growth has been estimated at 3% per year (Nakuru County, 2013). Currently, the population is estimated to be at 2.17 million people (to be corrected by 2019 census) and it is expected to rise to 5.5 million people by 2050. Additionally, people tend to move away from rural areas in favour of urban centres, where water consumption tends to be higher than in rural areas. Nakuru town is by far the largest urban centre in the county, hosting 0.5 million people currently but by 2050 this population is expected to exceed 2 million. The combination of population growth and urbanisation is expected to result in a sharp increase in water demand in the coming decades.

2.2.2 Climate change

Observations regarding climate change have already been made in Kenya. These include general warming, reduced amount of intense rainfall during the rainy season, and more intense and frequent rainfall during the rest of the year (Government of Kenya, 2010). Other literature also reports changes in the climate of Kenya, such as severe or prolonged drought (UNICEF, 2010), soil erosion, water pollution, desertification (Plan Kenya, 2013), and changing rainfall patterns (de Wit & Stankiewicz, 2006; UNICEF, 2010). A report by Chaocheva (2016) observed a slight and insignificant increase in precipitation in Nakuru county and a more significant increase in minimum temperature, while National Climate Change Response Strategy (NCCRS, 2010) state that climate change is *"already unmistakable and intensifying at an alarming rate as it is evident countrywide temperatures increases and rainfall irregularities and intensification"* in Kenya.

The observed trends are expected to intensify under expected climate change scenarios. The Intergovernmental Panel on Climate Change (IPCC; 2018) concludes that global warming is likely to reach 1.5˚C between 2030 and 2052 if it continues to increase at the current rate. Additionally, Africa focused studies find that warming for Kenya will likely be greater than the global average (ASSAR, 2018). Results of the studies indicate that for the climatic zone characterizing Nakuru County, whose northern boundary is on the equator and at high altitude, rainfall is expected to increase by at least 6%. It is likely that the amount of rain in heavy rainfall events will increase by 32% and streamflow will increase by more than 50%.

---

[1] m asl: meter above sea level. Sources for elevation references: SRTM and Wikipedia

Temperature increases are also expected for Nakuru county. In a study combining 21 different climate change forecast models in mild to extreme scenarios, an increase in minimum projected is clearly visible even for mild scenarios (see Figure 5).

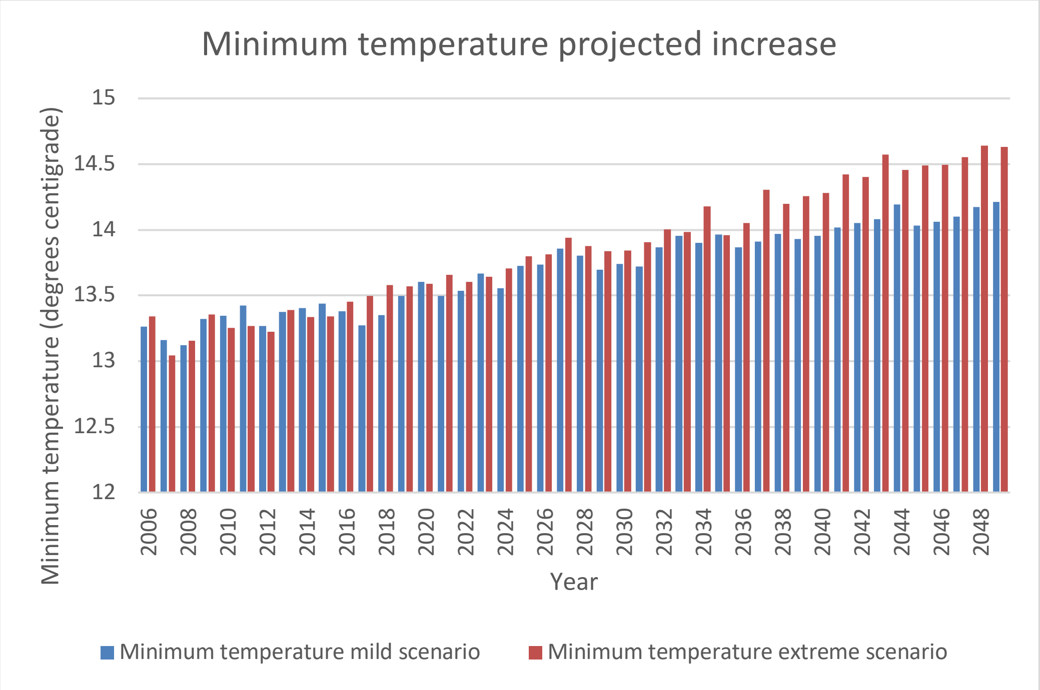


Figure 5. Projected increase in minimum temperature based on a combination of 21 climate change models.

2.2.3 Landcover change

Landcover changes have been reported throughout Nakuru county, particularly focusing on deforestation. Baker (2008) report reduction of forest in favour of agriculture in Njoro catchment, Ayuyo and Sweta (2014) and Olang & Kundu (2011) report reduction in Mau forest cover, Chepkochei and Njoroge (2012) report reduction of forest cover in the Menengai area, and Raini (2009) reports this across Nakuru catchment. Generally, landcover change is directly attributed to human activity (Ayuyo and Sweta, 2014; Raini, 2009). Many studies stress the effect these landcover changes have on the local hydrology (Baker, 2008; Shivoga, 2001; Olang & Kundu, 2011; Olang & Fürst, 2011), such as increases in floods, high flows and erosion. Raini (2009) and Shivoga et al (2005) stress effects on water quality, and subsequently ecosystems and biodiversity.

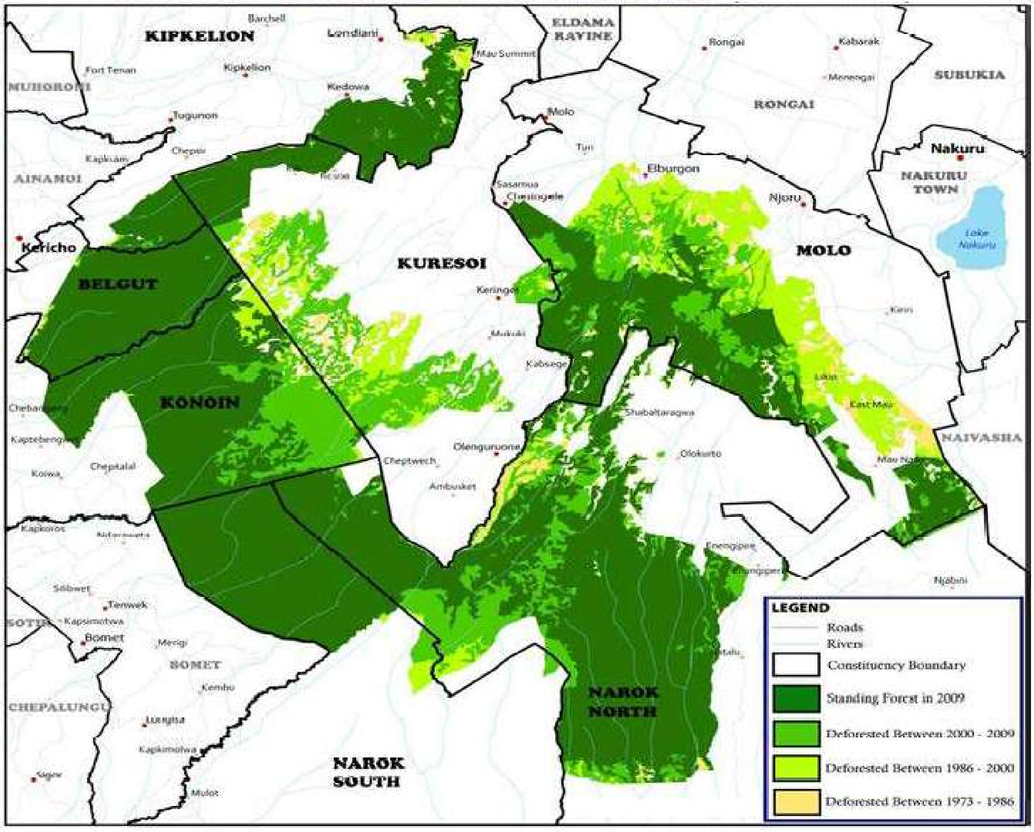


Figure 6. Forest reduction in Mau complex (Olang & Kundu, 2011).

2.2.4 Changes in lake levels

Lake levels of all Rift Valley lakes have proven to be very variable over the last century. At some points in time all lakes had all but disappeared, but since 2006 lake levels have been rising and are much higher than average. The underlying causes of the changes in water level have been a subject of debate, as no comprehensive objective study has been done so far. Ngaira (2006) largely attributed the shrinkage of Lake Baringo to climate change, but landcover changes and even tectonic events have also been listed as possible explanatory factors.

An interesting exception is Lake Naivasha. In 2018, unusually high lake levels were reported while the very next year an alarming drop in water levels was observed. This sharp drop has been strongly linked to human activity, specifically landcover change and abstraction upstream. As the main feeding rivers to lake Naivasha have dropped to almost zero as well. Since these rivers pass through the densest area of human activity within the study area, this link seems plausible (Odongo 2016).

2.2.5 Change in groundwater levels

Changes in groundwater levels have been reported as well. Rigter (2018) reports from personal communication with the Water Resources Authority (WRA) that “The Mau and Bahati forests for instance have been degraded so much that water levels dropped due to reduced recharge”. Besides upstream degradation, increased abstraction through discharge seems a likely cause for a reduction in groundwater levels, especially in the Naivasha region where many points of abstraction are known to exist. It is hard to confirm this however, as very few data exist on groundwater levels (although some was gathered during this study, see chapter 3.5.3).

2.2.6 Floods

Floods have been reported to occur more frequently in Nakuru and Naivasha towns (personal communication from NAWASSCO and NAIVAWASS). In Naivasha, they have recently built storm drains which have alleviated the worst of the effects. In Nakuru town however, floods remain a major issue.

The flooding is likely a result of both urbanization of the Nakuru town area and landcover changes in upstream areas. Urbanization leads to conversion of natural land to hard surfaces, promoting surface runoff instead of recharge, contributing to flooding directly. Similarly, upstream landcover change also increases surface runoff, which increases peak river flow and thus contributes to flooding in Nakuru town more indirectly but possibly to a larger degree.

2.2.7 Water quality

One of the main water quality concerns is the high fluoride levels in the study area. The fluoride concentration in Nakuru town is reported to be around 3 mg/l and even up to 8 mg/l, while the water quality standard recommended by the WHO is 1.5 mg/l (Rigter, 2018).

In addition, studies show that nutrient, organic silt and phosphorus loads in the Njoro and Makalia rivers have increased, subsequently leading to higher loads of these elements in Lake Nakuru. The studies relate this pollution to human activity and land degradation (Kulecho and Muhandiki, 2006; Shivoga et al, 2005).

Water and sanitation related diseases e.g. diarrhoeal diseases, skin diseases, eye infections, dysentery, cholera and bilharzia remain a major challenge in the county as well. Sanitation-related diseases account for more than 75% of the county's disease burden, and in 2017, the county reported three repeated waves of cholera outbreaks (World bank, 2019a).

2.2.8 Institutional challenges

The strategic sanitation plan by the World bank (2019b) reports that there is insufficient capacity within the county's public and private sectors to perform regulatory duties, carry out efficient revenue collection and provide management services to operate and maintain the ground water supply infrastructure.

Additionally, through personal communication it became apparent that cooperation between different governmental bodies was limited. Different institutions tend to work alone and only involve one another when absolutely necessary, both at the county level and at community level. The visions and mandates of the institutions are well-aligned however, suggesting that closer cooperation not only has high potential, but could be beneficial in terms of efficiency and impact.

3 Water resource assessment

3.1 Catchment delineation

Water resources assessments start with the differentiation of hydrological catchments. A hydrological catchment, or simply catchment, is defined as "any area of land where precipitation collects and drains off into a common outlet" (synonyms: watershed, drainage basin). A catchment is defined by its outlet point, whether this is a river, a lake or an ocean. The entire area where runoff from precipitation ends up in that endpoint is part of the catchment, with different catchments being separated by water divides (the higher parts of the area). As such, within a catchment all water resources are integrally linked. This is the reason that catchment delineation is vital for water resources assessments. Groundwater is also related to catchment boundaries to some degree, although often it is a bit more complicated since the subsurface comes into play.

3.1.1 Main catchments

Catchment differentiation in Nakuru county is relatively complicated. Since it is located in the middle of the Rift Valley, a considerable number of catchments can be distinguished, which can be grouped into different types. In this chapter, all different catchments and important sub-catchments are identified which will form the base for further water resource identification.

Hydrological catchments can be determined based on the topography. A total of nine different catchments have been identified for Nakuru county, illustrated in Figure 7. These catchments can be divided into two groups:
- Rift Valley lake basins; catchments with an internal drainage system, where the endpoint is one of the Rift Valley lakes; and
- Lake Victoria sub-catchments; catchments of rivers flowing into Lake Victoria.

The Mau complex forms the water divide between these two groups.

Rift Valley lake basins:
1. Baringo
2. Nakuru
3. Elementaita
4. Naivasha
5. Magadi
6. Natron

Lake Victoria sub-catchments:

7. Mara
8. Sondu
9. Nyando

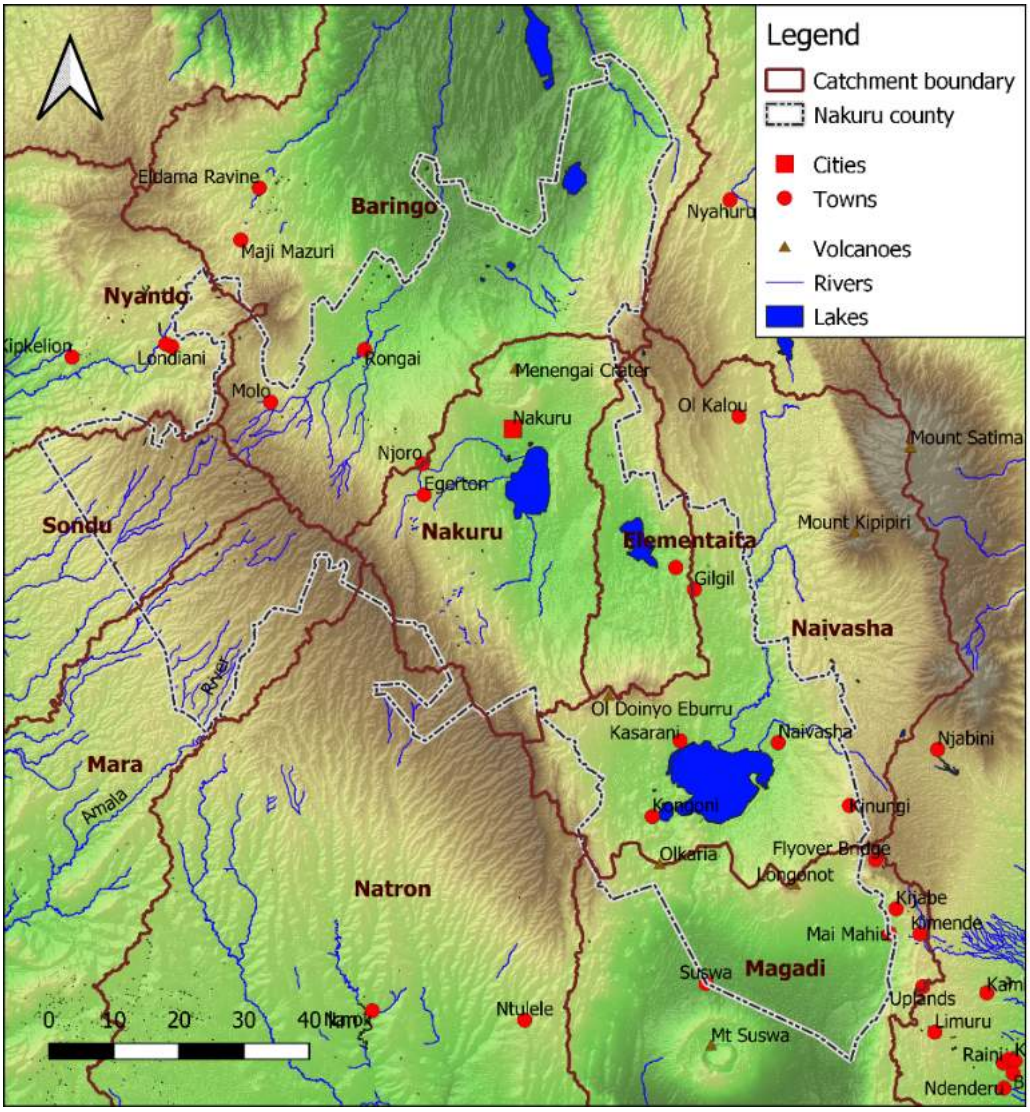


Figure 7. Catchments of Nakuru county.

For the purpose of this study, a second distinction has been made:

- catchments with their endpoint within Nakuru county; and
- catchments with their endpoint outside of Nakuru county.

