Report on field studies in Voi, Kenya

Soil Erosion and Flood Risk Management

„Integrated soil erosion and flood risk management in Voi, Kenya“

a short term student project in January 2013

Undertaken by teams from the Freie Universitaet Berlin (Germany), University of Kaiserslautern (Germany), Taita Taveta University College (Voi, Kenya) and Pwani University College (Kilifi, Kenya)

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Description of the cover
Photo: Gully erosion in the periphery of Voi, Kenya / Source: ARENDT 2013
Acknowledgement

The student field work was originated by an initiative by Prof. Dr. Robert Juepner (University of Kaiserslautern) and Prof. Dr. Achim Schulte (Freie Universitaet Berlin) and has its roots in the DAAD-Alumni-conference titled “Capacity Development for the County Governments in the New Constitutional Dispensation in Kenya” in November 2011.

Just one year later our common dream becomes reality: two German and two Kenyan Universities are undertaking a common student research project to contribute to the challenges the municipality council of Voi is faced with – soil erosion and flood risk management.

After some month of intensive preparation in Germany, the field work took place in January 2013 undertaken by eight joint German-Kenyan student research teams. This report contents the results of our efforts.

We are all very grateful for this opportunity and have learned a lot during the days we spent in Voi. Our acknowledgements are especially dedicated to

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1 Introduction

The Consolidated Plan of Action for Africa’s Science and Technology (CPA), (NEPAD, 2006) and also the Kenyan national water resources management strategy (NWRMS) (Ministry of Water and Irrigation, 2011) point out that the supply and availability of water is one bottleneck for the economic and social development not only for Kenya but for all sub-Saharan countries. "Kenya’s economy being mainly natural resource-based is highly vulnerable to climate change and variability. The economy has recently suffered from climate change related disasters, which include droughts (2000/2001, 2009), floods and mudslides (1997/98, 2006/7, 2010). [...] The costs of the 1997/8 and 2000 El Niño-related floods and La Niña related drought respectively cost the country about 15% of GDP (USD 867 per capita 2010) for three consecutive years (Ministry of Water and Irrigation, 2011)." Both the surplus on water during rainy seasons and the lack of water during the dry periods include also the problems of soil erosion, desertification, migration and water related diseases (CPA) (NEPAD, 2006). All these problems are well-known but remain unresolved and continue to increase the vulnerability of the whole society. The water related problems in Kenya must be solved at different political levels and by a common and practical approach of different disciplines to develop a long-term perspective for the local communities and their economy.

Voi city in the upper Voi river catchment in southern Kenya is regarded as a typical example facing several of the mentioned problems. The hydrological scenario of this area is characterized by a semi-arid climate with pronounced rainy and dry seasons during the year but mostly during the heavy rains of March – July, when precipitation is of highest intensity. The area is also characterized by soils of low water infiltration resulting into surface runoff, storm water floods and different types of soil erosion (and accumulation in places).

In the short rainy season of November and December 2011 the area experienced intensive rainfall events with disastrous flooding and serious erosion problems in different spatial scales (sheet and rill erosion up to severe gully erosion). Further, severe communication and transport infrastructure damage was experienced including the washing way of several infrastructures such as schools like St. Kevin School and a number of residential houses.

Voi Municipality area is also affected by the incision of the Voi River channel and its several tributaries passing through the town and draining it in form of gullies. The efforts of the Voi Municipality to reduce the damages are limited by the unclear hydrological and morphological processes as well as lack of adequate flood risk management strategies.

In order to improve the situation, this study proposed three key objectives: 1. to describe and localize the hydrological and morphological processes, 2. to understand strategies employed by the local communities in
coping with the flood risk menace and 3. to suggest appropriate additional engineering measures easily adoptable to the local scenario.

2 Framework

Water related problems are usually based on complex natural processes. Moreover, the climatic conditions in Kenya cannot be changed although there exists a possibility to create risk awareness and lower the vulnerability in terms of risk management both at the regional and local level. The precondition for such a successful and sustainable approach is at least a holistic understanding of the man-environmental-system under Kenyan boundary-conditions. This interdisciplinary investigation proposed a two throng approach; on one hand the need to describe the hydrology and geomorphology of the area in order to understand the aspects of sediment and water transport and other conditions that influence the hydrograph. On the other hand, it is necessary to design or rather recommend appropriate engineering measures that could be employed to cope with the situation. These engineering solutions had to be tailored to withstand the unique situations of the river Voi upper catchment, manageable by the stakeholders especially the Voi Municipal Council and able to deliver adequate services to the users. From several discussions and from engineering hindsight, the solutions need to be two-fold:

1) those that could be employed to retain the amount of water which contributes to a flood hydrograph or flood wave (water harvesting, enhanced ground water retention and infiltration) and control soil erosion and sediment transport

2) those that could ensure non-hazardous transport of sediment and water from the origin (headwater areas) to the Voi river.

But it is very necessary to emphasis that the Voi municipality lacks of a holistic plan for community development especially focusing on urban drainage and flood risk management (Master plan). The short term student project in January 2013 is not able to fill this gap but wants to contribute to the overall approach undertaken by the Mayor of Voi related to the recent flood and erosion problems.

3 Objectives

From the perspective of a soil-, sediment- and flood management; two main questions emerge:

1) What influences the conditions in the catchment hydrograph?"

2) What interventions can be undertaken to cope with the situation?"

These questions could best be answered through an interdisciplinary work of the disciplines of geomorphology, hydrology, ecology, civil engineering and social science.

