# Hydrology and Hydrogeology of Sponge City Kajiado, Kenya

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## Hydrology and hydrogeology Sponge City

### Introduction

The Sponge City project aims do develop a strong methodology to improve access to safe water supply for the urban poor. It intends to develop an integral solution in the urban setting, which targets a wide scope of issues related to urban development, i.e. increased direct runoff, decrease of recharge, pollution of groundwater, erosion and attenuation of natural vegetation, which in turn increases the effect of urban heat islands. The description of the hydrological and hydrogeological setting of Kajiado Town provides the technical background for planning of intentions in the context of Sponge City. The location of Kajiado Town is shown in Figure 1.

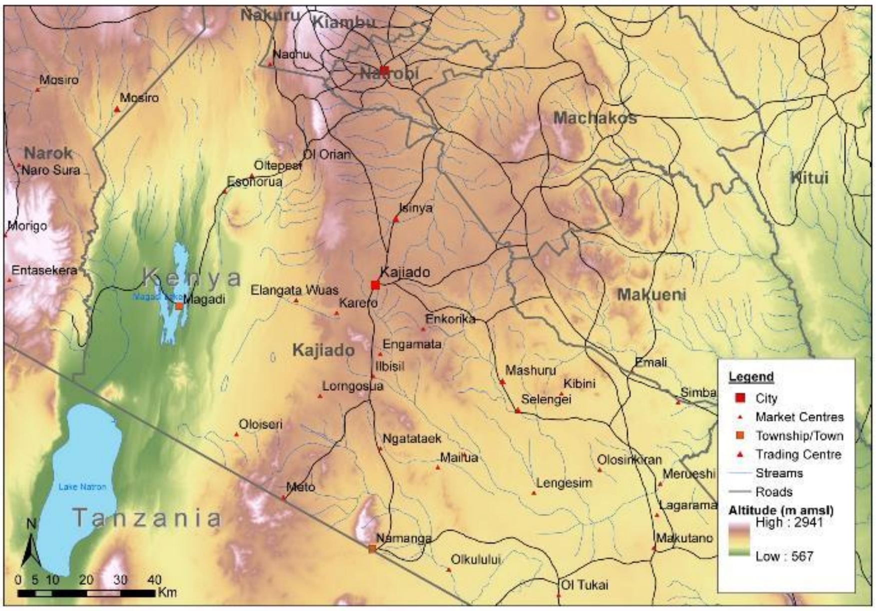


Figure 1: Location of Kajiado Town along Namanga Road to Tanzania.

From 6 to 10 February 2017 a field campaign was conducted in order to establish the hydrological and hydrogeological setting of Kajiado town and the surrounding areas. In the period of a week, geological walkovers, mapping of drainage patterns as well as hydrochemical measurements were done. Based on satellite image interpretation, combined with the results from the field campaign, a geophysical field campaign of one week was done as a follow up, in order to verify the subsurface geology, in relation to potential for infiltration of rainwater and (urban) runoff.

## Hydrology

Most of Kajiado County lies in the semi-arid and arid zones. The mean annual precipitation around Kajiado town is approximately 400 mm/year (1983-2015, ARC2 data). Rainfall is bimodal, with short rains from October to December and long rains from March to May. The distribution of rainfall is illustrated in Figure 2.

The mean actual evapotranspiration is approximately 400 mm/year (2000-2015, MODIS data). During the short and long rains precipitation exceeds the actual evapotranspiration.

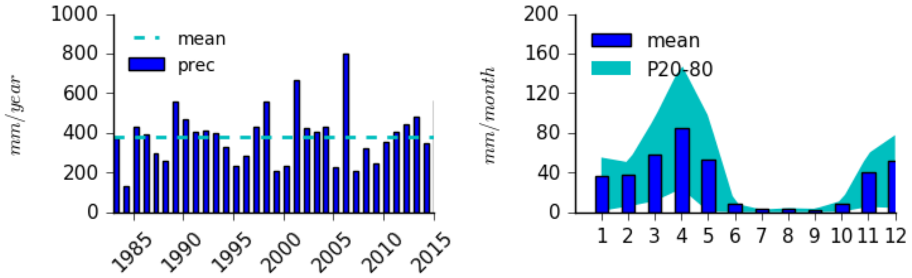


Figure 2: Annual precipitation (left) and monthly mean precipitation and variability (20 and 80 percentile) (right) based on ARC2 data (1983-2015).