For the first group, the whole catchment needs to be considered to determine water availability for the county. This group is referred to as the internal basins and consists of Nakuru, Elementaita and Naivasha catchments. Since Nakuru and Elementaita catchments are almost fully located inside Nakuru county, water management is relatively straightforward in practice. For Naivasha catchment however, a large part is located in Nyandarua county. What happens in this area will affect water resources downstream, so for proper water management it is important to closely look at activities within this county as well. For the second group however, where the endpoint of catchments is outside of the county, only those parts of the catchment where flow originates within the county are relevant.

3.1.2 Sub-catchment differentiation

To more able to better understand the second group, a subsequent classification of sub-catchments has been made:

- Rift Valley lake sub-catchments:
    - Molo (as part of Baringo)
    - Rongai-Olobanita (as part of Baringo)
    - Suswa sub-catchment (as part of Magadi)
- Lake Victoria sub-catchments:
    - Amala (as part of Mara)
    - Nyangores (as part of Mara)
    - Kipsonoi (as part of Sondu)
    - Itare (as part of Sondu)

For Mara and Sondu sub-catchments it should be noted that the identified sub-catchment area does not correspond fully to the entire corresponding river area, i.e. the full Amala, Nyangores, Kipsonoi and Itare river catchments are much larger. Instead, only the upper reaches draining to a confluence point just outside of Nakuru area are considered here.

Dividing these catchments into these sub-catchments covers the Nakuru county more adequately, since most of the area is covered. A few small remainder areas are left that cannot be properly divided into sub-catchments of significant size: parts of Mara and Sondu catchments and the overlapping parts of Natron and Nyando catchments with Nakuru county entirely. In Baringo there is one larger area of exception: the Lake Solai area. Strictly speaking Lake Solai is a catchment in itself, but it covers such a small area that for the scope of this research it is better considered as part of Lake Baringo catchment (a similar situation occurs for the Menengai crater within Lake Nakuru catchment). This area is considered together with some small areas where water flows towards Baringo and Bogoria lakes. All these different considerations and classifications taken together leads to a catchment differentiation as illustrated in Figure 8. An overview of general characteristics of the catchments is found in Table 2.

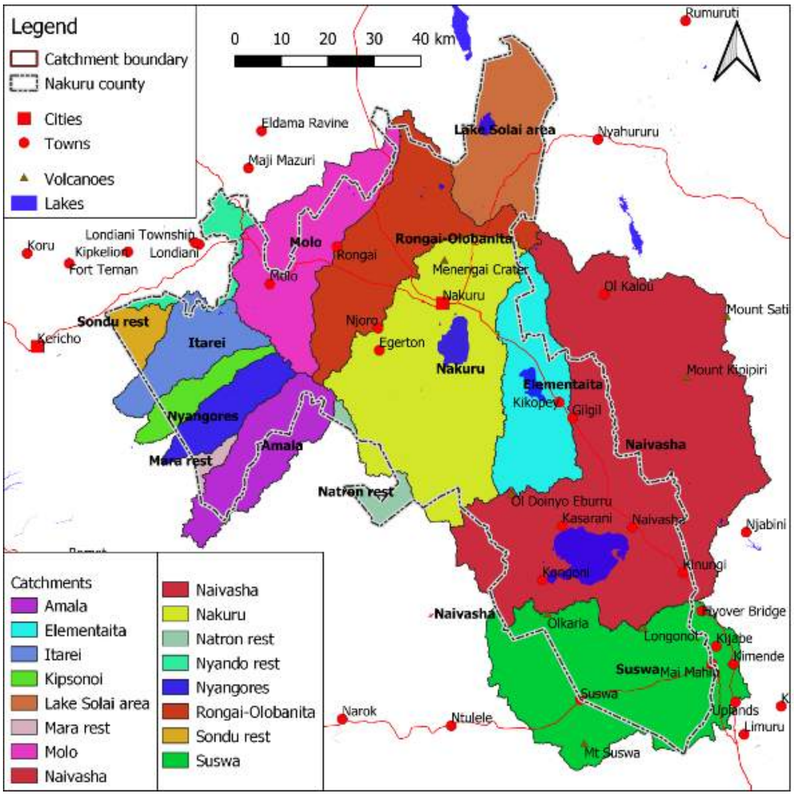


Figure 8. Full overview of basins, sub-catchments and remainder areas of Nakuru county.

Table 2. Area coverage of basins, sub-catchments and remainder areas of Nakuru county

Type	Catchment	Area (km^2)
Internal basins	Nakuru	1,602
	Elementaita	635
	Naivasha	3,215
Rift Valley lake sub-catchments	Molo	759
	Rongai-Olobanita	873
	Suswa	1,420
Lake Victoria sub-catchments	Amala	471
	Nyangores	253
	Kipsonoi	173
	Itare	359
Remainders	Lake Solai area	312
	Mara rest	40
	Sondu rest	113
	Nyando rest	116
	Natron rest	91

3.1.3 Concluding remarks

Ideally, water availability would be assessed for each of these areas individually, resulting in a complete water balance per area. As was realized during the course of the assignment however, within the WWX program as it running currently there has been very much a focus only on the most prominent catchment areas in the county: Nakuru, Elementaita and Naivasha catchments, as they are the most centrally located in Nakuru and inhabit the most people. As such, the differentiation in smaller sub-catchments and remainder areas will not be further considered in this report. The water resources assessment will focus on the catchment division as shown in Figure 7 with Nakuru, Elementaita and Naivasha considered in its entirety and the other catchments mostly limited to the area where the county overlaps with the catchment. The differentiation of smaller sub-catchments can be used for a more detailed future analysis.

3.2 Meteorology

3.2.1 Precipitation

Precipitation, mostly in the form of rainfall, forms the base of water availability in any area. Obtaining a reasonable estimate of precipitation in an area is the most important aspect of a water resources assessment.

Unfortunately, data availability is limited. For Nakuru county, a number of meteorological stations with precipitation measurements do exist, but there are not enough to provide a reasonable estimate for the entire area. Satellite datasets are available with comparatively better spatial coverage providing monthly or even daily datasets, but their uncertainty is generally high. Another option is a global dataset of average precipitation developed by Fick and Hijmans (2017) which is based on station data, topographic characteristics, and satellite data of temperature and cloud cover. The dataset has been validated against the available precipitation measuring station data and seems to perform reasonably well for Nakuru area. Therefore, this merged dataset was used in this study.

The spatial distribution of precipitation in Nakuru county and the relevant catchment areas is shown in Figure 9. As can be clearly seen, precipitation is lowest in the Rift Valley, particularly around Elementaita, Naivasha and Suswa, where precipitation values are as low as 600 mm/y. Precipitation is highest in in the upper Naivasha catchment in the east and in in the Sondu catchment in the west, where precipitation reaches over 1500 mm/y. The Mau complex and Kinangop plateau receive around 1000 mm/y.

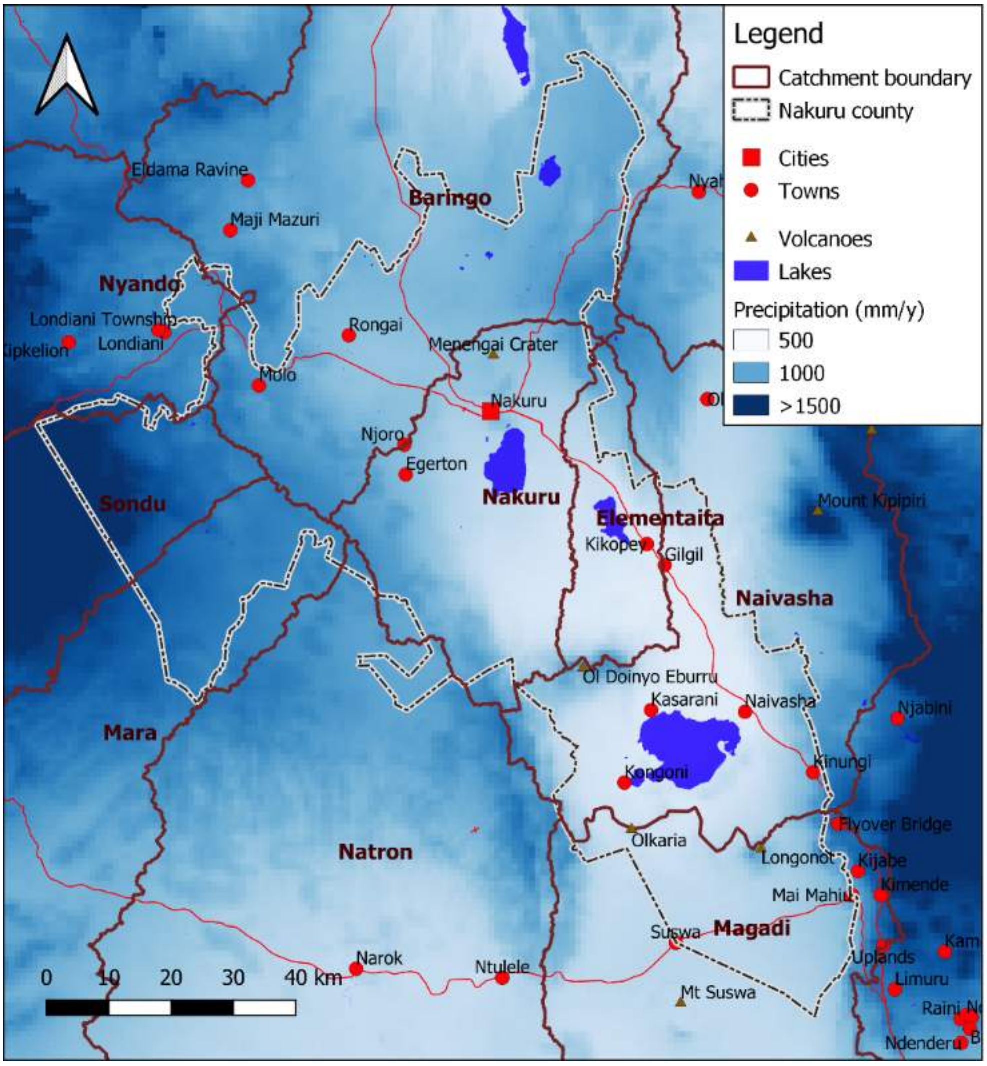


Figure 9. Average precipitation (mm/y) in Nakuru county. Source: WorldClim2

While Figure 9 illustrates average values across Nakuru county, it is known that precipitation can vary considerably between wet and dry years, but also varies seasonally between distinct wet and dry seasons. The variability of precipitation for two precipitation stations is depicted in Figure 10 and Figure 11. One station is located in the Rift Valley near Naivasha town and the other on the escarpment in Bahati forest.

As is evident from these figures, precipitation variability is indeed quite high between years and seasons. At the Naivasha station, there are quite a few years where precipitation is below 500 mm, sometimes even in consecutive years, while for one particular year precipitation is above 1000 mm. On average, there is more precipitation at Bahati forest station, with a similarly high variability between years. Seasonally, the highest peak is seen in April-May, known in Kenya as the long rains. The short rainy season around October/November is less pronounced, while the driest months of January/February are clearly visible, especially at the Bahati station.

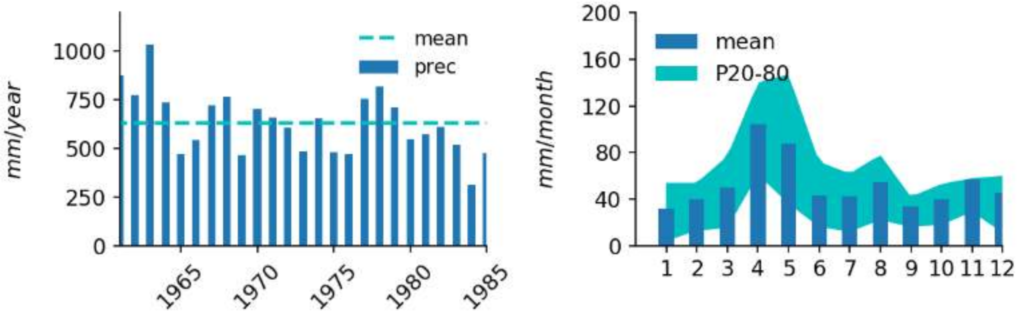


Figure 10. Precipitation data from Naivasha meteorological station (source: https://climexp.knmi.nl/start.cgi)

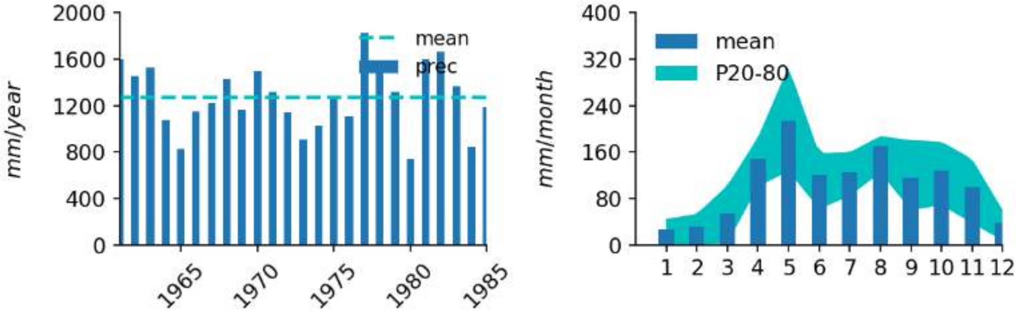


Figure 11. Annual precipitation data from Bahati forest meteorological station (left) and monthly averages (right), where P20-80 indicates the range falling within the 20th and 80th percentiles (source: https://climexp.knmi.nl/start.cgi)

3.2.2 Evapotranspiration

Evapotranspiration is the aggregation of the words *evaporation* and *transpiration*, which are the main routes by which water is transported from the surface to the air. The water lost by evapotranspiration to the atmosphere is not available for use, making evapotranspiration an important component of water resources assessments.

Compared to precipitation, evapotranspiration is difficult to measure in the field and no measurements of evapotranspiration were found for this study. Estimates based on satellite data are available, but just as for satellite precipitation datasets their uncertainty is generally high. In this study, a global dataset based on the Penman-Monteith equation using WorldClim2 precipitation as input was used. This dataset has been validated and seems to perform well for the project area. An important note for this dataset is that it does not cover evaporation of open water in places where water accumulates, like rivers, wetlands and lakes. This would only matter if a full water balance study would be calculated for an entire lake basin, which is not the case here.

Average values for evapotranspiration across Nakuru county are illustrated in Figure 12. The patterns are similar to those of precipitation, with the highest values in the Aberdares and Sondu catchment to the east and west respectively, and the lowest values in the Rift Valley, especially around Naivasha and Elementaita.

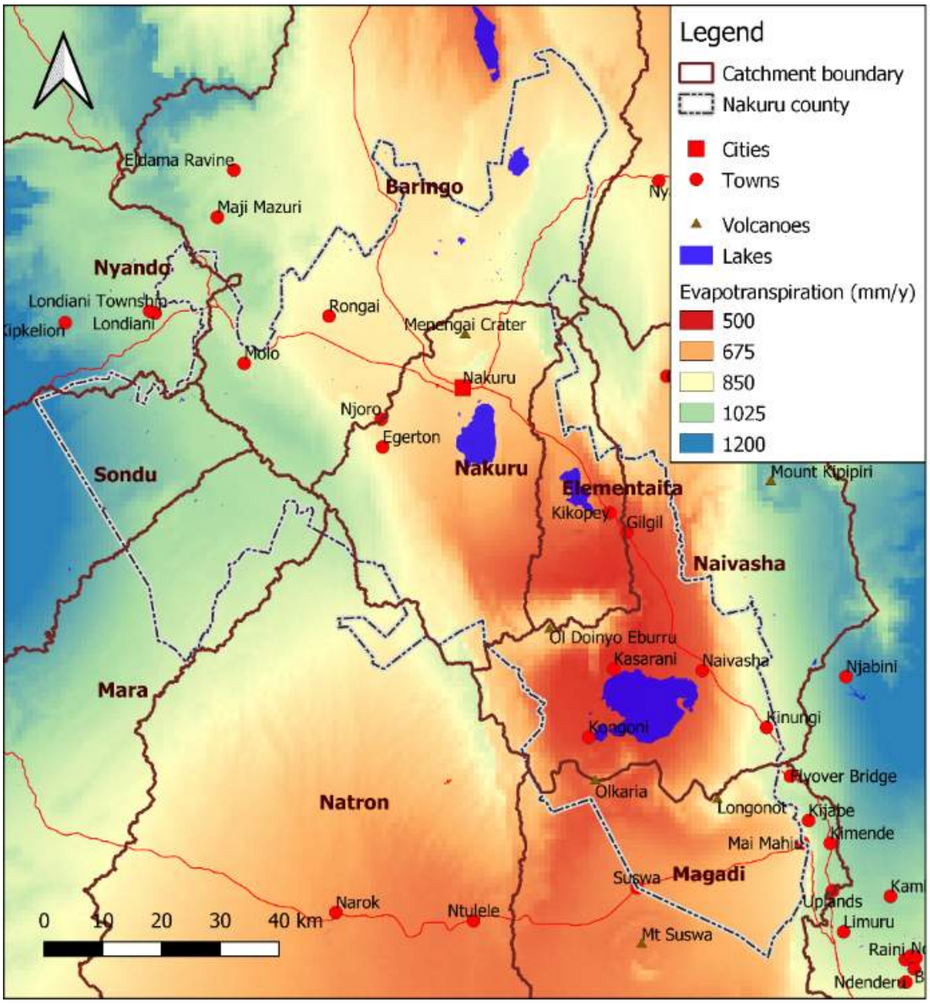


Figure 12. Average evapotranspiration (mm/y) in Nakuru county

3.2.3 Net precipitation

Net precipitation is determined by subtracting evapotranspiration from precipitation. Theoretically this is equal to the sum of runoff and percolation and is thus the amount of water that is available for exploitation. In practice, runoff and percolation are affected by a host of different factors. For example, the exploitation of water resources is influenced by topography and geology. Moreover, the net precipitation values are calculated using average estimates of precipitation and evapotranspiration, which show seasonal and inter-annual variability which is not taken into account in this analysis. And finally, it is not possible to capture all runoff and percolation for human use: runoff directly evaporates as well, which is not taken into account in the evapotranspiration dataset used here. In addition, a certain amount of runoff is needed for ecological purposes, groundwater will flow to unreachable places, etc. This means that net precipitation values should be treated with care. Nonetheless, net precipitation provides a good first estimate of water availability and is therefore used in this study.