To describe the problem from the hydrological point of view see fig.1.
The Problem illustrated in Figure 1 is based on the fact, that most of the existing drainage channels and gullies are able to transport more than a certain discharge $Q_t$ without inundating the surrounding area. If the discharge overtops this threshold and reaches a peak discharge $Q_{\text{max}}$, all resulting discharge ($Q_{\text{max}} - Q_t$) is exceeding the drainage capacity of the transport channel and leads to flood water which cause inundation within the city.

In order to adequately study the erosion and flood water processes and find appropriate solutions to the above research questions, the study team of 26 persons was subdivided into different groups. Each group had a specific research objective and members worked as a team both in the field as well as in generating a group report. Besides, each group gave a short presentation of their work after every two days. Below, is the summary of each group listed in chapter four.
4 Research topics

4.1 Land use

Author: Christoph Raab

4.1.1 Introduction

The main topic of this research concerns the estimation of land use types derived from remote sensing and field data. For this topic, high resolution satellite images were used to derive the necessary information. The ground truth data are collected to validate the derived land use classes like different types of vegetation or settlements. These data are produced for a subset area (Hotspot 2, location on map in the appendix). This data will be used to analyse the current status of land use in the Voi community with special regard to soil erosion and flood risk management.

4.1.2 Research questions

The main topic of the research is ‘Land use in the upper catchment of the Voi River, Kenya from Remote Sensing and field data’. From these, following questions arise:

- Which types of land use can be classified using high resolution satellite data?
- Which types of land use can be derived during the field work to validate the remote sensing data?

4.1.3 Methodology

To answer the mentioned questions, it is necessary to get appropriate satellite data. For this reason, high resolution satellite data were acquired in December 2012 with the following characteristics (figure2):

*WorldView2 satellite image – 01.23.2012*

- Multispectral 8 bands (MS 8) with a resolution of 2 m per pixel of each band
- Panchromatic band (PAN) with a resolution of 0.5 m per pixel

![Fig. 2: Wavelength of the WorldView 2 satellite. Each band is described with one colour (European Space Imaging 2012).](image)

The area for investigation was calculated by Steffen Lehmann and has a spatial extension of approximately 40 km². The delivered data are radiometric pre-processed but not orthorectified. This makes a rectification necessary and an atmospheric correction obsolete. All pre-processing steps were calculated with the software ERDAS IMAGINE 9.1.

For better visual image interpretation, some image enhancement tools from ERDAS IMAGINE 9.1 can be used. For example, the resolution merging of the MS 8 and PAN image is an appropriate tool to use the benefits of both scenes for better visual image interpretation. Figure 3 shows the raw data and the result of
the resolution merging using the HPF Resolution Merging algorithm implemented in ERDAS IMAGINE 9.1 for a subset (Hotspot 2) area.

Fig. 3: a) MS 8 true colour illustration, b) PAN illustration, c) Result of the HPF resolution merging algorithm

Additionally, there are a lot of different methods for image enhancement. These include principal component analyses and spatial feature manipulation or contrast manipulations which are not described here. The next steps of digital satellite image processing are the rationing and classification methods. To get a first impression of the mathematical separability of the spectral information, the ISODATA-algorithm is used for an unsupervised classification. The ISODATA-algorithm uses the spectral information of each band for clustering by applying the minimum distance method. After n-iterations - given by the processer - and a predefined convergence threshold, an unsupervised classification is calculated. Using the knowledge of the results given by the unsupervised classification, the supervised classification can be processed. A predefined spectrum of classes must be characterised by an appropriate count of AOIs (Area Of Interest). The AOIs are created by the operator and as possible the spatial distribution must be consistent. The characteristic spectral informations for each class - extracted from the satellite image by the AOIs - are subsequently used for the supervised classification.

Tab. 1: Ground truth sheet

<table>
<thead>
<tr>
<th>Project</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date, Time</td>
<td>Waypoint #</td>
</tr>
<tr>
<td>Name of point</td>
<td>Land use</td>
</tr>
<tr>
<td>Photo #</td>
<td>Land cover</td>
</tr>
<tr>
<td>Coordinate system</td>
<td>Ground cover</td>
</tr>
<tr>
<td>Coordinates</td>
<td>Remarks</td>
</tr>
</tbody>
</table>
Map 1: Digitalised streets in the investigation area Hotspot 2
For the field work it is recommended to use ground truth sheets, which can be seen in table 1. The main streets were digitalised from the WorldView2 satellite image using ArcGIS 9.3 for mapping the land use in the investigation area (Map 1). It is important to note that the field work took place January, 7th and 8th 2013 and the satellite image was taken January, 23rd 2012. Differences between the vegetation cover may occur.

Furthermore a subset of the investigation area was created from the satellite image. This is useful to mark ground truth information like GPS points. For more details, information photos were taken during the field work from the areas around the GPS points and other regions.

The collected ground truth data are digitalised using the software ArcGIS 9.3.

4.1.4 Results

The results represent the calculated and collected data from Hotspot 2. First, the unsupervised and supervised classification is analysed. Subsequently, the ground truth data are digitalised to create a land use map.

**Unsupervised classification derived from satellite data**

The first result created is the unsupervised classification which can be seen in Map 2. The ISODATA-algorithm calculated the maximum likelihood attached to all pixels. Two different classes of built up areas are possible to derive. Two classes of shadow were calculated as well. Furthermore, four different classes of vegetation and three types of different soils were derived.