Kajiado Town formally lies in the Athi River Basin; Athi River flows north of the County boundary. A contributory of the ephemeral Kajiado River (or Olkejuado River) lies 3 km west of town. Kajiado Town and its sub-catchments are shown in figure 3. The headwater area of the Kajiado River lies north and northwest of town and has a catchment area of 200 $km^2$ up to the river confluence southeast of Kajiado. Kajiado Town lies on a water divide; south of the main road (Namanga Road) water drains to the south, from where it flows into the Kajiado River. North of the road water drains to the west towards a more upstream section of the Kajiado River though three parallel east-west oriented gullies (a,b and c), see figure 4.

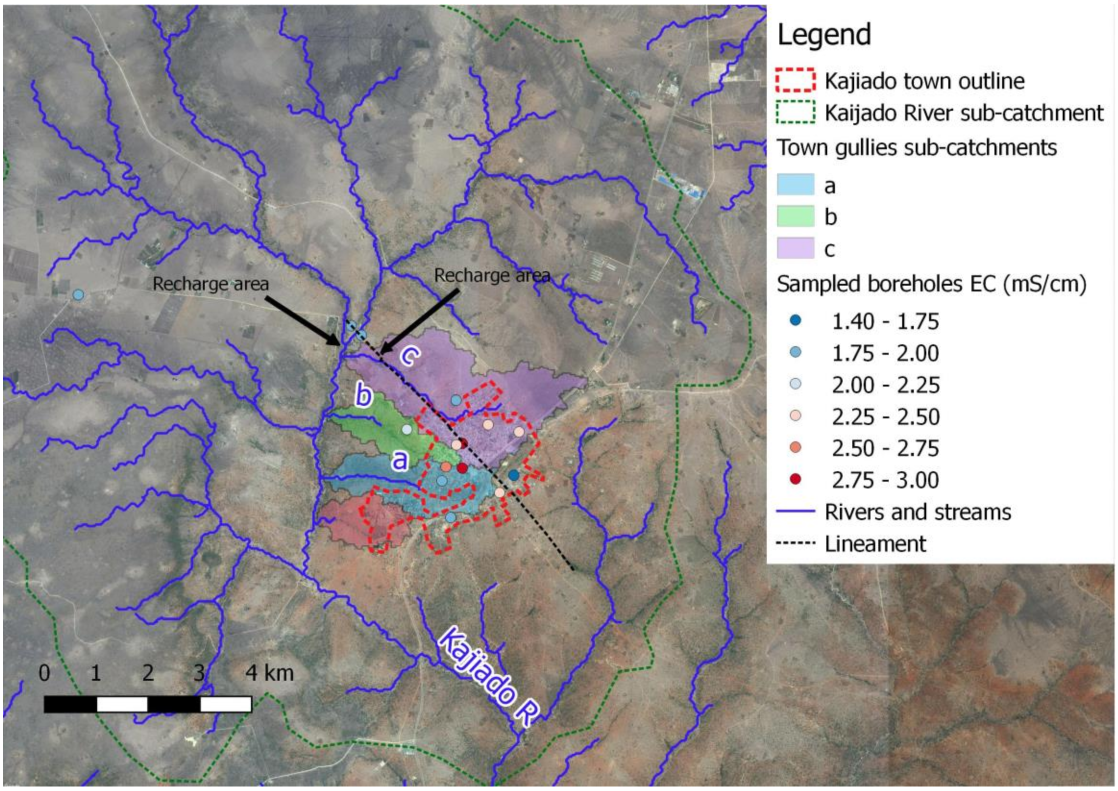


Figure 3: Kajiado Town and its surrounding rivers and streams. The sub-catchments of the gullies draining town (a, b and c) are highlighted, as well as high potential recharge areas outside the urban areas. This figure also shows a large lineament, that is possibly a water bearing fracture where groundwater flow is concentrated. Several boreholes were sampled for quality. The electrical conductivity (EC-value) is a measure for the salinity of the water (national limit EC=2.5 mS/cm).