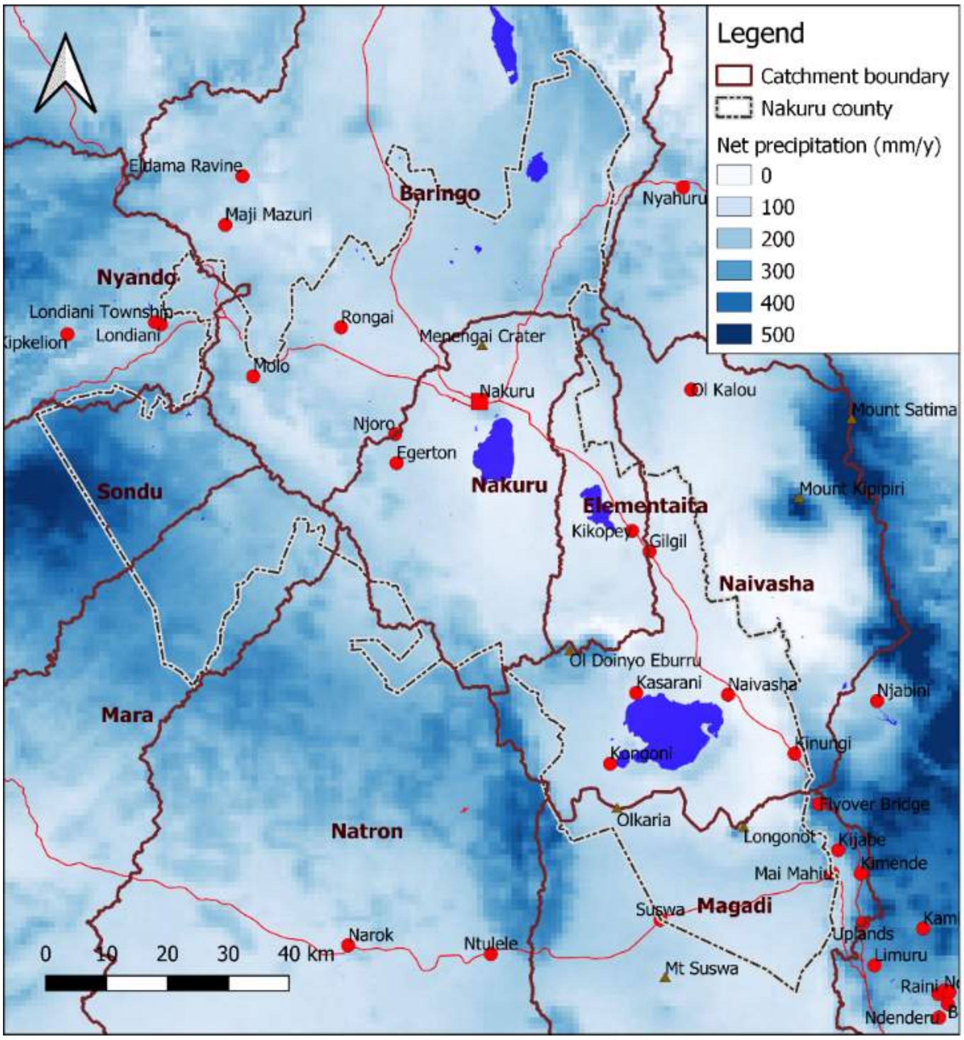


Figure 13. Average net precipitation (mm/y) in Nakuru county.

The spatial patterns of net precipitation in the Nakuru area is presented in Figure 13. In Table 3, the average precipitation, evapotranspiration and net precipitation are given for each of the identified catchments, sub-catchments and rest areas. Net precipitation is provided in mm/y as well as in millions of cubic meters.

Table 3. Summary of meteorological components of the water balance for the different catchments in Nakuru county

Type of catchment	Catchment name	Precipitation (mm/y)	Evapotranspiration (mm/y)	Net precipitation	
				(mm/y)	(m^3/d)
Full internal basins	Nakuru	886	772	114	500,000
	Elementaita	755	667	89	150,000
	Naivasha	928	787	141	1,240,000
Rift Valley lake sub-catchment areas	Baringo	1072	922	150	810,000
	Magadi	988	844	144	670,000
	Natron	872	701	171	50,000
Lake Victoria sub-catchments	Mara	1216	967	249	530,000
	Sondu	1284	1019	266	590,000
	Nyando	1378	1058	320	70,000

3.2.4 From net precipitation to water availability

Net precipitation is an indicator of the amount of runoff and percolation in a catchment. For water resources assessments, it is important to divide net precipitation into the two components: for each catchment, a certain percentage will become runoff and the remainder will percolate.

The division between runoff and percolation depends on a number of physical factors, including:

- Soil
- Vegetation
- Land use
- Slope and catchment size
- Antecedent soil moisture
- Precipitation intensity

This dynamic can be captured comprehensively through a modelling study. However, such an analysis goes beyond the scope of this study. Here, the analysis will be limited to some basic steps, with support from data as much as possible. Final runoff/river flow and percolation/groundwater will be determined through the following steps:

1. Analysing river flow data
2. Investigating hydrogeology
3. Analysing groundwater data

3.3 River flow

Most of the surface runoff will end up as river flow. In fact, rivers are the places where runoff is usually harvested. In Nakuru county, river flow data is available for a number of rivers, which are listed in Table 4. The river discharge is compared to the net precipitation in the catchment.

The Malewa river has by far the largest measured discharge. The discharge is equal to 77% of net precipitation, which is very high. This suggests that either very little water percolates in the upstream area and most of the net precipitation directly becomes runoff, or that a large portion of the water that percolates returns to the river as baseflow. In Rongai catchment, runoff consists of an even larger portion of the net precipitation, for Molo, Njoro and Gilgil this number is lower. For Karati, accumulated river flow is higher than net precipitation. This can only be explained in two cases: either Karati river receives baseflow from outside the catchment (unlikely but not impossible) or there is a large error in the data (either river flow data or net precipitation). The latter is the most likely: such databases tend to record days of no flow as no data, and thus such days are not taken into account in the calculation of average flow which causes an overestimation. Such errors have a significant impact on water resources assessments. An in-depth analysis into the water balance of this catchment is necessary to determine whether this result is realistic, while it also needs to be determined if a similar bias is present for the discharge data of the other rivers.

Table 4. River flow data for major rivers in Nakuru county

River	River discharge		Net precipitation (million m^3/y)	Percentage of net precipitation	Source
	(m^3/s)	(million m^3/y)			
Malewa	6.1	191	247	77%	Cheruiyot et al. 2018
Molo	1.2	37	66	56%	WRA
Rongai	0.8	24	28	86%	WRA
Njoro	0.7	22	33	67%	WRA
Gilgil	0.4	19	32	59%	WRA Everard et al 2002
Karati	1.0	33	27	122%	WRA

It is important to note that the data in these chapters are the best available estimations, but still contain uncertainties. Firstly, while the precipitation and evaporation datasets have been validated and perform adequately in the study region, the data may contain errors. The same is the case for river flow data, which are likely to contain errors even under the best circumstances. In addition, the point of measurement was not entirely clear for some of these rivers. Malewa measuring location was recorded, but for most of the others the endpoint of the river was assumed to be the point of measurement: for Njoro, Gilgil and Karati. For Njoro and Rongai, the more logical point of measurement was determined to be around Rongai town. These locations need to be confirmed.

3.4 Groundwater

3.4.1 Geological history

Nakuru county lies in the middle of the East African Rift, an active continental rift where the African plate is in the process of splitting into two tectonic plates. The Somali plate is drifting to the east, leaving the Nubian plate behind. The process started 22-25 million years ago and is continuing at an estimated rate of 6-7 mm every year. In the future, the Somali plate will eventually split from the Nubian plate and a new ocean basin will form, in an estimated 10 million years.

The Rift system is a complex fault trough with a general north-south orientation. It is however broken up by a variety of oblique structures and shorter rifts. Nakuru County itself is located at the intersection of two larger rifts within the greater Rift system: the Gregory Rift Valley (from Tanzania to Ethiopia) and the Kavirondo Rift Valley, extending westward from the shores of Lake Victoria. This location at an intersection of two rifts affects the local geology in two ways. Firstly, the fault structures are more complex, and secondly the area has been subjected to intense volcanism, evidenced by the presence of a number of volcanoes (Menengai, Eburru, Longonot and more).

Up to recent times, the area has been subjected to tectonics like smaller faulting and events of volcanism like basalt flows, while concurrently sedimentation took place. Lakes were formed through internal drainage only to be broken up again by faulting and dammed up by lava flows, giving rise to formation of new lakes through renewed internal drainage patterns. In the Pleistocene (2 million – 10,000 years ago), one great lake existed in the current Nakuru county area, extending from Menengai over the Gilgil escarpment to Hells gate and Longonot, which has since diminished to form to current

Nakuru, Naivasha and Elementaita lakes. Even today, tectonic activity is important in this region.

3.4.2 Current (hydro)geology

The current hydrogeological map of Nakuru county is presented in Figure 14. The formations are a mix of different volcanic materials; this map indicates very little in terms of groundwater availability. A more telling image is given by Figure 15. The different events of volcanism, tectonics and sedimentation have given rise to a complex geological pattern in the area. This means that for most of the area a combination of different geological formations can be found, and that these formations can be quite distorted within short distances of each other.

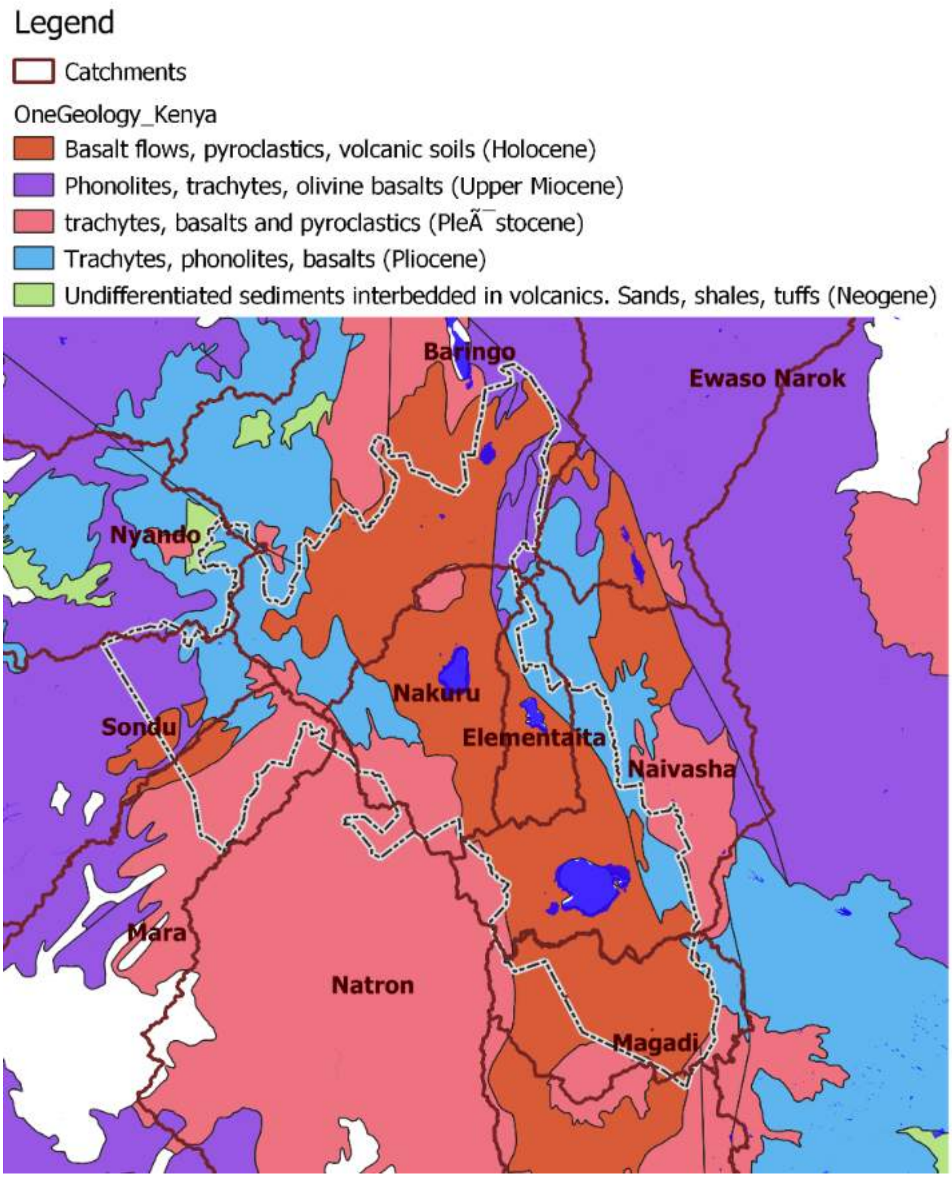


Figure 14. Geological map of Nakuru county area (source: OneGeology)

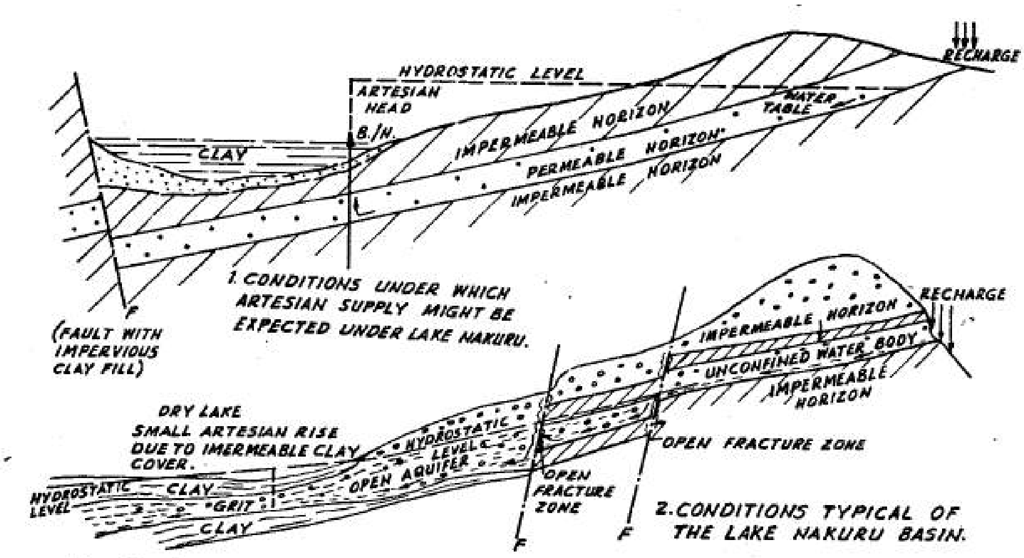


Fig. 10.—Comparison of a confined aquifer producing artesian conditions and the open system of aquifers typical of the floor of the Rift Valley.

Figure 15. Typical hydrogeological transects for Nakuru county

In the Nakuru area, four types of favourable formations for aquifers have been identified:

1. Sedimentary intercalations in the faulted lava flows
2. Old land surfaces separating lava flows
3. Fissures within the body of the lava flows and welded tuff formations
4. Lacustrine sediments deposited subsequent to the major faulting.

Most of the identified favourable aquifers are of the first two types: sedimentary intercalcations and old land surfaces between lava flows throughout the volcanic rock. These types account for over 90% of the aquifers in the area. In fact, such layers are so abundant that borehole failures are identified mostly as areas where piezometric head or favourable formations were too deep, not because of an absence. Kampi-ya-Moto, where the borehole failure rate has been high, is such an area. Additionally, it is not uncommon to find several water tables in a single formation, where clay layers separate aquifers.