<table>
<thead>
<tr>
<th>Class name</th>
<th>Area [ha]</th>
<th>Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>0.96</td>
<td>0.689</td>
</tr>
<tr>
<td>Shadow</td>
<td>14.36</td>
<td>10.314</td>
</tr>
<tr>
<td>Vegetation</td>
<td>61.96</td>
<td>44.505</td>
</tr>
<tr>
<td>Soil</td>
<td>58.60</td>
<td>42.091</td>
</tr>
<tr>
<td>Built up area</td>
<td>3.34</td>
<td>2.399</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>139.22</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

In table 2 the areas per class can be seen. Vegetation and soil together cover more than 86 % of the investigation area. Built up areas like the St. Kevin Hills Voi and other houses cover around 2.4 % of Hotspot 2. The total area covers 139.22 ha.
Map 2: Screenshot from the result of the Unsupervised Classification with 12 classes, a maximum of 60 ISODATA-algorithm iterations and a convergence threshold of 0.9.
Supervised classification derived from satellite data

The supervised classification was processed for the whole investigation area around Voi. The Map 3 presents the results for the hotspot area 2 with 18 different classes. In general built up area 4 is good to separate with a minimum amount of mixtures with other classes. In comparison to build up area 2 a lot of other structures were classified as built up areas when they aren´t vegetation, especially trees are good to separate and the distribution seems natural. The sisal class covers a lot of the investigation area. Also the river class occurs on the hill. A lot of areas are classified as agriculture barren. Barren land occurs in the North East and in parts of the built up areas
Map 3: Supervised classification of Hotspot area 2
In Table 3 the areas of the different classes can be seen. For the built up area class an area of 17.1 ha is calculated. The river class occurs with 7.5 ha and a shadow class with 5.6 ha. Barren land only covers 0.03 ha and agriculture barren class covers 38 ha. Sisal class is classified for an area of 21 ha and a percentage of around 15 %. The total area of interest covers 139.22 ha.

Table 3: The proportion of classes in ha and the percentage

<table>
<thead>
<tr>
<th>Class name</th>
<th>Area [Ha]</th>
<th>Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>12.8</td>
<td>9.194</td>
</tr>
<tr>
<td>Grass land</td>
<td>10</td>
<td>7.182</td>
</tr>
<tr>
<td>Barren land</td>
<td>0.03</td>
<td>0.021</td>
</tr>
<tr>
<td>Rock</td>
<td>3.1</td>
<td>2.226</td>
</tr>
<tr>
<td>Built up area</td>
<td>17.1</td>
<td>12.282</td>
</tr>
<tr>
<td>Sand road</td>
<td>2.7</td>
<td>1.939</td>
</tr>
<tr>
<td>Earth road</td>
<td>9.4</td>
<td>6.751</td>
</tr>
<tr>
<td>Agriculture vegetated</td>
<td>11.6</td>
<td>8.332</td>
</tr>
<tr>
<td>Agriculture barren</td>
<td>38</td>
<td>28.294</td>
</tr>
<tr>
<td>Shadow</td>
<td>5.6</td>
<td>4.022</td>
</tr>
<tr>
<td>River</td>
<td>7.5</td>
<td>5.387</td>
</tr>
<tr>
<td>Tarmac road</td>
<td>0.3</td>
<td>0.215</td>
</tr>
<tr>
<td>Sisal</td>
<td>21</td>
<td>15.084</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>139.22</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Land use map derived from ground truth

The Hotspot area 2 can be classified into three main classes as per the already collected ground truth data. Tab. 4 summarises the class with photos and a short description.

The class ‘built up area’ describes public buildings and areas like St. Kevin Hills, Voi without agriculture. The class ‘meadow with single trees and bushes’ dominates the hill within some scattered parts of the class ‘small scale farming with low building density’. Also in the East a large area of ‘meadow with single trees and bushes’ takes place. In both areas pastoral usage was observed. The agricultural activities in the class ‘small scale farming with low building density’ is dominated by maize and beans. In general a big part of this class is covered by grassland and single trees. Also barren land was observed in many areas. The first results are summarised in Map 4.
**Tab. 4: Class description and photos**

<table>
<thead>
<tr>
<th>Photos from classes</th>
<th>Classes and description</th>
</tr>
</thead>
</table>
| ![built up area](image) | **built up area**  
Man made structures, public buildings, soccer fields, among others.  
No agricultural activities.  
Left: St. Kevin Hills, Voi  
Right: Tsavo Lodge |
| ![small scale farming with low building density](image) | **small scale farming with low building density**  
Small scale farming, dominated by maize and beans.  
Low building density  
Pastoral usage observed  
Single trees like Acacias  
Bushes  
Grassland |
| ![meadow with single trees and bushes](image) | **meadow with single trees and bushes**  
Meadow  
Single trees like Acacias  
Thicket  
Bushes  
Pastoral usage observed  
Some small scattered holders  
Rock |
Map 4: Land use forms in the Hotspot area 2
4.1.5 Discussion

The results given by the unsupervised classification describe the area as a soil (~42 %) and vegetation (~44 %) dominated area. In comparison to the satellite image and the supervised classification the built up areas (2.4 %) seems to be under-estimated.

More critical the supervised classification has to be discussed. The ground truth data does not support the 15 % of sisal class, because minimal sisal was found in this area. Sand roads and deposition zones show similar characteristics, so that deposition zones are classified as sand roads. The river class is estimated to have a proportion of about 5 %. This value cannot be correct since no structures like a river with water were found during the ground truthing. It seems that the river class has similar characteristics to shadow class. This explains the reason for its high over-estimation. An equal problem can be noticed between the classes ‘agriculture barren’ and ‘barren land’. It might be better to put these classes together in one class or separate it more precise against the AOIs. It seems that on one hand classes like tarmac road, forest and rock are appropriate and on the other hand classes like agriculture barren, barren land, shadow and river must be changed.