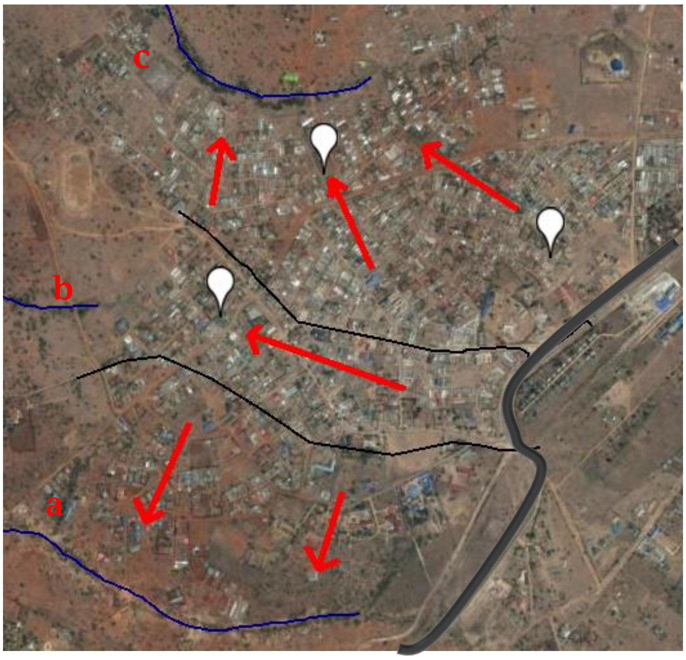


Figure 4: Satellite image of Kajiado Town with the sub-catchment boundaries of the three gullies (a,b and c) in black and the general flow-direction of road drainage in red and in blue the gullies that flow towards the Kajiado river. The main road is highlighted in gray.

## Hydrogeology

Kajiado Town itself is underlain by Basement rock (mainly gneisses). The soils in the area are red, loamy to sandy and often shallow. On the southern side of town the basement is found very close the surface with thin soils. Towards the north the thickness of the weathered zone seems to increase, although the actual thickness is unknown. Outcrops of gneisses are found along the entire stretch of the southernmost gully (gully a) draining town. In the middle (b) and northernmost gully (b) draining town (see figure 3), some gneiss outcrops are found along the stream bed, but large sections of the bottom of the gullies contain (sandy) river sediments. From geological walkovers as well as excavations it is clear that the depth to the basement in town itself is limited (near surface to several meters below the surface).

In basement areas, groundwater can be found in fractures or in weathered zones with sufficient thickness. A fracture is a separation in the geologic formation, that divides the rock into two or more pieces. Large scale fractures can be found by studying aerial photographs (lineament interpretation) and confirming their presence with geophysical exploration methods. From satellite imagery, several pronounced lineaments are found along the northern gully and the main river. One large lineament seems to be crossing town from the southeast and continues in north-western direction where it crosses the main river (see figure 3). Several boreholes with medium to good yields are found along this line, such as the Haraf borehole near the river (15 $m^3$/h). Verified fractures could have high potential for groundwater abstraction as well as infiltration.

Verification of the presence of fractures was done in collaboration with the ISGEAG geophysical study project (https://www.viawater.nl/community/isgeag-project-kick-off). Geophysical studies use physical methods at the surface of the Earth to measure the physical properties of the subsurface, along with the anomalies in those properties, such as fractures. Different geophysical techniques were applied (traditional as well as advanced); all methods used, measure the same geophysical parameter: geo-electrical resistance, a measure for the presence of weathered zones, fractured rock, the presence of groundwater and depth to the basement rock. Because of the urbanisation and the vicinity of power lines, there was limited space for the geophysical (long) lines needed for the desired exploration depth. Therefore most of the work has been done very close to, but outside to the urbanized part of town. Extrapolating the results to gain insight in the hydrogeological setting of the town proved to be useful. Furthermore, it lead to the identification of suitable locations for downstream or peripheral interventions to increase groundwater recharge.

The major result of the study is the detection of recharge areas close to town. Such recharge areas are indicated near the main river and the northernmost gulley draining town (see figure 3). Based on geophysical measurements, the hydrogeology consists of a deep fractured zone in the basement, in combination with a possible paleo river valley or a zone of deep and highly weathered basement along the main river west of town.

## Water resources and water quality

Kajiado town had a projected population of 16,000 in 2013. Currently, there is no adequate municipal water supply system. Given the absence of perennial surface water sources, groundwater is used as a water source. Drinking water is mainly supplied through commercially sold water from boreholes. A well field west of the main river is another water source for Kajiado Town and is pumped to Kajiado through a pipeline. The water from this scheme, however, is insufficient for town water supply.


Figure 5: Water supply from boreholes sold commercially

Several boreholes are located in and around town, that have low to medium yields. Several boreholes closer to the river have higher yields (10-15 $m^3$/hour). During the kick-off week, several boreholes in town were sampled for chemical analysis in the laboratory, to determine the water quality and to attempt to determine the origin of the water. Generally speaking, the water in town is fresh to slightly brackish. Nitrate levels are mostly high, especially in the central part of town and in several cases concentrations exceed the national limit. The high nitrate levels are likely to be the result of pit latrines in town.