The third type of aquifer is much less common and much less dependable as well. Fissures are widely spaced and steeply inclined, and it cannot be considered reasonable to site such aquifers deliberately.

The fourth type of aquifer consists of more recent lake beds, where a thick layer of sedimentation can occur. The area around Lake Elementaita, known to be a good borehole site, is the largest such formation in the area. Mineralization tends to be high in these aquifers though, with a chance of high salinity and especially high fluoride concentrations.

Underground connection between lakes

A complicating factor is underground connectivity between the lakes. Most of the lakes are saline or have otherwise high alkaline concentrations, which would be expected of interior basin lakes; no outflow combined with high evaporation causes mineral concentrations to increase. Two large exceptions occur however: Naivasha and Baringo are freshwater lakes.

This implies that underground outflow occurs for these lakes, on which consensus seems apparent (although the magnitude and direction of the flow is a subject of discussion). The latest study on this subject, Becht et al. (2006) use a water balance approach to quantify underground contribution of groundwater flow to and from Rift Valley lakes, in which they conclude that Lake Naivasha loses an estimated 55 million m^3/y to groundwater outflow, while Lake Bogoria, Elementaita, Nakuru and Magadi receive groundwater inflow of 28, 24, 16 and 71 million m^3/y respectively. The combined groundwater inflow of the lakes is around 40% of estimated groundwater outflow from Lake Naivasha; additional analysis indicates that Elementaita and Bogoria receive the bulk of their underground inflow from Naivasha lake, with just a small part going to Nakuru, which receives mostly recharge from local groundwater. Around half of the underground outflow from Naivasha is estimated to go to Magadi.

3.4.3 Groundwater exploitation

Boreholes have been sited successfully across the county; looking at the hydrogeology, this is not surprising. The abundant presence of different type of aquifers ensures that in most locations, there should be groundwater somewhere. This can be in the form of perched groundwater tables, confined aquifers, or a larger connected aquifer system. These different types of aquifers, however, mean that estimating the extent of the aquifers and the recharge they each receive is very difficult.

As such, the following considerations are vital for sustainable exploitation of groundwater resources:

1. Identify likely areas of recharge for the aquifer. Faults, wetlands, any losing stream systems that can be identified. If the recharge area is known, boreholes can be placed to exploit this recharge more directly and the source of recharge can be appropriately protected and even enhanced.
2. Monitoring. Even when properly sited near a recharge zone, exact recharge of the specific aquifer will never be known if water levels of the aquifer are not monitored, which is vital information for sustainable management of water resources.

Some groundwater monitoring data was provided by WRA for this study, covering the time between 2010 and 2017 (Figure 16 and Figure 17). While the water levels in boreholes around Nakuru generally increase between 2010 and 2015, a decreasing trend is observed over the most recent years. Naivasha boreholes seem relatively stable, with the exception of the Panda borehole; more data is needed to confirm the status of groundwater levels near this borehole. Decreasing groundwater levels have been reported for the DTI boreholes near Naivasha. Considering the hydrogeology, it is very plausible that within the same area some boreholes tap into local aquifers sustainably while other local aquifers are over-abstracted.

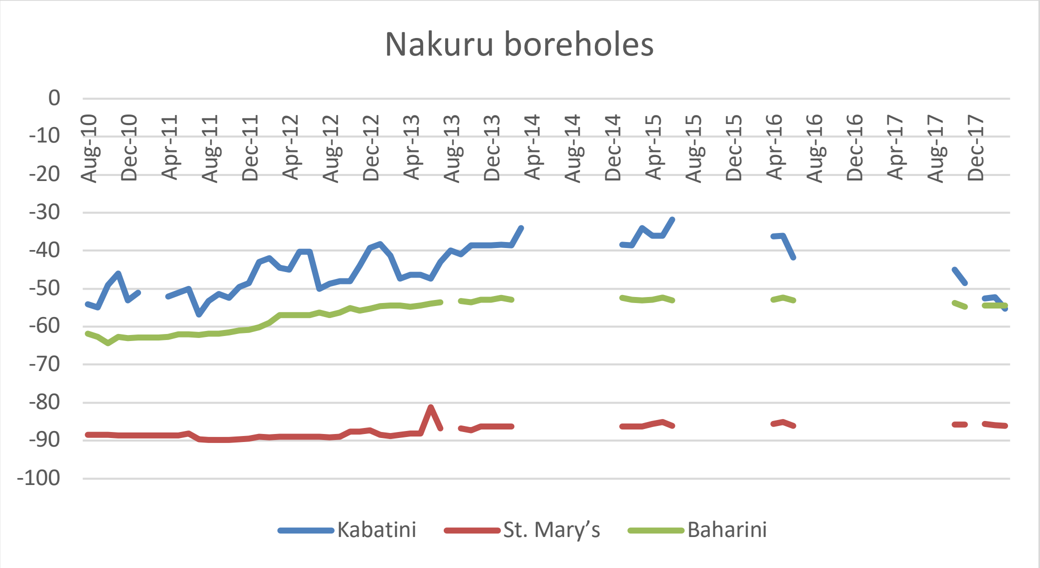


Figure 16. Groundwater levels around Nakuru town

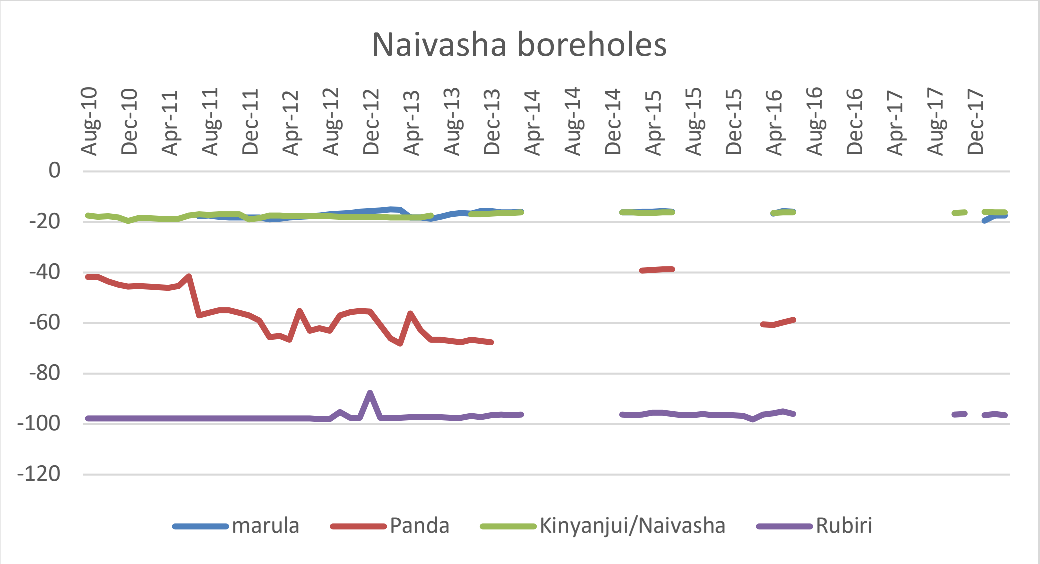


Figure 17. Groundwater levels around Naivasha town

3.4.4 Baseflow

In chapter 3.4 it was stated that Malewa river may receive a large portion of its water from percolated water returning to the surface as baseflow. Getting a better picture of the occurrence of baseflow in Nakuru county is important as it determines the viability of recharge promoting measures upstream of rivers. A modelling study by Muthuwatta (2004) was done for the Malewa and Gilgil rivers among others quantified baseflow contribution to these rivers. The conclusions are shown in Table 5. From this table it is evident that baseflow contribution to these rivers is high, about 40% for Malewa river and about 30% for Gilgil river. Such high contribution of baseflow is favourable for sustainable water management: baseflow is the main contributor of flow in the dry season, and such a contribution means that measures promoting infiltration in the upstream area are likely to be successful.

Table 5. Baseflow/runoff contribution to Naivasha rivers

	Total river flow (million m³/y)	From runoff (million m³/y)	From baseflow (million m³/y)
Malewa	209	122	87
Gilgil	29	20	9

3.5 Water quality

3.5.1 River water quality

River water quality has not been comprehensively researched in this report, but some basic information is available. For instance, high phosphorus levels have been reported in some rivers, such as the Njoro (Shivoga et al., 2005). This was attributed to agriculture, in which the use of fertilizer has become increasingly common. High concentrations of pesticides were found as well in both Lake Naivasha (Otieno et al., 2015) and in Lake Nakuru plus its feeder rivers (Mavura and Wangila, 2003). WRA was able to share some information on the quality of the Naivasha rivers of Malewa and Karati. Turbidity was very high, which is also likely related to changing land use patterns upstream: conversion to agricultural land often results in more erosion. Moreover, they report high levels of E. coli. Therefore, river water should be treated before domestic use. On the other hand, fluoride is reported to be low: 1.18 mg/l for Karati river and 0.23 mg/l for Malewa river. The low fluoride levels despite the large groundwater contribution in the Malewa river implies that percolated water upstream from Malewa travels to the river relatively quickly. This highlights the potential effectiveness of measures promoting infiltration in upstream areas.

3.5.2 Groundwater quality

Nakuru county is known to have high fluoride levels in the groundwater. Gevera and Mouri (2018) report fluoride levels ranging from 0.5 to 72 mg/l, with an average of 11.08 mg/l. Additionally, they report a strong positive correlation with the dominant physicochemical parameters and borehole depth, and a negative correlation with calcium and water hardness. These correlations suggest that mineral dissolution and evaporative enrichment are the main processes of fluoride release and concentration in groundwater, which means that the older the groundwater, the higher the fluoride concentration. Moreover, spatial analysis showed that fluoride concentrations were not confined to a certain type of aquifer, but rather to their locations. Low-fluoride aquifers were located close to the rift's Bahati and Mau escarpments, while high fluoride aquifers were found in the rift valley floor. Dilution of groundwater by high rainfall and short residence times in the escarpment recharge zones lead to low fluoride concentrations. Dissolved solutes accumulate in the rift valley floor aquifers due to and evaporative enrichment as groundwater flows for a longer time through the sub-surface, driven by high temperatures underground. This process leads to higher fluoride concentrations.

These conclusions are somewhat confirmed by the borehole database used in this study (Figure 18). Boreholes tend to have a higher fluoride in the bottom of the Rift Valley while lower concentrations occur on the escarpments. However, the availability of mineral data for boreholes in the latter area is very limited.

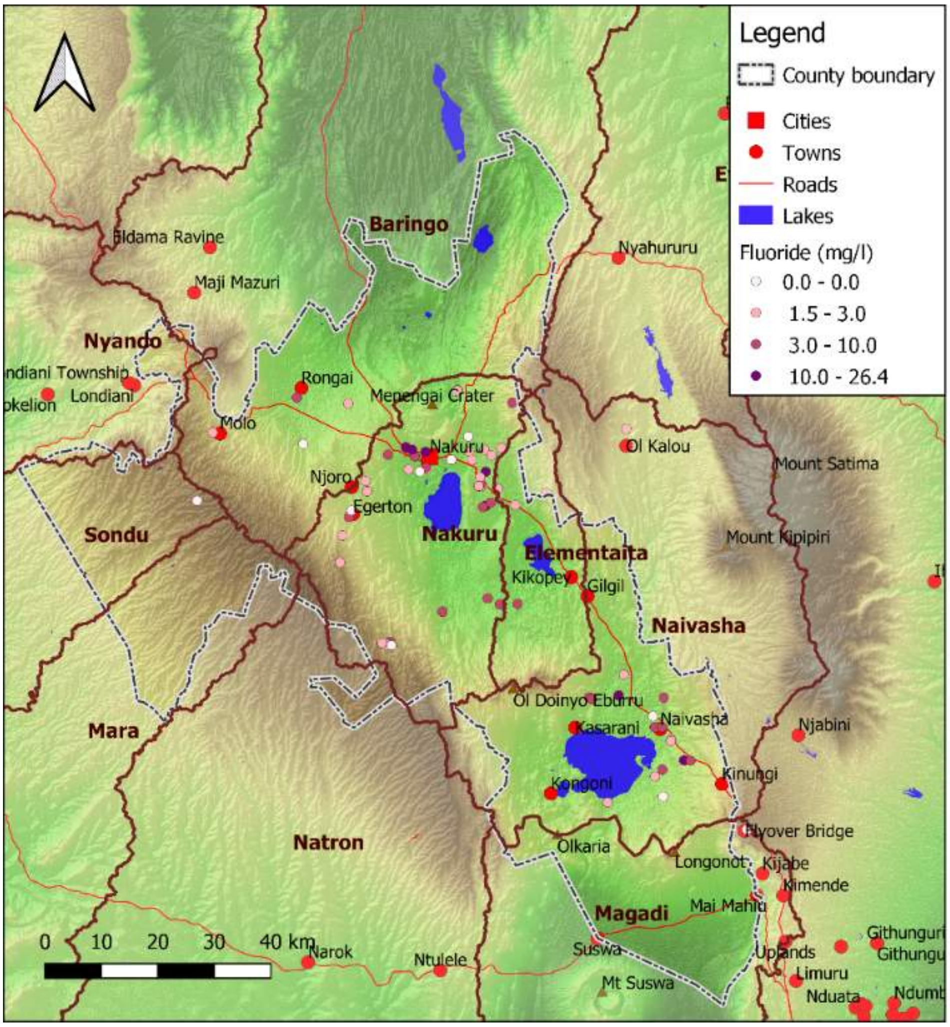


Figure 18. Fluoride levels in Nakuru county

3.6 Water demand and use

An important factor determining the quantification of water resources is an assessment of water demand and use. This information is needed to assess whether resources are underexploited or overexploited.

3.6.1 Water demand

Water demand constitutes the complete need for water for all activities in the county. This includes domestic, agriculture, livestock, industry, etc. At the time of writing of this report, only the domestic demand had been analysed. The water demand data are presented in Table 6.

Figures in this paragraph are taken directly from the ‘2019.07.01 Data Nakuru County_v7.xlsx’ document shared among WWX project partners. They are shown here purely for comparison with actual water use and as input for the source vulnerability study; they will not be elaborated upon in this document.

Table 6. Water demand of Nakuru county, current (2019) and future projections (2050)[2]

	Population 2019	Population 2050	Water demand 2019 (m³/d)	Water demand 2050 (m³/d)
NAWASSCO	533,800	2,089,100	40,000	191,000
NARUWASCO	526,300	1,335,900	36,600	139,900
NAIVAWASS	174,800	443,700	3,100	28,100
Other[3]	930,300	1,626,500	-	19,000
Total	**2,165,200**	**5,495,200**	**69,700**	**378,000**

3.6.2 Water use

Water use data for each of the WSPs were readily available and are shown in Table 7. Differentiation is made between water abstracted and water billed; water abstracted is to be compared with availability to determine sustainability of the water sources, while water billed is to be compared to water demand as this should depict water actually used.

As can be seen, while abstracted water meets the demand for NAIVAWASS easily, is just short for NAWASSCO and lacking for NARUWASCO. Water billed is moreover much less still, where even for NAIVAWASS it does not meet the demand. Quite a lot is to be gained through reduction of non-revenue water (NRW), but it is still necessary to increase water provision. Moreover, the predicted demand in 2050 far exceeds the current abstraction.

Table 7. Water use of WSPs in Nakuru county, averaged for the last year data was available

	Abstracted (m³/d)	Billed (m³/d)
NAWASSCO	37,900	22,000
NARUWASCO	22,000	7,700
NAIVAWASS	5,500	1,830

WSPs are not the only water users in the country. Many people use groundwater through private boreholes for a variety of uses, while river water is used directly mainly for domestic or irrigation use. For river water, it is at this point not possible to make an estimation of the quantity that is used, which is a big gap that needs to be filled. Boreholes, however, are generally recorded before use. Data from these boreholes can be used to estimate water use from private sources.

Three borehole databases were collected:

1. From WRA regional office in Nakuru, covering 194 boreholes throughout Nakuru county (and more outside);
2. From WRA Naivasha office, covering 637 boreholes (33 of which overlap with the Nakuru database and 6 of which are of NAIVAWASS (Table 7); and
3. From NAWASSCO, covering 22 private boreholes in Nakuru town (no apparent overlap with first WRA database, though this is not conclusive).

It is important to note that the data contained within each of these databases are not consistent and are not always complete.

---

[2] Irregularities were encountered with water demand, use and billed, where local figures differ from official figures. In this report only official figures are incorporated in such cases

[3] This concerns the area not currently covered by NARUWASCO but under the official jurisdiction and is planned to be covered

Coordinates were recorded for 131 of the 194 boreholes in the first database, and for all boreholes in the third database. Though no coordinates were recorded in the second database broad indications were given for location indicating a concentration in the Naivasha area. As far as possible, all boreholes were mapped, including WSP boreholes and other water sources (Figure 19).