The ground truth information delivers an appropriate result to check the classifications. The created land use map gives an overview over the main land use and land cover manifestations.

A solution to estimate the right proportion of sisal class can be the masking of the Voi Sisal plantations. This would be possible because of the clear structures. It is recommended to reclassify the supervised classification with changed classes and give an accuracy assessment. Furthermore, for every land use class an example should be described with a higher spatial resolution.

Sources
4.2 Physical Soil Characteristics

Authors: Kevin Sieger, Angela, Wairimu

4.2.1 Introduction

Soil erosion, the formation of gullies and the related sediment transport and floods can cause serious damages to infrastructure, buildings and risks for the daily lives of the people who live nearby or downhill. Causes for formation of the gullies and the soil erosion in this region are partly known and almost no research at the Voi municipality was undertaken up till now. Therefore the mitigation of gully formation and soil erosion needs a better knowledge of local soil physical properties (shear stress, soil density, hydraulic conductivity, soil texture). The headwater areas of the catchments are of main interest. The surroundings of the Mwakingali hills (Hotspot zone 2) were selected for the first survey with help of satellite images and maps provided by Lehmann and Raab 2013 from Freie Universitaet Berlin.

4.2.2 Research questions

Three questions are formulated before field investigation:

1. Which hydraulic conductivity can be expected in the selected headwater area?
2. What are the maximum shear stress and density of the soil?
3. How much do hydraulic conductivity depend on the given soil characteristics?

4.2.3 Methodology

At hotspot 2 different locations with varying soil textures and geomorphology were identified to carry out measurements. Grain sizes and soil humidity were described by finger probes. Minidisc Infiltrometer (MDI) developed by Decagon Ltd. was used to measure hydraulic conductivity. Its use of less water, quick measurement, precision and portability makes it highly efficient.

Soil density of different soils at different locations in the study area was determined by exerting pressure on the soil surface using a penetrometer (penetrometer test). All locations were recorded with the GPS device and identified in the maps.

Soil samples from each site were collected, put in clear polythene bags and labeled for laboratory test (grain size analysis, organic matter). Lab values will give additional information about the soil water characteristics.
4.2.4 Results

Seven different locations were observed and tested. Location 002, 006, 007 and 008 were situated on the pediment layer, with sample 003-005 being located at the headwater area. The pediment and headwater area showed different behaviors in their soil characteristics and geomorphology. Soils with loamy sandy grain size originated from the Headwater area, overlaid with some gravel.

<table>
<thead>
<tr>
<th>sample number</th>
<th>location</th>
<th>grain size (field data)</th>
<th>soil humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>002</td>
<td>Pediment</td>
<td>loamy sand</td>
<td>slightly humid</td>
</tr>
<tr>
<td>003</td>
<td>Headwater Area</td>
<td>loamy sand with some gravels</td>
<td>slightly humid</td>
</tr>
<tr>
<td>004</td>
<td>Headwater Area</td>
<td>slightly loamy middle sand with some gravel</td>
<td>slightly humid</td>
</tr>
<tr>
<td>005</td>
<td>Headwater Area</td>
<td>mainly fine sand, middle loam, with some gravel</td>
<td>slightly humid</td>
</tr>
<tr>
<td>006</td>
<td>Pediment</td>
<td>mainly loam, some fine sand (us)</td>
<td>dry</td>
</tr>
<tr>
<td>b007</td>
<td>Pediment</td>
<td>loamy sand</td>
<td>dry</td>
</tr>
<tr>
<td>008</td>
<td>Pediment</td>
<td>sand, loamy sand</td>
<td>dry</td>
</tr>
</tbody>
</table>
It was noticed that the pediment layer differed from the headwater area because of the slope which decreased from the later to the former. Measured grain sizes at the pediment were much loamier and the gravel content was lacking. Most moisture measurements were taken in the morning when soils were humid in the upper soil layer while those taken in the afternoon had less humidity.

Soil density in the pediment area was measured with minimum and maximum recordings being taken at location 002 and 007 respectively. The highest shear stress was also measured at the study site 005 and minimum record taken at location 002. Mean soil density and soil shear stress in the pediment was lower than that in the headwater area.

Fig. 4: Soil density and soil shear stress of test sites and averaged values for the pediment and headwater area
Measurements of hydraulic conductivity were taken for each study site. The lowest observed measurements were taken at study site 002 with an infiltration rate of 55.44 mm/h while the highest was at location 008. Infiltration value of location 008 was 2100 mm/h. The mean of infiltration from the pediment area was 630 mm/h while that from headwater area was 67.2 mm/h.

4.2.5 Discussion

The area of investigation is affected by different kinds of soil erosion like gully formation, rill erosion and probably sheet erosion which has a certain impact on the range of measured values. The observed soil shear stress in the headwater area was higher than expected due to high heterogeneity of the grain sizes. With the handy shear stress apertature, only small samples could be explained. Gravel and stones in the headwater area could not be described, because of their size and therefore only the sandy materials were tested. Soil density trend for pediment and headwater area could not be observed. The pediment was overlaid by a thin layer of sand, which influenced the measurements and contributed the conclusion that some areas are affected by sheet floods as indicated in soil sample 007-008. The MDI is a very small unit, which shows an overview of infiltration rate.