## Groundwater recharge

Throughout the year, there is a diffuse (polluted) recharge component from the pit latrines, spread over town; there is no sewage system and septic tanks are uncommon in general in this region and even more so due to the water shortage. Direct recharge in town is otherwise limited, due to roofs, paved roads and impermeable dirt roads. Considerable localized indirect recharge takes place in the downstream part of the northernmost gully. Observations of rapidly infiltrating water (urban runoff) were made during the second geophysical campaign in April 2017. The gully seems to be situated on an open fracture, causing rapid infiltration of runoff water. This gully, as well as some sections of the main river west of town have a high potential for large scale infiltration of water. When combined with a waste management plan, this could improve the groundwater storage in the aquifer.

**Because of the urban setting, the available space for augmented recharge is limited within the town's outline and should focus on small scale interventions**. Retention of water in the upper (urban) catchment leads to decrease of direct runoff and increase of recharge. Implementation of interventions that focus on these aspects could lead to a more natural hydrological behavior, i.e. the situation as it was before urban development. Small scale solutions along roads, at public spaces such as the mosque and the stadium, as well as within compounds could lead to an increase of recharge within the town itself, diluting the diffuse sources of pollution from pit latrines and protecting downstream areas from an excess of runoff. As part of the Sponge City concept, these recharge areas should be combined with urban beautification, through planting of vegetation and trees along these recharge areas, reducing the effect of urban heat islands (Kurn *et al.*, 1994) and potentially increasing infiltrating through the expansion of roots in the subsurface. Furthermore, trees and vegetation lead to more shade, improve air quality, enhance storm water management and improve the water quality (McPherson *et al.*, 2005). Rooftop harvesting is another small scale solution for water storage and runoff reduction. However, this method does not attribute to other formulated goals, such as increased groundwater recharge, reduction if the effect of heat islands, etc.

In order to test the recharge potential, a controlled infiltration pilot was implemented; an in-stream infiltration pit, which was baptized a Sponge Infiltration Pit (SIP), see figure 6. The pilot was meant to demonstrate the simplicity of infiltration pits and provide useful information on the hydraulic properties of the sub-surface and the viability of such low-tech solutions. A small pit (1.2 x 1.2 m) was excavated down to the basement rock (2 m below the surface) and filled with gravel and river sand. Approximately 1.2 $m^3$ of water was pumped into the pit, after which infiltration could start. Moderate to rapid infiltration was visible though a quickly subsiding water level, measured with a datalogger. A drop in water level of 65 cm was realized in one hour, after which the infiltration rate dropped considerably to 3 cm/hour, due to the lower water pressure and the fact that storage in the surrounding rocks is filled.
The initial infiltration rate therefore was 0.25 $m^3$ per square meter per hour. The effect of small scale upstream interventions is illustrated in the text box below.

**Effect on runoff and recharge: example**

To illustrate the effect of upstream small scale interventions to augment recharge and reduce runoff, an example calculation is given. The sub-catchment area upstream of the SIP is approximately 2 hectares. Typical storm events are 10 mm per day or less (65%). Let's assume the rainfall is concentrated in one hour. The runoff coefficient in urban areas is quite high (50-80% of rainfall contributes to runoff). Assuming 70% runoff in this example (which is on the high side), this results in a discharge of 140 $m^3$/hour at the infiltration site.

If an infiltration trench of 100 $m^2$ and 2 m deep is installed under the gully (for example 100 m long, 1 m wide), 80 $m^3$ of the runoff can be stored in the trench (40% porosity). Additionally, 25 $m^3$ infiltrates in the first hour. In this case, 70% of the runoff is captured, thereby reducing erosion and downstream flooding. Furthermore, most of the stored water will eventually infiltrate into the deeper groundwater system. This way, most of the precipitation is used for aquifer recharge, while in the current situation only a small fraction of total rainfall infiltrates in the upstream areas.

Figure 6: The Sponge Infiltration Pit demo was installed in gully along a dirt road to test the infiltration capacity of a small scale in-situ infiltration site.

## Conclusion

From the hydrogeological survey, it was concluded that 1. **small scale interventions** that help reduce direct runoff and augment recharge, **will improve the groundwater situation in town**. As runoff water was found to be free of nitrates, increased recharge could help reduce the nitrite levels, especially if combined with improved sanitation and waste treatment. Solutions in the urban setting will reduce erosion and attenuate natural vegetation, which in turn increases the effect of urban heat islands and leads to use of nitrates, thus removing them from the goundwater system.

2. **Large scale infiltration**, using runoff water from Kajiado town and the surrounding catchments has the highest potential in the northernmost gully draining town, as well as the main river west of town. Augmented recharge at this scale **could have a more regional effect,** increasing the long term potential for groundwater exploitation near town.