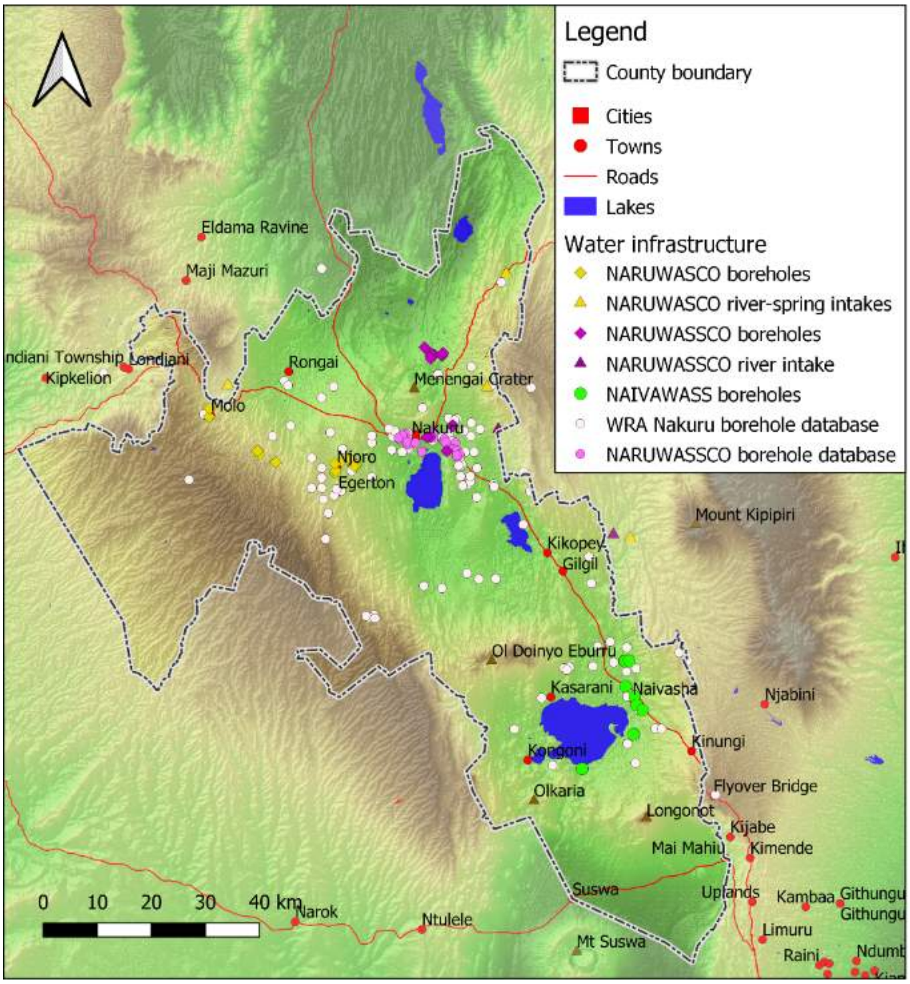


Figure 19. Water infrastructure of Nakuru county

The first two databases contain information about the purpose of the extraction for most boreholes, see Table 8. About half of all boreholes are sunk for domestic purposes, about 20% for irrigation purposes, and a decent number for mixed use (12-27%), mainly domestic and irrigation. Looking at the relative abstractions however, a clear difference between the Nakuru and Naivasha databases is observed. Abstraction rates are in line with the number of boreholes for Nakuru, with the most notable difference being that abstraction for domestic is smaller and for irrigation higher than would be expected based on the number of boreholes alone. In Naivasha, this effect is much more extreme: pure domestic use is almost negligible, with irrigation and mixed use making up 90% of the total abstraction. This difference can be explained by the lower number of residents in Naivasha and the high amount of agricultural activity in the region. Only a small number of wells are used for other purposes like public use, industry, construction, monitoring, etc. The relative abstraction rates for these uses are comparatively small as well.

Table 8. Purpose of boreholes

Borehole purpose	WRA Nakuru database (% of boreholes)	WRA Naivasha database (% of boreholes)	WRA Nakuru (% of abstraction)	WRA Naivasha (% of abstraction)
Domestic	56	45	41	4
Irrigation	16	21	36	49
Public	8	4	7	2
Industry	6	1	3	0
Mixed use	12	27	10	41
Other	2	2	2	4

Finally, for a number of these boreholes yield was recorded: 131 out of 194 for the first database and almost all of the second database (while none for the third database). These yields are reported in Table 9. In some cases, the unit of the reported yield was uncertain. In the table, these entries have been noted separately from the boreholes where the units of the abstractions were clear.

Interestingly, reported yield is much higher for the Naivasha area, almost ten times higher than the Nakuru database while this database covers a much larger area. Farming activity is known to be high in Naivasha, so it is plausible that abstractions are higher, but such a large difference should be validated.

Table 9. Borehole yield

	Clear reported yield (m^3/d)	Uncertain reported yield (m^3/d)	Total (m^3/d)
WRA Nakuru database	19,500	21,300	**40,800**
WRA Naivasha database	-	395,000	**395,000**

Due to the gaps in available data and the uncertainty regarding the exact location, units of measurement, and current operationality of the boreholes in the three databases, the numbers and figures in this paragraph should be used with caution. The data are used to give the best possible approximation of water use, but efforts should be made to increase completeness and reduce uncertainties in order to be able to work with more accurate figures.

3.6.3 Water use summary

Currently, all WSPs meet the water demand within their jurisdiction in terms of abstracted water, although actual provision still comes up slightly short. Water demand is expected to increase significantly, however, with a total increase of over eight times the current demand by 2050 (Table 10 on the next page).

Total abstraction is not restricted to WSPs, there are a number of private boreholes across the county and surface water is used as well. Use of surface water cannot be quantified currently, but global estimates of borehole abstraction can be given (see Table 11). Many uncertainties pertain these numbers however and thus they should be verified and used with caution until then.

Table 10. Water demand summary

	Water demand 2019 (m^3/d)	Water demand 2050 (m^3/d)
NAWASSCO	40,000	191,000
NARUWASCO	36,600	139,900
NAIVAWASS	3,100	28,100
Other	-	19,000
Total	**69,700**	**378,000**

Table 11. Water use summary

	Water abstraction (m^3/d)
NAWASSCO	37,900
NARUWASCO	22,000
NAIVAWASS	3,500
WRA Nakuru database	40,800
WRA Naivasha database	395,000
Total	499,200

3.7 Source vulnerability

In the future, temperatures are expected to increase as a result of climate change. The major consequence of this is that evapotranspiration will likely increase, which may result in lower net precipitation. As Nakuru county is located mostly in an ASAL (Arid or Semi-Arid Land) area, the change in evapotranspiration is likely not as strong as the change in temperature because the area is water scarce. However, even slightly lower net precipitation will increase pressure on resources in an area already short on water.

The change in rainfall patterns will likely be a more important factor than temperature. Annual rainfall totals are expected to increase slightly, but the pattern of rainfall within the year will change. More intense showers lead to increased runoff and decreased recharge. This means that recharge groundwater resources may be lower than under the current climate. This further highlights the need to closely monitor groundwater resources.

Landcover change will lead to an increase in runoff due to the increase in hard surfaces, and thus an increase in peak river flow. This means that river flow as a source will increase, but only in the form of extreme events. This comes at the cost of increased erosion and flooding; this is expected to lead to land degradation, decrease in water quality and siltation of dams (the main river flow harvest mechanism).

Moreover, landcover change comes at the cost of decreased recharge. Since groundwater is still the main source of water for people in Nakuru, this is a serious consequence. Dropping water levels in recent years are indicate that over-abstraction may already be an issue. This issue will be exacerbated by the expected population growth and the accompanying increase in water demand. Moreover, decreased recharge means less natural mixing of water, which may result in higher fluoride levels.

All in all, especially groundwater resources are coming under increased pressure, although this will trickle down to river flow as well as baseflow contributes majorly to rivers.

3.8 Conclusion

A summary of the different components of the water balance, from net precipitation to river flow, diffuse recharge and water use, is presented in Table 12.

Table 12. Summary water balance catchments of Nakuru county

Type of catchment	Catchment name	Net precipitation (m^3/d)	River flow (m^3/d)	Diffuse recharge (m^3/d)	Water use (m^3/d)
Full internal basins	Nakuru	500,000	350,000	150,000	56,000
	Elementaita	150,000	105,000	45,000	2,800
	Naivasha	1,240,000	868,000	372,000	400,000
Rift Valley lake sub-catchment areas	Baringo	810,000	567,000	243,000	2,400
	Magadi	670,000	469,000	201,000	
	Natron	50,000	35,000	15,000	
Lake Victoria sub-catchments	Mara	530,000	371,000	159,000	
	Sondu	590,000	413,000	177,000	
	Nyando	70,000	49,000	21,000	

Based on the findings of this chapter and the water balance above, a few conclusions can be drawn:

1. Groundwater resources in Naivasha are likely overexploited. Groundwater abstraction is higher than diffuse recharge, and that is not even considering the abstraction in Nyandarua on the Kinangop plateau. In reality, the actual groundwater recharge may be higher than the estimate based on net precipitation due to additional recharge from rivers and floodplains, but a more detailed analysis is required to determine this. In fact, while some boreholes do report decreased groundwater levels, others report steady groundwater levels, which indicates that the suspected over-abstraction is likely mostly local. In any case, the water resources in this area need to be handled very carefully, as Lake Naivasha is dependent on these as well. This will require to engage local abstracters for irrigation, to monitor their abstractions and maybe even limit their abstractions, which will not be easy.
2. The Malewa river is in a very unique position as it drains the largest area with the highest precipitation in Nakuru county. Baseflow is an important component of the river flow, and travel times are relatively fast. Promoting infiltration measures upstream of the Malewa river could safeguard and even enhance Nakuru's largest resource quite effectively. This area is mostly located in Nyandarua county however, so such activities and possible strategies need to be discussed with Nyandarua county government first.
3. Water use in Nakuru and Elementaita catchments is lower than the estimated recharge, suggesting that water use is sustainable under the current conditions. However, with the projected increase in water demand, groundwater resources will be subjected to considerable pressure if no steps are taken. Especially for Nakuru town, relying mainly on groundwater will not be sustainable in the future and alternatives will have to be considered.
4. Groundwater quality is an important issue. Especially in the middle of the Rift Valley, groundwater can be expected to have high fluoride concentrations. As fluoride concentrations seem to have a direct correlation with time spent underground.

Therefore, elevated fluoride concentrations can be expected in recharge areas like floodplains and losing stream systems, and areas close to the Rift Valley escarpments.

5. The Lake Victoria sub-catchments on the west side of the Mau complex receive a considerable amount of total and net precipitation despite their small area. Potentially, water resources from these areas could be used to supply Nakuru town and relieve pressure on local groundwater resources (as is currently planned with the Itare dam), though information about water use and demand for these sub-catchments is required to determine whether this is a sustainable course of action.
6. While there is now a reasonably comprehensive understanding of the major catchments of Nakuru, Elementaita and Naivasha, large gaps exist especially for the peripheral catchments. No data was shared for use in the Lake Victoria sub-catchments, very little for Baringo and Magadi catchments, and upstream Naivasha catchment very little was known as well. Filling of these and more gaps should be part of any new strategy, especially if water resources will be transported between these catchments. This is discussed further in chapter 4.4.

For groundwater exploitation, the following steps should be undertaken:

1. Consider the regional distribution of fluoride levels. The overall trend of fluoride is highest in the middle of the Rift Valley and lower towards the escarpments, but local areas of recharge and local formations cannot be disregarded. Keeping an up-to-date database of fluoride levels and considering them before groundwater exploitation is essential.
2. Consider the local hydrogeology. Identifying recharge zones will ensure more sustainable groundwater extractions with better water quality.
3. Geophysical measurements. Such measurements are necessary to establish whether the right type of aquifer does occur at a proposed drilling site.

4 Implementation

4.1 Water resource potential and climate change mitigation

The largest single water resource in the county is Malewa River. Not only does it drain the largest catchment area with the highest rainfall in the region, a very considerable part of its flow is baseflow from groundwater. However, the river is already considered to be overexploited, as the last few years very little water reaches Lake Naivasha. Focussing on upstream infiltration promoting measures (working in tandem with Nyandarua county government) should be a very large priority for sustainable water management as it protects the source of the area's largest water resource and even can increase the baseflow to the river.

Meanwhile, the use of this resource and the groundwater resources related to Malewa river needs to be considered carefully. If validation of the borehole database shows that Naivasha groundwater resources are indeed overexploited, groundwater abstraction needs to be limited. Farmers will have to be restricted in their irrigation use as to not deplete the local aquifers. They might have to be steered towards alternative water sources, like surface water.

Surface water resources in general deserve more attention in Nakuru county. These do not necessarily have to be made available by large dams; many small to medium scale infrastructure exist that can provide water as a resource. 3R is a framework for such interventions, including water pans and sand-, valley- or hillside dams. These interventions can capture runoff water more directly. Water quality can be of varying levels, but fluoride levels are bound to be low, and mixing with borehole water can be considered. Moreover, such infrastructure tends to work well in rural areas as the intervention size can be tailored to the community water demand.

Alternatively, a focus on local water recharge can be very effective. When groundwater recharge is known, well-sited boreholes will be more sustainable. Enhancing recharge through runoff reduction/infiltration promoting interventions should be very effective as well and could even improve water quality. An even more effective technique to promote infiltration is called Managed Aquifer Recharge (MAR). This technique is aimed at effectively recharging runoff water very locally, so it can be pumped up again when necessary (dry period). This can be done passively (e.g. through ponds) or actively (e.g. through injection wells). Even without these types of interventions, the protection of the recharge zone should be considered (the 3R framework covers protection as well).

Another pillar of the 3R framework is Soil and Water Conservation (SWC). Increased runoff and soil erosion have been reported in the area, as a result of increased farming practices. Whether this has led to a decrease in soil fertility and loss of arable land yet is not certain, but unless sustainable farming practices are applied this will almost certainly be the case. A good way to protect or even restore agricultural land is through application of SWC measures: contour mechanisms (stone bunds, trenching, etc.), terracing, mulching, etc. These interventions are focussed mostly on slowing down run-off to retain local nutrients and soil moisture, and thus improving soil conditions for agriculture. In addition to improving soil conditions, SWC measures mitigate issues with flooding and river water quality due to decreased runoff and erosion, while increasing groundwater resources due to increased infiltration. Annex 1 provides more information on 3R and MAR.

Different interventions have now been put forward. Not all of these interventions are suited in every location however; especially for 3R the specific environment matters a lot for which intervention is the most effective. To aid the decision-making process, a map can be developed which indicates for the entire area which interventions are most suited where (an example is given for Northern Kenya in Figure 20). Developing such a map would be a good first step for the decision-making process.

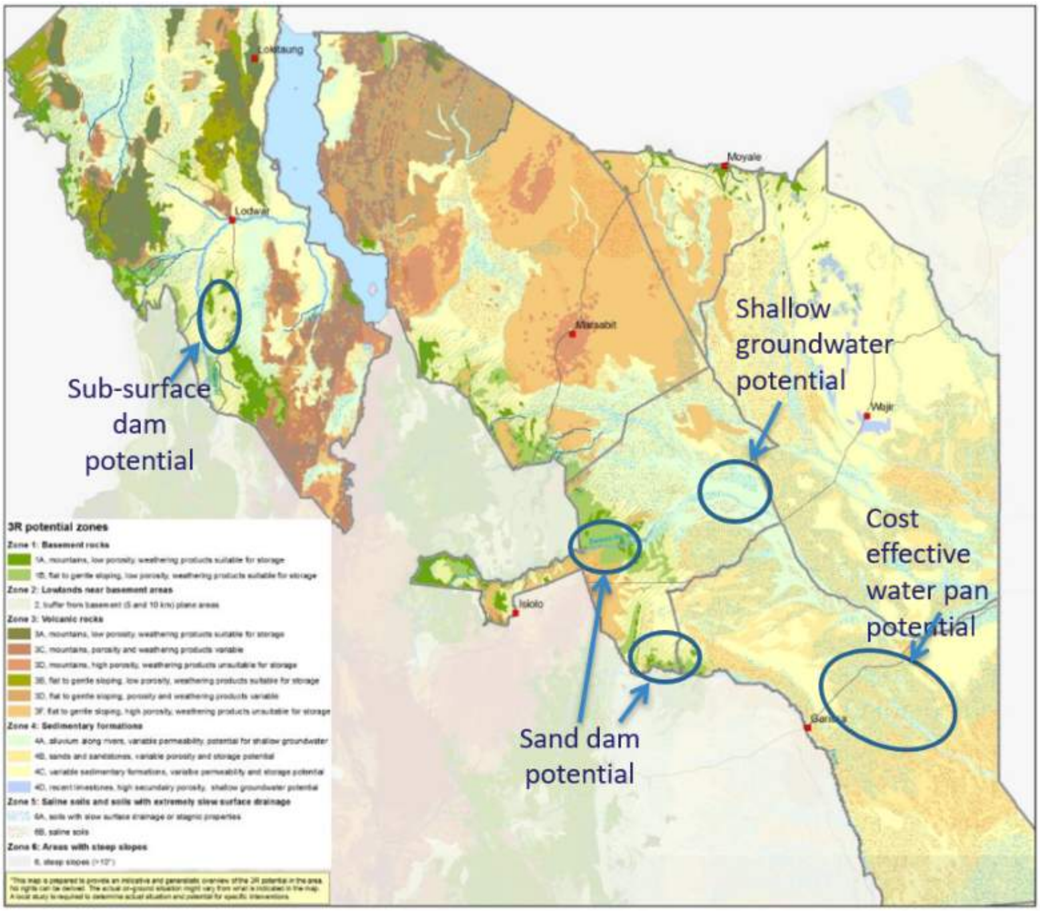


Figure 20. Intervention potential map of Northern Kenya

Water resources in the Naivasha catchment are under the most pressure based on the analysis in Chapter 3 (although the water use assessment needs to be validated). There is still more potential in Nakuru and Elementaita catchments, but to meet the water demand in Nakuru town in the future, using resources from other catchments is inevitable. The Sondu and Mara catchments, in particular, could be used to relieve pressure on local water resources, as precipitation and net precipitation are relatively high in these areas. The currently planned Itare dam is aiming to do exactly that and thus this plan should be continued. Demand is expected to even rise far beyond of the provision of the Itare dam, however, and the necessity of additional projects of a similar nature should be assessed. However, for both Itare dam and any additional plans to transport water resources, local use in the Sondu and Mara catchments (within Nakuru county as well as downstream) should be quantified and taken into account.