Figure 6 shows three very important parameters that influenced measurement. First, in areas with high soil humidity, the infiltration went low with a vertical component while very dry samples had large horizontal infiltration components. Second, grain size was a factor that influenced infiltration measurements. In areas with dry sandy grain sizes the infiltration rate was seen to increase excessively. Last but not least was the
suction factor, which most measurements were taken with a rate of -2 cm as, recommended by the producer. It’s however important to note that taking measurements of infiltration rate for sandy soil with these suction rate is impossible.

![Diagram showing influences on infiltration rate](image)

*Fig. 6: Influences on infiltration rate*

The above three factors influenced the infiltration measurement of location 008. To give evidence to the suction rate more measurements should be taken. Precipitation data is needed to describe the possible highest infiltration and more data collected from other study sites to verify ones measurements. The influence of pastoralism and farming on the observed soil properties should be clarified. So it seems to be necessary to get more detailed information about the relationship between land use types and soil properties. The field survey is still in progress thus the additional data of the forthcoming days will give a more detailed picture of the situation in the surroundings of the Voi community.
4.3 Local Gully System

Authors: Steffen Lehmann, Hiram Maina

4.3.1 Introduction

Gully Erosion is a serious problem for semi-arid areas in Africa, especially for landscape in Kenya. This Research took place in the surrounding area of the settlement of Voi, which is situated along the Nairobi-Mombasa Highway. The applied methods are used in a subarea in the northeast of the settlement of Voi, where extensive gully formation has taken place at different scales and locations.

4.3.2 Research Questions

The issues existing of gully erosion can be described by an exact detection of the positions of the gully systems. It is necessary to know the correct location of the gullies for further analysis and research. There are different types of gullies as a result of different parameters. Many authors classified gullies systems into rills, ephemeral and bank gullies, simple isolated gullies, simple continuous and complex discontinuous gully structures and others. This classification is a result of different controlling factors.

The existence of gullies depends on the topographic position, which is the most important factor contributing to the gully formation. Other controlling parameters are precipitation intensity, slope, vegetation, soil structure, land use etc.

Resulting from these aspects this research answers the following questions:

1. Where are the latest gully systems located?
2. What types of gullies are situated in the investigation area?
3. What are the main boundary conditions, which enforce the development of gully systems?

4.3.3 Methods

The applied methods in this research consist of the analysis and interpretation of topographic maps, satellite images and field mapping in the investigation area by the Geographic Information System (GIS).

The methods are supported by GPS-Measurement (Global Position System).

Analysis and interpretation of topographic maps and satellite images:

The first step for collecting data during the field work includes the analysis and interpretation of topographic maps and satellite images. The information derived from the maps and satellite images give an overview of the hotspot areas of gully erosion. High spatial resolution satellite images like World View 2 or Google Earth enable an extraction of gully structures before starting the field work. The creation of maps resulting by the analysis of topographic maps and satellite images in the GIS-Software supports the orientation during field work and shows the location of the largest gullies.
Steps for creation of maps used for field work:

1. Collection of data into the GIS
2. Georeferencing of the topographic and thematic maps
3. Detection and digitalization of gully systems using satellite images
4. Creation of maps (topographic subarea maps including satellite data, gully structures, vegetation, soil structures etc.)

The topographic maps and the GPS data provide additional information about the difference between the highest and lowest areas in the investigation area. These informations are necessary for the development of the Digital Elevation Model (DEM), which leads to a detailed statement of the slope and the watershed in the investigation area.

Steps for creation of Digital Elevation Model:

1. Extraction of the height information in the GIS-Software (elevation points, contours)
2. Input of GPS data into GIS-Software
3. Interpolation of all height resources for the model creation

Field Mapping and GPS-Measurements

Field mapping is a common method for collecting information with spatial reference into maps. The equipment for field mapping consists of maps and writing sets. The writing set is used for drawing the gully structures into the maps. Afterwards the data must be digitalized in the GIS-Software for the completion of data collection.

Steps for Field Mapping:

1. Observation of gully structures in the investigation area
2. Mapping of observed gully structures
3. Integration of collected data in the GIS-Software

The GPS measurement supports the accuracy of the mapping and gives additional information about the geographic position and the height, which are also used for getting a higher density of elevation points. The GPS measurements relay on satellite signals. The minimum number of available satellites must be at least 3 to get a GPS-Point, which can be saved on the GPS-Measurement as waypoint. After field work the elevation points must be integrated into the Digital Elevation Model.
Steps for the use of the GPS measurements:

1. Control of availability of the satellite signal (accuracy)
2. Saving waypoints in the GPS measurement
3. Integration of GPS points into the GIS software

4.3.4 Results

Location of gullies and other predominant types of erosion

Most of the actual gully systems could be extracted from the satellite images before moving into the field. Only a few gullies are mapped during the field work. The GPS points show the exact position of the mapped gullies in the investigated subarea (Map 6 and 7).

The majority of the gullies are situated in the Pediment where the slope is less than on the Inselbergs. Streets represent often the starting point of a gully system. All areas above the starting points are called gully heads which are usually situated at the Inselbergs. The dominating process in the gully heads is sheet and rill erosion resulting from the high level of slope and the position of bedrock close to the surface.

Fig. 7: Investigated gully systems in hotspot area 3 and 4 (Lehmann 2013)
Gullies are also located and mapped on the pediment and in the glacis, the latter marked as an area with a high accumulation of sediments (alluvial fans, Fig. 7 and Map 6).