4.2 Nakuru Sponge City

As is evident from this report, Nakuru town is facing a number of issues. A shortage of water supplied is already an issue for the whole county, and with the estimated population growth this shortage is likely to get bigger, especially in Nakuru town. Meanwhile, the major current water sources of Nakuru town have high fluoride levels. Current data does indicate that water resources in the Nakuru town area are overexploited, which makes sense as direct recharge has been minimized due to current nature of Nakuru town: hard surface allowing little infiltration. Moreover, this hard surface promotes extreme runoff, resulting in floods which is another major issue in Nakuru town. Finally, while not specifically reported as a problem, large towns such as Nakuru almost always incur large-scale pollution; garbage in the streets, chemicals leaking into the ground, air pollution, etc. Whether or not this is considered to be a major issue now, this will become increasingly relevant as the population increases if no measures are taken.

A new approach is being developed to increase water availability throughout the year and buffer floods: the Sponge City concept (Figure 21; Acacia Water et al., 2019). This approach utilizes the 3R framework referenced in chapter 4.1 (see Annex 1), focussing on interventions which retain, recharge and re-use water to create a town or city which absorbs as much water as possible (like a sponge) instead of letting all the water become runoff. Such interventions can effectively reduce flooding while increasing direct water service provision or groundwater availability and can help combat pollution in a number of ways.

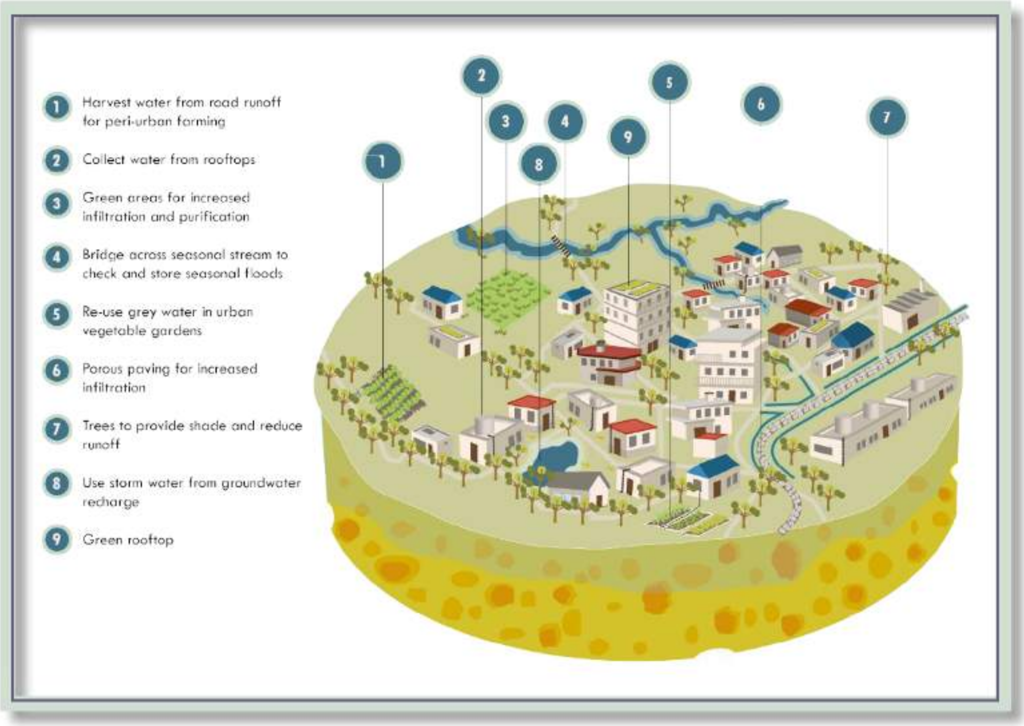


Figure 21. Sponge city concept

The first and most foremost suitable intervention is large-scale implementation of storage tanks for direct use. Storage tanks can capture rainwater, which may otherwise contribute to the flooding, and can directly service water need of households. There is a major obstacle to overcome for this idea however from a WSP standpoint: providing households with water tanks will release a WSP of part of its income.

This issue should be addressed by building a new business model around the provision of water tanks. If households can pay their water tanks on a monthly fee basis for instance, this could create an additional revenue stream for the WSP. Additional study is needed to properly assess the potential of water tanks and feasibility of a new finance model in the study area, this idea should be explored further.

Other suitable interventions are more focussed on promoting recharge. Building parks, infiltration ditches, swales and similar structures can significantly improve recharge. Especially when sited strategically, like confluence points of runoff and near (over)exploited aquifers, multiple issues can be dealt with at once. The major challenge with these measures is finding the space to do it, as urban areas tend to be quite congested. Again, it is about finding the balance between the expected benefits of the intervention and its costs.

The highest potential for such interventions is in relatively densely urbanized areas: around CBD, Shabab, Afraha and Rhoda. A total area of about 12 km^2 is covered by such densely urbanized, hard-surface area. With an average rainfall of 870 mm/y, that is an average potential of about 28,700 m^3/d. This is almost as much as current demand. It is not reasonable to expect to be able to capture all this water. However, by making a quick-and-dirty calculation a more reasonable number can be found. Assuming an average roof area of 30% where rainfall can be captured, and if an additional third of the remaining runoff can be captured as groundwater, the potential water resource would deliver about 15,300 m^3/d, about half of current demand. Of course, demand is expected to rise as population grows, but this will be accompanied by an increase in urbanized compacted area. Assumptions made here need to be verified as reasonable, but a quick analysis shows that such Sponge City infrastructure indeed has a lot of potential to provide water resources directly to its inhabitants.

Identifying the right partners is also a very important aspect of a Sponge City. Organizations and people which are affected by water resources issues in Nakuru town can contribute to Sponge City interventions. Participants are more likely to be motivated to be involved if it can help them directly (e.g. for flooding these parties can often be identified directly). Even better, sometimes people can directly benefit from helping alleviate problems, like empowering garbage collectors (NAWASSCOAL is a good example of this).

Nakuru town storm water management programme of the Ministry of Water and Sanitation

Additionally, at the time of writing, a different project is being set up by the Ministry of Water and Sanitation focussed on management of waste and storm water, with a concept note developed in April 2019 titled '*Concept on Nakuru Town waste and storm water management programme*'. In the current concept note multiple strategies are proposed aligning directly with the Sponge City approach: to *'implement a comprehensive waste and storm water management system for recycling and reuse'*, *'to develop approaches for artificial groundwater recharge/managed aquifer recharge'* and *'to develop and* *implement rain water harvesting programme'.* Setting up a collaboration between this project and the WWX project would make great sense; at the very least to make sure no double or interfering work is being performed, but potentially joined goals can be set up and resources can even be pooled to achieve these goals, which would lead to greater accomplishments.

4.3 Towards sustainable cooperation

The original partners of the WWX programme in Nakuru county are the WSPs: NAWASSCO, NARUWASCO and NAIVAWASS. As such, during the formation of the project outline the focus has been on the WSPs to work together on all parts of the project, including the parts related to water resources. A water resources officer was appointed from each of the WSPs, with the ambition to let these officers consider water resources for all future activities. However, over the course of the mission, this setup was determined as unlikely to be sustainable. Firstly, because managing water resources is not in the mandate of a WSP, which is restricted to provision of water. And secondly, all of the appointed water resource officers had different duties besides water resources, duties which were more directly related to water provision. Although the officers appeared eager and engaged, it is likely that if they are not continuously directed through the WWX program to keep considering water resources, focus will fall back upon their other activities which are much more closely aligned to the mandate of the WSPs.

The premise is that official mandate will safeguard the continuity of related activities. So, to make sure activities concerning water resources are continually carried out, the organization with the mandate to manage water resources needs to be included. As a result, it was decided to focus on the Water Resources Authority (WRA) and aim for them to own the Water Resources Assessment.

WRA is not currently part of the WWX consortium. Contact and initial cooperation has been established by means of an official letter expressing this need for cooperation signed by both parties with WRA Nakuru, the regional office for Rift Valley catchment. Contact has been established with the sub-regional office in Naivasha as well, although a base for cooperation is still in development. A third office, the one which governs the Sondu and Mara catchments of WRA Lake Victoria is yet to be contacted.

The current idea is to make WRA members a regular participant in the stakeholder forum. The stakeholder forum would allow close contact to be kept between the WSPs, WRA and other relevant parties. Whether or not inclusion on the stakeholder forum is enough or some additional consolidation is required, like setting up an MoU, remains to be determined. **The stakeholder managers should keep a close eye on this, discuss it among themselves and with WRA.**

What is important to keep in mind during the consolidation of the cooperation, is that to be able to get WRA on board the cooperation needs to be mutually beneficial. This aspect should be stressed in the beginning and safeguarded during the formation.

What is asked of WRA:

- Clear communication on their considerations concerning water resources
- Clear suggestions on water allocation
- Development of a shared database

What is offered to WRA:

- That their considerations are taken into account by the WSPs and stakeholder forum, thus safeguarding their interests (water resources)
- Opportunities for combined strategies/activities (e.g. monitoring, watershed protection, capacity building; WWX can possibly directly contribute to this)
- Development of a shared database

Another suggestion has been put forward: to have a true water resource expert for the WSPs. This water resource expert will operate for all three WSPs and will be the link between the WRA and the WSPs on a technical level. Two options were put forward: assigning someone from within the WSPs or hosting someone from WRA to perform this function. Whether the second option is viable depends on the willingness of WRA.

Additionally, this cooperation needs to trickle down to lower levels. WRA does very little on the ground, these activities go through Water Resource Users Associations (WRUAs). For the WSPs, similar structures exist, with Water Users Associations (WUAs) managing water service provision on the ground. How to establish cooperation from county level to this level will need to be discussed within the stakeholder forum.

At this point, initial contact has been established WRA Rift Valley Basin Area; with the regional office in Nakuru and the sub-regional office in Naivasha. However, as explained in chapter 3.1, a part of Nakuru county (Sondu and Mara sub-catchments) is located the Lake Victoria basin. This area is governed by a different WRA office, WRA Lake Victoria South Basin Area in Kisumu. Cooperation should be established with this office as well.

Lastly, while for management of water resources specifically WRA is the most important actor to consider, for water management as a whole and through the interconnectedness of water with other resources many more actors need to be engaged: the county government (departments of water and environment, agriculture, lands, etc), other regulatory agencies (WASREB, NEMA, KWS, KFS, etc), CSOs, CBOs, and many more. The degree of engagement needed will differ per actor.

To conclude:

- Cooperation with WRA is vital for sustainable management of water resources;
- The stakeholder platform could provide a good base for cooperation;
- Further consolidation might be required however to safeguard cooperation, like through an MoU;
- During establishment and consolidation of cooperation mutual benefits should be continuously stressed;
- WRA Nakuru regional office is already engaged, WRA Naivasha sub-regional office is being engaged while the relevant WRA office for Lake Victoria sub-catchments still has to be engaged;
- An interesting option is to appoint a full-time water resource officer for the WSPs, although feasibility has to be established first;
- Cooperation needs to trickle down to lower levels (WUAs with WRUAs) as well;
- Cooperation needs to be established with both the Rift Valley Basin Area offices (Nakuru regional office and Naivasha sub-regional office) and the Lake Victoria South Basin Area in Kisumu; and
- Cooperation should not be limited to WRA, but many different organizations should be engaged to different degrees.

4.4 Financing & investment perspectives

Financing is an important part of making a water supply plan climate proof and resilient. There is a wide range of multi- and bilateral donors that can be explored, such as the World Bank Group[4], African Development Bank (AfDB)[5], Green Climate Fund (GCF)[6] to financing opportunities through the Dutch Embassy in Nairobi (EKN). However, there are financing mechanisms which are perhaps more fitting to the climate adaptation objectives of this climate resilient water supply program 2050 assignment and include:

1. The Nordic Climate Facility (NCF)[7], an initiative by the Nordic Development Fund (NDF), which offers grants between EUR 250,000 and 500,000 for innovative climate change projects in 21 developing countries, including Kenya. An important condition is, however, that there must be at least a partnership between Nordic and local partners. Potential Nordic partners could be NORDECO[8] or the Stockholm Environment Institute (SEI)[9]. Furthermore, the project partners need to mobilise at least 25% co-financing (cash or in-kind) of the requested NCF grant as loan, equity and/or grant[10];
2. *Partners voor Water (PvW)*: Water security in urban delta's (WWSD)[11] of the Netherlands Enterprise Agency (RVO), stimulates the demonstration and feasibility of innovative technologies and methodologies in the field of water – such as the Sponge City or MAR system concepts – and in urban delta's, and encourages partnerships between Dutch and local consortium parties. New tenders can be submitted until September 6th, 2019;
3. Another option is Develop2Build (D2B)[12], also from the Netherlands Enterprise Agency (RVO), which is a Government-to-Government program and assists in setting up infrastructural projects by financing execution of feasibility studies, conceptual designs and/or environmental impact assessment reports.

It is advisable to investigate the possibilities for cooperation and financing at an early stage with potential donors but also with strategic partners. Experience shows that parties are eager to think along with you and that together you often come further and to more innovative solutions, both technically, strategically and financially.

4.5 Towards climate resilient management of water resources

4.5.1 Gaps

In this report, a first overview of water resources has been given. However, the assessment is by no means a complete and a large number of gaps has been established. In order to manage water resources sustainably and to prepare for the challenges ahead, the assessment of water resources needs to be continued and expanded upon.

---

[4] https://www.worldbank.org/

[5] https://www.afdb.org/en

[6] https://www.greenclimate.fund/home

[7] https://uutiskirje.ndf.fi/a/s/160071856-e7a9162e9d6d0164e335e4a20a3b981a/2624637

[8] https://www.nordeco.dk/

[9] https://www.sei.org/centres/africa/

[10] Read for more funding principles paragraph 4.3 of NCF Application Guidelines: https://www.nordicclimatefacility.com/documents/NCF-9-Concept-Note-Application-Guidelines.pdf

[11] https://www.rvo.nl/subsidies-regelingen/partners-voor-water-pvw (in Dutch)

[12] https://english.rvo.nl/subsidies-programmes/develop2build-d2b

The following gaps should be filled:

- Adjust demand to 2019 census
- Map demand types other than domestic
- Map actual use of surface water
- Complete and verify water use database:
    - Missing/faulty locations and missing/faulty abstraction rates
    - Little to no data for Baringo and Magadi catchments and Lake Victoria sub-catchments
    - Confirm operationality of borehole databases (especially Naivasha database)
- Map abstraction in more detail spatially
- Confirm river flow measuring locations
- Check existence no-data bias of days of no discharge for river flow measurements.

The identified gaps should be not only be filled, but all water resources data should be regularly monitored and kept up-to-date, and the knowledge base should continuously be built upon. Only then can water resource sustainably be governed. This includes:

- Continuous monitoring of:
    - River discharge
    - Groundwater levels
    - Water quality (especially fluoride)
- Keep borehole/water infrastructure data updated, particularly:
    - Yield
    - Water level
    - Location
    - Operationality
    - Water quality
    - Keep water demand and water use updated, especially in light of expected population growth and urbanization
    - **Continually process and assess this data!**

4.5.2 No regret measures

Many recommendations have been made in this report. There are quite some opportunities, but these need to be prioritized. To aid the process of prioritization, a small list of no regret measures is given here: measures that are smart already at this moment, and future developments will not make them counterproductive.

- Increasing monitoring: install more monitoring boreholes for water levels and monitoring points at discharge stations for river flow (under management of WRA);
- 3R measures for Nakuru town: building water tanks and (where space allows) infiltration measures at public spaces, schools, NAWASSCO plaza, government offices, sports clubs, churches, private companies, etc.;
- Catchment protection for wellfields and MAR at wellfields of NAWASSCO and NARUWASCO;
- Catchment protection and riverbank infiltration for Malewa river near Naivasha.