Classification of gully systems
The upper areas belong to the Inselbergs and are characterized by several rills. Rills are small drainage channels which have a very parallel course in the steeper parts of the mountain. This kind of erosion is similar to a shallow gully system. There are rills in the pediment and glacis areas too. That means this type of erosion is not limited by strict slope and specific soil structures, vegetation and land use types (Fig. 8A).

The most gully systems in the investigated area correspond to complex gully systems in the pediment (Fig. 8B). These gully types are characterized by a lot of smaller gullies and rills flowing into the main gully. Wide spread catchments also characterise complex gully systems (Fig. 7 and 8). The area of the glacis represent often gully systems which are characterized as simple, isolated, linear structures. In general these types of gullies are very wide and deep (Fig. 8C)

Fig. 8: A = rills on eastside of Mwakingali Mountain, B = complex gully system in the pediment, C = simple isolate gully in the glacis

4.3.5 Discussion
The combination of field mapping and interpretation of topographic maps and satellite images produce good results during the research in the northeast subarea. The accuracy of gully location depends on the skills and experiences of the mapper.

The GPS measurements support the exact localization of the gullies with an accuracy of 3 m which is sufficient for integrating this information into the Digital Elevation Model. For example the elevation of Mwakingali Mountain from the topographic map approximates 818 metres. The GPS measures the same elevation of 818 metres on the top of the mountain.

The majority of the gullies are situated in the pediment where the slope is less and correspond to complex gully systems (Fig. 8B). These gully types are characterized by a lot of smaller gullies and rills flowing into the main gully. Streets represent often the starting point of a gully system. The dominating process in the gully heads is sheet and rill erosion resulting from the high level of slope and the position of bedrock close to the surface. The area of the glacis represent often gully systems which are characterized as simple, isolated, linear structures. In general these types of gullies are very wide and deep.

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Map 6: Data Collection during field work (Hotspot 3 and 4)
Map 7: Digital Elevation Model (Hotspot 3 and 4)
4.4 Gully Investigation

Authors: Aline Girard, Alexander Kasyoki, Robert Arendt

4.4.1 Research questions

It is very important to understand the genesis of gullies in the upper regions of Voi, because the gully systems causing a huge amount of damages in the city. To know what kind of processes are leading to those damages, it is necessary to analyse the highly dynamic system itself. Therefore different questions have to be answered. These would be:

1. Where does the gully genesis begin?
2. When does the gully change its direction and his course of flow?
3. Does the slope affect the depth of the gully?
4. Can the measurements obtained be used to describe the gully geneses?
5. What are the effects of the structures constructed across the gully on the gully system?
6. Is it important to consider the gully parameters constructing selected structures across the gully?

4.4.2 Methodology

One gully-system in the upper Voi catchment area was selected to measure cross profiles with a laser distance measurement gadget (©Leica Disto D8), including slope measurements. Furthermore a Garmin © GPS-gadget was used. At every measured point, photos and a GPS point was taken. The GPS points were used for calculating the distance between the initial rills of the gully system and the cross profiles. The tracking points could be found on the satellite image (Map 8).

At the beginning of the fieldwork it is necessary to identify the initial point of the investigated gully.
system. It was found out that four rills create the gully head. Three rills enter directly into the gully head. The other one enters a few meters later of the head cut of the gully. At this particular gully the slope and the distance from the road between the starting point of the first rill erosion to the last rill starting point were determined. At each rill the feature, the GPS point, the slope, the height and the length were measured.

In total 20 cross profiles were investigated. The first cross profile was taken at the point were the first two big rills entering the main gully head. Subsequent cross profiles were taken when a change in the slope, the width, the direction, and the depth or special features in the gully was identified. The parameters of each cross profile were measured by using the distometer and the GPS.

The field data were analysed to create a map with the taken GPS points locating the starting points of the rills and the measured cross profiles. The results of the cross profile measurements were presented in form of sketches. The map was used as the basic information to calculate the area were the gully system went into a sheet flow.

4.4.3 Results

It was found out that the gully genesis begins with surface runoff at the top of the hill. The map shows the GPS points which were taken at the rills and the cross profiles. The density of the GPS points on the hill causes by the occurrence of the four rills, which were measured out (Map 8). This particular small drainage area pass the water downhill crossing the street into the rills (GPS points) or it is concentrated in the culvert and drained into the main gully system.
Map 8: GPS points along the gully marking the structure and points of cross profiles
Three main gully types were selected to describe the variety of the morphological features of the 20 investigated gully profiles. It was found out, that one of the main factors, which can change the gully genesis, is the variation of slope inclination.

At the slope area with a high amount of bedrock occurrence the starting point of the rills and the gully heads were located. In this area the slope inclination is very high. This could be the reason why the investigated gully is in this part deep and side erosion take place. After a few meters downhill the gully began to meander and deposition of sediments starts to decrease the depth of the gully.

The first cross profile was taken a few meters after the two rills enter in the gully head. The slope in this area is very steep with bedrock. The gully walls are high (ca. 4.0 m) and the average width at the bottom of the gully is small (ca.3,50 m).

The cross profile 12 was measured after a road crossed the gully. The slope was 5° and in the case of storm water, the street on the left side was flooded (notice that the picture and the cross profile were taken in the direction to the hill). It is visible that the water formed some new rills on the street (Fig. 10 and 11).

![Cross profile 12](image)

*Fig. 10: Cross profile 12*

The profile 13 (figure 11) describes a part of the gully, where the slope is gentle and the gully change into the sheet flow type. Another gully entered in this gully system near the St.Kelvin academy. The pathway of the storm water entered in this place in a large sheet flow area (Map 8) and crosses the street afterwards.

The cross profile 17 (figure 12 describes the gully formation a few meters after a culvert which was constructed one year ago. The vertical erosion was more pronounced than the horizontal erosion. That can take place when the water discharge is very high. The water came from the area with the sheet flow pattern and was concentrated in front of the construction.
Thus a high discharge passed through the canal and flew with a very high intensity in the gully. Another gully located at the meteorological station side joined this gully before the last cross profile near the CIT (Coast Institute of Technology) gate. However the depth was not very high because of relatively flat surface.

4.4.4 Discussion
The gully genesis can be visualized by the selected methods but it is useful to know that the collected data are taken objective. It is not possible to measure all the necessary points in the investigation time because this can lead to loss of important information at a special point. One of the results of the investigation is that the longitudinal slope is a main factor to trigger the changes in the gully formation. This could be observed in the field as well as in the cross profiles with the measured slope describing this phenomena very well.

By analysing the results of this investigation it is possible to characterize this gully with specific details. These results are not common; this means that the data cannot be reflected on the other gully systems implying that if it is necessary to know more about the other gully systems it would be inevitable to make the same fieldwork in every single gully.
Another aspect is the infiltration rate of the soil, which is very low at the starting point due to the steep slope and the bedrocks on the gully bottom. The water cannot infiltrate and it flew on the bottom of the gully hence intensive side erosion.

In the next days more cross profiles will be measured and the collected data will be used for the hydraulic visualisation. The hydraulic modelling will be used to understand better the gully genesis.
4.5 Flood Water Risk & Management

Authors: Timo Dilly; Ian Krop; Sergej Friedel, Florian Sedelmeier, Sheila W. Mumbi

4.5.1 Research Questions

This part of the study focuses on flood risk vs. use and the development of a basic strategy to deal with the flood risks in Voi (flood risk management). Therefore, the following questions have to be picked:

1) What are the flood risks and why do they exist in the Voi area?
2) Where are the most vulnerable flood-prone areas in Voi and what are the local conditions?

To develop a basic flood risk management strategy, it is important to know what is the existing strategy for dealing with flood risks in Voi.

4.5.2 Methodology

In this case study, several methods were used:
- Data collection from satellite images
- Interviews of the responsible officer of Voi municipality during the field work
- Mapping relevant information in the field
- Interviewing affected residents in their residential homes.

The satellite images and the mapped hotspot areas were used to get basic information about flood water pathways. For more detailed information, a member of the municipal staff, Mr. Mwajewe, was interviewed on January 8, 2013. Mr. Mwajewe is very familiar with the special flood risk situation in Voi and gave a guided tour through Voi and to the hot spot areas in the city. Throughout the tour, observation, photographs, interviews, and note-taking were used to select two special areas to investigate in more detail (Hotspot 1 and Hotspot 2). They are considered as representative hot spots within Voi.

The actually existing gullies in these hotspots could be very precisely identified with the help of satellite images. The longitudinal profile of the gullies could be divided into three main categories, the upper part, middle part, and the lower part (Map 11 and 12). These gullies additionally leading to a flood risk in the lower parts of the investigated area. The analyzing of the longitudinal gully profiles leads to understand the flood flow paths and its associated risks. More than twenty local residents were interviewed about the flood risk to their private properties. A handheld GPS was used for mapping the interview points and other investigated information.

4.5.3 Results

Flood risk is the product of flood hazard and possible consequences (vulnerability). There exists a wide range between the two extremes, no and very high flood risk. If there is a high amount of consequences in the flood-prone area, a high flood risk is assumed. If there is no flood hazard and only
"potential vulnerability", there is no flood risk to expect. In Voi, there are settlements in flood prone areas hence flood risk and therefore a need to act. (PASCHKE, 2000)

The Voi area was surrounded by mountains (almost Inselbergs) in the North, East and South east. Due to this particular situation of the city, Voi is located as well on the lower part of the slopes (Pediment), within the basin (Glacis) and on the floodplain of the Voi River, the pathway of the storm flow affecting the residential and economic zones.

Most of the population is concentrated in the town center which is the business center. The residential zones spread all around with concentrations on some regions e.g. the Sophia or Bondeni locations. Flood risk is a serious problem in Voi, this can be seen in terms of houses affected by the storm water, the cutting of roads making them impassable and breaking of water pipes, among others.

*Interview with Mr. Mwajewe (Municipality of Voi) on January, 8:*

Rain periods dictate the seasons in Voi, Kenya. Long period of rainfall with low intensity is experienced between March and May. The region receives dry spell season from June till September and this affects the vegetation. The trees lose their leaves during the dry season and nearly all the grass is desiccated by the end of the dry season. Short and heavy rainfalls occur from October till December, and whereby most problems related with storm water are experienced in December.

Forecast about intense rains are not precise enough and are often wrong. Nevertheless the residents are informed by radio, television and newspaper about the oncoming weather and weather warnings. But these warnings are sometimes ignored, because the majority of the people focus on information on seasonal rainfall intensity for planning of agricultural projects. Local people predict the weather and rainfall conditions through observation of special plants, the movement of birds and even the moonrise.