4.5.3 What to be done by who

The majority of this report is focussed strongly on water resources. As such, most of the content of this report is targeted to the water resources managing partner within the WWX program (advised to be WRA). The conclusions and recommendations however (from chapter 3.8 onward) pertain to all of the WWX partners.

Statements in this chapter are based on discussions held with the project partners and by the personal judgement of the author; in the end however, **responsibilities should be assigned by and agreed upon by the WWX partners themselves.**

Chapter 3.8 should be read by all WWX partners and its content should be kept in mind throughout the initial stages of the program.

Chapter 4.1 and 4.2 is direct input for the 'Climate resilient water supply program 2050' strategic plan. This plan will be a shared result of all WWX partners, so the responsibility considering the recommendations of these chapters for input of this plan is shared as well. The stakeholder forum will have the largest contribution to the plan however, and thus will have the largest responsibility towards linking this report to the plan, plus initial responsibility of following up on smaller more pressing recommendations such as:

- Filling of gaps on and validation of demand and use;
- Assessment of potential and feasibility of water tank promotion with alternative financing structure;
- Establishing contact with the Ministry of Water and Sanitation in regard to the *'Concept on Nakuru town waste and storm water management programme'* and exploring opportunities for collaboration.

Chapter 4.3 is input for the stakeholder platform; its recommendations should be followed up by their members.

Chapter 4.4 is input for WWX project leaders, WWX acquisition officers (or project members with similar functions) and VEI.

Chapter 4.5.1 is a list of the most straightforward but pressing gaps to fill. As these gaps are mostly related to water resources (and serve as direct input for an updated water resources assessment), they should be under primary responsibility of the water resource managing partner of the program.
This is advised to be WRA, but as cooperation is still being discussed, initial responsibility is given to the stakeholder platform. Shifting of this responsibility should be done along the way of establishing and consolidating cooperation, always in agreement. Even at a later stage, responsibility will always be partly shared as input will be needed from both WSPs as WRA (developing a shared database will aid this collaboration).

References

- Acacia Water, Amref, MetaMeta, MTTI, NIA, RainAidenvironment, Sasol, South Eastern Kenya University & VIA Water. (2019). How to create a sponge town? Sponge Town Guideline.

- ASSAR. (2018). Determining what global warming of 1.5°C and higher means for the semi-arid regions of Africa - overview of analyses.

- Ayuyo, I. O. A., & Sweta, L. (2014). Land cover and land use mapping and change detection of Mau Complex in Kenya using geospatial technology. International Journal of Science and Research (IJSR) ISSN (Online), 2319-7064.

- Baker, Tracy. (2008). Land Cover and Land Use Change in the Njoro Watershed, Kenya: A Threat to Human and Ecosystem Health.

- Becht, R., Mwango, F., & Muno, F. A. (2006). Groundwater links between Kenyan rift valley lakes.

- Chepkochei, L., & Njoroge, F. (2012). Analysis of land use/cover changes in the Menengai landscape, geothermal prospect using landsat TM. Trans Geotherm Resource Counc, 36, 621-4.

- Everard, M., Vale, J. A., Harper, D. M., & Tarras-Wahlberg, H. (2002). The physical attributes of the Lake Naivasha catchment rivers. In *Lake Naivasha, Kenya* (pp. 13-25). Springer, Dordrecht.

- Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International journal of climatology*, *37*(12), 4302-4315.

- Gevera, P., & Mouri, H. (2018). Natural occurrence of potentially harmful fluoride contamination in groundwater: an example from Nakuru County, the Kenyan Rift Valley. *Environmental earth sciences*, *77*(10), 365.

- Intergovernmental Panel on Climate Change. (2014). Long-term Climate Change: Projections, Commitments and Irreversibility. In Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1029-1136. Cambridge: Cambridge University Press

- Kulecho, A., & Muhandiki, V. (2006). Water quality trends and input loads to Lake Nakuru.

- Mavura, W. J., & Wangila, P. T. (2003). The pollution status of Lake Nakuru, Kenya: heavy metals and pesticide residues, 1999/2000. *African Journal of Aquatic Science*, *28*(1), 13-18.

- Muthuwatta, L. P. (2004, March). Long term rainfall-runoff: lake level modelling of the lake Naivasha basin, Kenya. ITC.

- Nakuru County. (2013). *Nakuru County Integrated Development Plan (2013-2017).* Kenya.

- Ngaira, J. K. (2006). Implications of climate change on the management of Rift Valley lakes in Kenya. The case of Lake Baringo.

- Odongo, V. O. (2016). How climate and land use determine the hydrology of Lake Naivasha Basin. University of Twente Faculty of Geo-Information and Earth Observation (ITC).

- Olang, L. O., & Fürst, J. (2011). Effects of land cover change on flood peak discharges and runoff volumes: model estimates for the Nyando River Basin, Kenya. *Hydrological Processes*, *25*(1), 80-89.

- Olang, L. O., & Kundu, P. M. (2011). Land degradation of the Mau forest complex in Eastern Africa: a review for management and restoration planning. In Environmental Monitoring. IntechOpen.

- Olang, L. O., & Kundu, P. M. (2012, April). Land degradation and hydrological effects in the Mau Forest Complex of Kenya. In *EGU General Assembly Conference Abstracts* (Vol. 14, p. 8996).

- Otieno, P., Okinda Owuor, P., Lalah, J. O., Pfister, G., & Schramm, K. W. (2015). Monitoring the occurrence and distribution of selected organophosphates and carbamate pesticide residues in the ecosystem of Lake Naivasha, Kenya. *Toxicological & Environmental Chemistry*, *97*(1), 51-61.

- Raini, J. A. (2009). Impact of land use changes on water resources and biodiversity of Lake Nakuru catchment basin, Kenya. African Journal of Ecology, 47, 39-45.

- Rigter, L. (2018). Water security in Nakuru town, Kenya. About the challenges in the formal water sector and how to adapt to them. University of Amsterdam.

- Shivoga, W. A., Muchiri, M., Kibichi, S., Odanga, J., Miller, S. N., Baldyga, T. J., & Gichaba, C. M. (2005, June). Impact of land use on water quality in River Njoro Watershed, Kenya. *In Proceedings of the International Grasslands Conference: Grasslands–a Global Resource*, Dublin, Ireland.

- World bank. (2019a). Nakuru Countywide Strategic Sanitation Plan, Countywide Inclusive Sanitation Strategy

- World bank. (2019b). Nakuru Countywide Strategic Sanitation Plan, consolidated – situation analysis, needs and constraints report draft.

Annex 1

The 3R approach

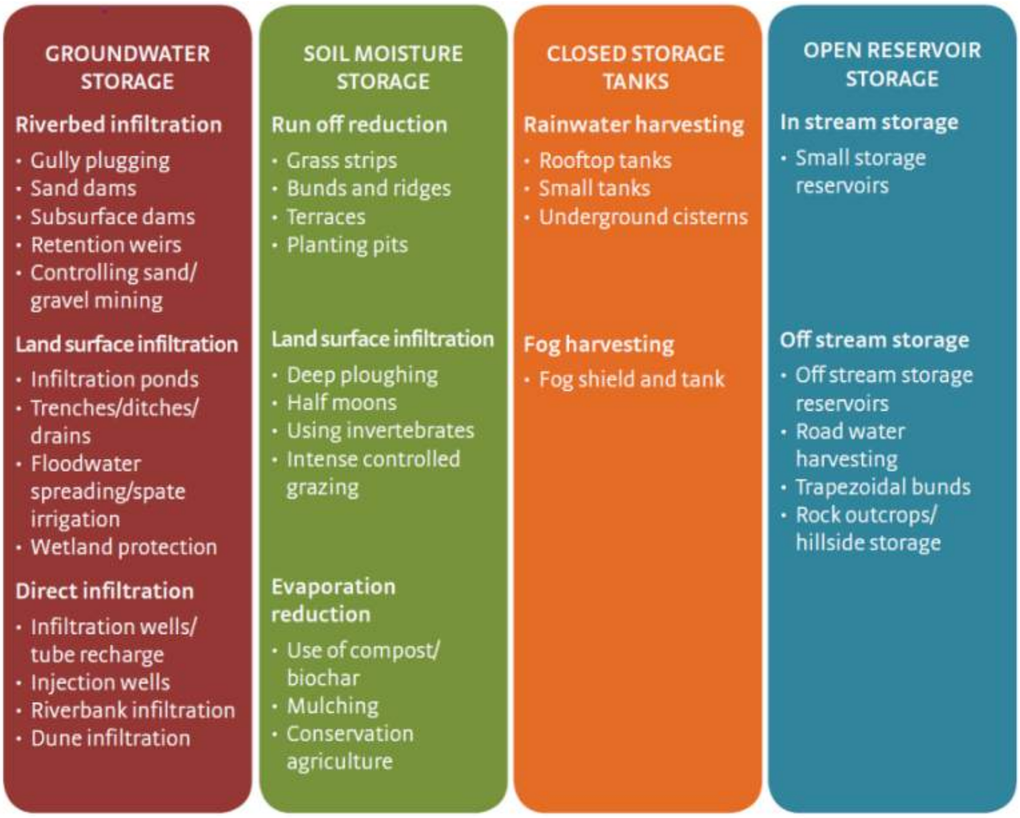
The following is based on the publication 'Profit from Storage, The costs and benefits of water buffering', Tuinhof et al., 2012.

The resource determines the amount of water that is potentially available, while the infrastructure makes it accessible. In many areas that currently suffer from droughts, the resources are in total enough to fulfil the demand. However, the moments that water is naturally available are limited in time, and long periods of droughts may occur. Therefore, infrastructure is required to store the water and make it available when and where it is needed. The larger idea thus is that tackling a local water crisis is not so much about reallocating scarce water, but to store water when it is plentiful and to make it available for the dry periods – and also to extend the chain of uses. This is the central thought of the 3R approach[13], in which through Recharge, Retention and Reuse the amount of usable water is increased. The focus of the 3R approach is on increasing storage and availability of water. 3R interventions and techniques are already broadly used. Figure 22 provides an overview of different often well-known types of 3R interventions that exist. Many of these have the potential to be implemented in more places besides the regions where they are currently applied, creating the opportunity to increase the water storage, and thus creating resilience against dry periods. Four main categories of interventions can be distinguished:

1. Storage in groundwater (either for domestic or agricultural water supply)
2. Storage in soil moisture in the unsaturated zone (generally for agricultural purposes)
3. Storage in closed tanks and cisterns (usually rainwater harvesting and small of scale)
4. Storage in open reservoirs (usually medium to large scale)

---

[13] For more on 3R, see: http://www.bebuffered.com/



GROUNDWATER STORAGE	SOIL MOISTURE STORAGE	CLOSED STORAGE TANKS	OPEN RESERVOIR STORAGE
Riverbed infiltration · Gully plugging · Sand dams · Subsurface dams · Retention weirs · Controlling sand/ gravel mining	**Run off reduction** · Grass strips · Bunds and ridges · Terraces · Planting pits	**Rainwater harvesting** · Rooftop tanks · Small tanks · Underground cisterns	**In stream storage** · Small storage reservoirs
Land surface infiltration · Infiltration ponds · Trenches/ditches/ drains · Floodwater spreading/spate irrigation · Wetland protection	**Land surface infiltration** · Deep ploughing · Half moons · Using invertebrates · Intense controlled grazing	**Fog harvesting** · Fog shield and tank	**Off stream storage** · Off stream storage reservoirs · Road water harvesting · Trapezoidal bunds · Rock outcrops/ hillside storage
Direct infiltration · Infiltration wells/ tube recharge · Injection wells · Riverbank infiltration · Dune infiltration	**Evaporation reduction** · Use of compost/ biochar · Mulching · Conservation agriculture		

Figure 22. Overview of 3R techniques (replicated from Tuinhof et al., 2012)

Each type of buffer has its own strengths and weaknesses. The time that water is retained and stored differs between the systems. In general, the buffering capacity increases as one moves from small to large storage and from surface to soil/underground storage. Whereas small tanks and soil moisture will help to bridge for example a dry season, large surface storage and particularly groundwater storage can help bridge even an unusual dry year or series thereof. Usually different types of storage complement each other in water buffering at landscape and basin level.

The selection of suitable 3R interventions depends on the intended use of the water. For drinking water, where high quality is desirable, closed storage in tanks or in groundwater storage are most suited. The demand for cattle or irrigation water may be suited with water from a lower quality, which broadens the range of possible 3R interventions with open water storage and soil moisture (the latter mainly for crops or grazing lands).

Figure 23. Some examples of 3R intervention possibilities per category

Some examples of 3R interventions per category are presented in Figure 23 above. However, for successful implementation, the 3R interventions have to fit within the characteristics of the landscape. To locate the areas where different 3R interventions can be applied, a landscape analysis is therefore required. For example, storage of groundwater can be very beneficial, but it can only be applied where the ground is sufficient porous and where the water is not lost to too large depths. As an alternative, when the infiltration capacity is low, open water storage may become an option. Depending on the sediment in the rivers, reservoirs may fill up with sand, thus creating an excellent new location for groundwater storage in the form of sand dams. The application of the different options is thus dictated by the geo-hydrological characteristics of the landscape.

The 3R analysis focuses on this physical landscape analysis, in order to provide an advice about the best manner to store water in the wet period and make it available for use in the dry periods. This also includes an advice on the kind of locations where interventions should be placed to accumulate sufficient water to recharge the reservoirs. Combined with the demand from the MUS analysis this provides an estimate of the size and the number of interventions required to make the area resilient for (long) drought periods. Hence, the kind of intervention that suit in the physical landscape, and the best areas for implementation are indicated by the 3R analysis.

Box 1: 3R – Recharge, Retention and Reuse of Water

With 3R, the water buffer (where water is stored during wet periods) is managed through Recharge, Retention and Reuse. The idea is to create strong buffers and extend the chain of water uses.

Recharge

Recharge adds water to the buffer. Recharge can be natural, for example the infiltration of rain and run-off water in the landscape, or it can be managed (artificial recharge) through special structures or by the considerate planning of roads and paved surfaces. Recharge can also be the welcome by-product of for instance inefficient irrigation or leakage in existing water systems.

Retention

Retention means that water is stored to make it available in the dry periods. It creates wet buffers, so that it is easier to retrieve the water. Retention can also help to extend the chain of water uses. Additionally, retention may raise the groundwater table and may affect soil moisture and soil chemistry, which can have a large impact on agricultural productivity.

Reuse

Reuse comprises different elements. The simplest form is the use of the water in the dry period which was stored in the wet period. It can be further extended when the water is kept in active circulation. This can be achieved with the management of water quality, to make sure that water can move from one use to another, even as the water quality changes in the chain of uses. Further, reuse can be enhanced by reducing non-beneficial evaporation to the atmosphere, and by capturing air moisture, such as dew, where possible.

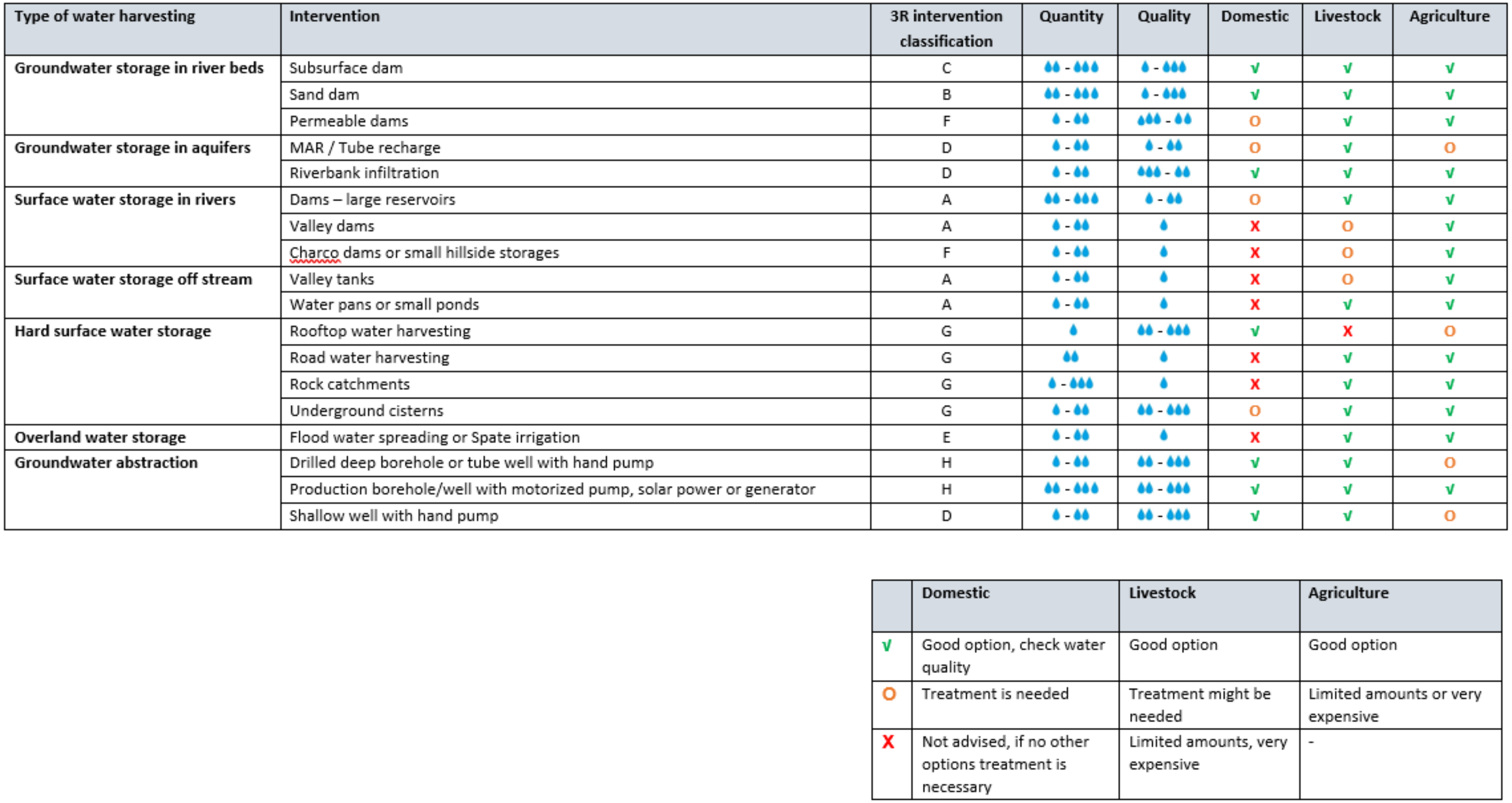
3R water harvesting types and intervention groups

Based on the four main 3R intervention categories, one could also distinguish 7 types of 3R water harvesting techniques, namely:

I. Groundwater storage in riverbeds;
II. Groundwater storage in aquifers;
III. Surface water storage in rivers;
IV. Surface water storage off-stream;
V. Hard surface water storage;
VI. Overland water storage;
VII. Groundwater abstraction.

To each of this main water harvesting types different interventions or techniques can be linked. To provide an overview of some of these interventions per intervention group the 3R intervention possibilities factsheet (also referred to as '3R Factsheet') was developed. See also Figure 24. It was developed to provide an extensive overview of 3R and rainwater harvesting intervention possibilities and the main characteristics.

In the next paragraphs, the main and most interesting 3R interventions for the five ASAL counties of the Kenya RAPID program will be discussed, including the 3R classification related intervention group behind it in brackets. This 3R classification is also tabulated and provided with the developed 3R potential map.



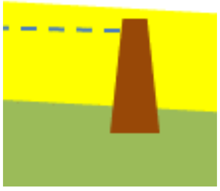
Type of water harvesting	Intervention	3R intervention classification	Quantity	Quality	Domestic	Livestock	Agriculture
Groundwater storage in river beds	Subsurface dam	C	💧💧 - 💧💧💧	💧 - 💧💧💧	✓	✓	✓
	Sand dam	B	💧💧 - 💧💧💧	💧 - 💧💧💧	✓	✓	✓
	Permeable dams	F	💧 - 💧💧	💧💧💧 - 💧💧	O	✓	✓
Groundwater storage in aquifers	MAR / Tube recharge	D	💧 - 💧💧	💧 - 💧💧	O	✓	O
	Riverbank infiltration	D	💧 - 💧💧	💧💧💧 - 💧💧	✓	✓	✓
Surface water storage in rivers	Dams – large reservoirs	A	💧💧 - 💧💧💧	💧 - 💧💧	O	✓	✓
	Valley dams	A	💧 - 💧💧	💧	X	O	✓
	Charco dams or small hillside storages	F	💧 - 💧💧	💧	X	O	✓
Surface water storage off stream	Valley tanks	A	💧 - 💧💧	💧	X	O	✓
	Water pans or small ponds	A	💧 - 💧💧	💧	X	✓	✓
Hard surface water storage	Rooftop water harvesting	G	💧	💧💧 - 💧💧💧	✓	X	O
	Road water harvesting	G	💧💧	💧	X	✓	✓
	Rock catchments	G	💧 - 💧💧💧	💧	X	✓	✓
	Underground cisterns	G	💧 - 💧💧	💧💧 - 💧💧💧	O	✓	✓
Overland water storage	Flood water spreading or Spate irrigation	E	💧 - 💧💧	💧	X	✓	✓
Groundwater abstraction	Drilled deep borehole or tube well with hand pump	H	💧 - 💧💧	💧💧 - 💧💧💧	✓	✓	O
	Production borehole/well with motorized pump, solar power or generator	H	💧💧 - 💧💧💧	💧💧 - 💧💧💧	✓	✓	✓
	Shallow well with hand pump	D	💧 - 💧💧	💧💧 - 💧💧💧	✓	✓	O

	Domestic	Livestock	Agriculture
✓	Good option, check water quality	Good option	Good option
O	Treatment is needed	Treatment might be needed	Limited amounts or very expensive
X	Not advised, if no other options treatment is necessary	Limited amounts, very expensive	-

Figure 24. 3R intervention possibilities and water quality of those interventions

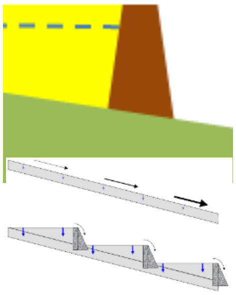
Groundwater storage in riverbeds

Subsurface dam



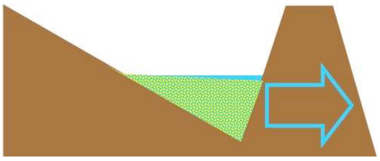
A subsurface dam is constructed within the existing riverbed sediment, funded on an impermeable layer, abstraction with hand pump or motorized pump. The main advantage of a subsurface dam is that the natural storage of a riverbed is utilized. Subsurface dams are recommended to be constructed in parts of the river with lower slopes (0 – 5%), with an impermeable layer under the riverbed and coarse sand/gravel present. Usual storage capacity ranges between 1,000 and over 50,000 m³.

Sand dam



A sand dam is raised above the riverbed, increasing the sand volume, anchored in an impermeable layer, while abstraction is achieved with hand pump. Sand dams or often constructed in smaller seasonal streams or tributaries to reduce flash flood and to increase base flow and rise of local groundwater levels, while in-ground infiltration and protection from evaporation is achieved. Sand dams are constructed in parts of the river with lower to gentle slopes (0 – 10%) and requires shallow bedrock or clay layer and coarse sand/gravel to be present. Usual storage capacity ranges between 200 and 5,000 m³.

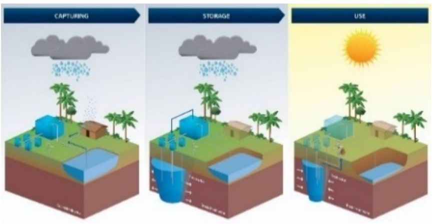
Permeable dams



Permeable dams could be catch dams or gully plugs, which are small to large scale permeable dams made of stone, rocks, boulders or even made from strong branches, such as bamboo sticks. Behind the dam silt is trapped while water is slowed down. Its main function is to reduce erosion and run-off velocity, increase the base flow of a river and to locally enhance (shallow) groundwater infiltration. Permeable dams are recommended to be constructed in far upstream parts of the river with gentle to steep slopes (>5 – 10%). Usual storage capacity ranges between 200 and 5,000 m³.

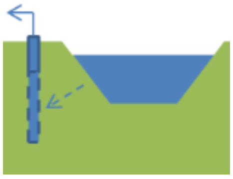
Groundwater storage in aquifers

Managed Aquifer Recharge (MAR) and Tube recharge solutions



MAR and tube recharge solutions can strengthen aquifer recharge with rainwater through very local retention, recharge and reuse (3R) of water. Via these solutions water can be retained and infiltrated via small to medium scale infiltration systems. Expected storage capacity ranges between 1,000 and 20,000 m³, with daily infiltration rates (depending on the permeability of the sub-soil) around rain events of 2 to 300 m³ per day.

Riverbank infiltration



Riverbank infiltration can be achieved through water abstraction from wells next to a river or other surface water body. Water is induced to infiltrate into the riverbank which provides natural filtration, while evaporation losses are very low. The site therefore requires permeable formation that is hydrological connected to the surface water body. Infiltration can be increased when combined with dams, floodwater spreading, infiltration ponds and well infiltration. Possible abstraction rates can be as high as 2 to 20 m³/hour per borehole or well related to the infiltration point.

Surface water storage in rivers

The following main harvesting methods can be distinguished among the surface water storage in rivers:

Dams – large reservoirs

Valley dams

Charco dams or small hillside storages

Dams – large reservoirs

Large scale structures build particular on the river, in order to block the river and create a big reservoir for open water storage. Although relatively easy and cost-effective to construct, large open surface water bodies are sensitive to contamination, and very high evaporation and seepage losses. Usual storage capacity is over 50,000 m³.

Valley dams

Valley dams are typically built in small streams in a concave location, perpendicular to the stream of a valley, where with a wall a relatively large reservoir can be build. Although relatively easy and cost-effective to implement, valley dams are sensitive to contamination, and high evaporation and possible leakage losses. Usual storage is between 500 and 5,000 m³.

Charco dams or small hillside storages

Charco dams are (small) earthen dams on gently sloping to flat agricultural lands that are mostly constructed in natural depressions where water can accumulate as seasonal surface and groundwater. Although relatively easy and cost-effective to implement, charco dams are sensitive to contamination, high evaporation and possible leakage losses and have a limited storage potential. Usual storage is between 200 and 2,000 m³.

Surface water storage off-stream

The following main harvesting methods can be distinguished among the surface water storage off-streams:

Valley tanks

Water pans and small pounds

Valley tanks

Valley tanks are large excavations in depressions or low-laying areas. Water is stored as an open reservoir. The reservoir is constructed off-stream.

Although relatively easy and cost-effective to implement, valley tanks are sensitive to contamination, high evaporation and possible leakage losses and have a limited storage potential. Usual storage is between 500 and 5,000 m³.

Water pans or small ponds

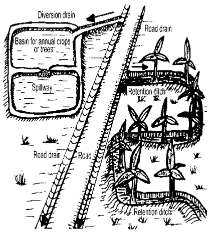
Excavated water reservoirs, also referred to as ponds, dug-out or valley tanks. Although they can strengthen water resources through recharge and can reduce flash floods, water pans have often high evaporation and leakage losses, while they generally have low water quality and are not reliable in dry years. Usual storage is between 5,000 and 25,000 m³.

Hard surface water storage

Rooftop water harvesting

Intercepts rainwater from hard roof surface whereinafter it is conveyed to a storage tank via a system of gutters. Very efficient as it can harvest up to 80% of run-off, low losses due to evaporation and leakage, and easy abstraction close to homestead. Disadvantage is that it is relatively expensive per m³, often not sufficient to cover the dry period and it is sensitive to breakdowns and deterioration of the water quality. Usual storage volume is between 5 and 200 m³.

Road water harvesting

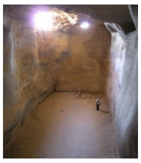


Water harvesting via side drains of roads into a water harvesting pit to recharge groundwater levels, support crop production and livestock watering. It also slows down runoff, preventing damage to the road itself. When taken into account with the design of road construction and maintenance itself, road water harvesting usually does not come with extra costs. Water harvesting from roads is often not sufficient to cover the dry period and it is sensitive to deterioration of the water quality. Typically, 50% of the rainfall or run-off can be harvested per m² of road surface.

Rock catchments

Rock catchments are water harvesting systems built at rock outcrops. All rainwater flowing from the rocks in brought into a storage from where it can be used. Water harvesting from rock catchments is often not sufficient to cover the dry period, while it is sensitive to deterioration of the water quality. Typically, 80% of the run-off can be harvested per m² of rock catchment area.

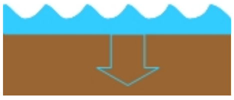
Underground cisterns



Underground cisterns are rainwater harvesting systems built where large areas of bare rock are present. Water in the cistern remains cool and somewhat protected against contamination since it is stored in the underground. Usual storage is between 200 and 2,000 m³.

Overland water storage

Flood water spreading or spate irrigation



Flood water from gently sloping to mountain catchments is diverted from riverbeds (wadi's) and spread over large flat areas. It increases the amount of water that is added to the soil by slowing down the surface run-off and thereby soil-moisture for vegetation development, both on rangeland and agricultural land. It is however risk-prone due to very unpredictable flooding, making it an uncertain water harvesting method.

Groundwater abstraction

For groundwater abstraction three main harvesting methods can be identified:
A drilled deep borehole or tube well with hand pump;
Production borehole/well with motorized pump, solar power or generator;
Shallow well with handpump.

Drilled deep borehole or tube well with hand pump

A deep drilled source with hand pump is often a reliable dry season resource with limited fluctuations in water quantity and quality and relative low operation cost. On the other hand, it also has a high financial initial investment for limited output. When the O&M is also in hands of the community, there will be a high risk of long-term non-functionality in case of a breakdown. Abstraction rate is limited by the handpump, and typically will not exceed 700 L/hour (0.7 m^3/h).

Production borehole/well with motorized pump, solar power or generator

Production boreholes generally have a high abstraction capacity and function as a reliable dry season water resource with good bacteriological water quality. Implementation, however, requires also a very high initial investment while the risk of drilling a dry borehole and/or with low water quantity or quality is quite significant. Production boreholes are sensitive to breakdowns and have high asset replacement costs. When it's a standalone water point for a large grazing area there is also a high risk of environmental degradation. Dependent on the aquifer capacity, abstraction rates of production boreholes typically lie between 1 and 20 m^3/h.

Shallow well with hand pump

Shallow wells are a bit more sensitive to bacteriological contamination, making the proper construction and sealing of the well extremely important. In comparison with deep wells, shallow wells have lower operation and maintenance costs. During the dry season the risk of increased salinity and rapidly dropping water levels and yields increase significantly. Abstraction rate is limited by the handpump, and typically will not exceed 700 L/hour (0.7 m^3/h).

Managed Aquifer Recharge (MAR) highlighted

In principle, all areas where (an increased potential for) groundwater is expected there is potential for managed aquifer recharge (MAR) systems too. A suitable aquifer which can easily be accessed by infiltration and where further groundwater flow is limited will greatly increase the success of MAR systems.

The building blocks for developing a MAR potential map include: precipitation, evapotranspiration, lithology, soil, land cover, vegetation, flow accumulation, Topographic Wetness Index (TWI), Normalized Difference Vegetation Index (NDVI) and catchment delineations.

Figure 25 on the next page provides an illustration of the different shallow MAR methodology groups that are determined. Per MAR methodology group the following interventions can be considered:

1. **Diffuse land surface infiltration:** floodwater spreading, spate irrigation or dune infiltration are examples of this methodology, whereby the central idea is to direct floodwater to areas with a high infiltration capacity to recharge groundwater;
2. **Localized land surface infiltration:** infiltration which is realized by removing the low infiltration upper layer through techniques such as: infiltration/percolation ponds, contour trenches and infiltration ditches;
3. **Direct aquifer infiltration:** Examples of direct aquifer infiltration are infiltration wells and tube recharge, along (seasonal) rivers for example;
4. **Surface water storage:** Open water storage can be combined with MAR, it can provide a temporary storage facility for large volumes of water, from where water can be recharged into aquifers more gradually.

Selection and implementation of any of the recommended interventions should be preceded by a local study and site investigation.

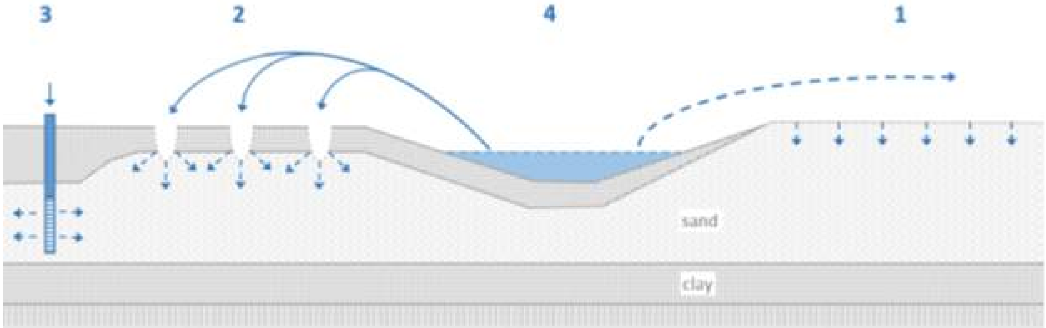


Figure 25. MAR technology groups: (1) diffuse land surface infiltration, (2) localized land surface infiltration, (3) direct aquifer infiltration, and (4) surface water storage (source: Acacia Water)

van Hogendoornplein 4
2805 BM Gouda

Telefoon: +31(0)182 – 686 424
Internet: www.acaciawater.com
Email: info@acaciawater.com