Precaution measures that the municipality of Voi include giving sandbags to the residents of areas affected by flood water. These sandbags have to be filled and built up by the residents themselves. During the rain and resulting storm water the residents build up temporary measures and raises different types of fences to protect their buildings. But often these measures are too weak to resist the strength of the current of water and sediments. Other precaution and mitigation measures are not available.

Regeneration is taking place only on roads. The roads in Voi are subdivided in different classes. The main road which goes through Voi is part of the national highway from Nairobi to Mombasa and it is administered by the Kenya National Highways Authority [KeNHA]. Most of the other roads in Voi are urban roads and are liable to the Kenya Urban Road Authority [KURA]. These institutions define the financial framework for all works at the road network in Voi, including regeneration after flood damages. When there is flood damage on the roads, the engineering department of Voi gets this information mostly by the residents. This information is received very fast by KURA because an assistant of KURA works closely with the Municipality department of Voi. KURA sends an engineer
to record the damage and to generate a solution. This process needs time and in most cases a person designs short time solutions just for a certain spot and period. There isn’t any management strategy for regeneration of the affected settlements. 

The settlements of Voi which are most affected are Tanzania, Bondeni and Sophia (figure 13).

Flow Direction in the Hot Spot 1 and 2 areas (see map 9, 10 and figure 14) 

The storm water runs typically from the top of the hill through the dynamic gully system developed at the hill slope. Most of the storm water drains into a big gully system which crosses the area near the St. Kelvin’s school. A wall built at the St. Kelvin’s school to the road nearby divides the discharge in two pathways. A few meters after this point a junction with flood water from an adjacent gully system occurred with the consequence of increasing the discharge. At the location of the Coast Institute of Technology, a ford and gully system directs this flood water directly into the lower part of the city i.e. Sophia. All the gullies generated in the upper and middle parts drains into the very lower part of this particular area of the city toward the Voi River resulting into adverse effects like damaged houses and roads.
Fig. 14: longitudinal Profile–Hotspot 1 and 2
Map 9: Flow direction Hot spot 1
Map 10: Flow direction Hotspot 2
Hotspot 1 & 2 can be separated into 3 flood prone areas. In terms of population density, vegetation density and slope inclination they are called a upper, middle and lower part (map 11 and 12).

**Upper Part**
In the upper part of the investigated area the population density is low. The land use is dominated by grazing of livestock and some agricultural activities. At the time of the field work a dense vegetation cover was found. The slope inclination is high, rill erosion and gully heads occurred.

**Middle Part**
In this part the population density is still low only scattered houses were found. Several schools and Institutes were located in this part including St.Kelvin’s and St.Agnes school and the Coast Institute of Technology. Land use is characterized by small scale farming mainly subsistence. The slope of the gullies decrease while their width increase.

**Lower Part**
High population density is found on the lower parts. The land use is residential area with low agricultural activities in between. The slope inclination is very low, the gully depth decrease, sediment accumulation occurred. Accumulation of sediments mostly occurred on the roads enhancing further damages due to storm water. A small gully network developed especially in the interior roads.
Kenya, Voi
Hotspot 2 - Research Points

Legend:
- Interview
- Research Points
- Middle Part
- Upper Part

Scale:
0 100 200 300 Meter

Basic Information for Mapping:
Topographical Map of Voi
Spheroid: WGS 1984
Scale: 1:50 000
Proportion: UTM
Sheet 1963
Grid Zone 37 N
Kenya Government 1991

Design and Mapping:
Florian Sedimeier

Friedrich-Alexander-Universität
Institute of Geographical Sciences
Environmental Hydrology and Resource Management
Lead Partner:
Prof. Dr. Achim Schulze

University of Kaiserslautern
Civil Engineering
Hydraulic Engineering and Water Management
Lead Partner:
Prof. Dr. Robert Jäger
Map 12: Research points – Hotspot 1
Evaluation of the resident interviews

The evaluation of the resident interviews gives an overview over the flood risks take place in Voi. Beside this it is evident to know which kind of emergency measures are used in the settlements and how the regeneration is implemented. The frequency of storm water events was expressed to in average 3.5 times a year.

To analyze the results the flood damages of buildings and properties are subdivided in 5 different damage categories: a) properties without damage; b) properties which are affected just in the surrounding of the building; c) properties with flooded houses; d) properties with damaged houses and e) properties with destroyed houses.

One of the results of the interviews and overview indicates that the damages in the lower part are always more serious and at higher level than in the middle part (figure 15).

![Fig. 15: Different damages at properties](image)

This information goes ahead with the statements of the residents referring maximum water level. The maximum water level occur mostly in the middle and lower part (figure 16). The information derived from the interviews about the maximum water level in the upper part shows, that the bank full discharge is never reached. Therefore in this region the hazard is clearly asses as not that high as in the upper and middle part of the investigated area.
The precaution and emergency measures are usually used are building sand walls, cutting trees to get material to build fences and constructing barriers with sand bags. Also some houses are protected with rocks but these measures are not efficient.

The time to build up emergency measures is really short. Depending on the rainfall intensity the storm water hit the houses within a period from 12 up to 60 min after the start of the rainfall event. The majority of the residents don’t get any help to setup their measures (figure 17). There isn’t any alarm or action plan for the affected settlements. For regeneration there is mostly help from and within the community (figure 18). There isn’t any financial support to repair damages.

**4.5.4 Discussion**

In response to flood risks, generally it’s necessary to create a basic strategy to deal with flood risks. This may involve three main procedures of flood or storm water management:
a. The precaution measures, which could be done before a storm water event occur
b. The emergency measures, which could be done during the flood
c. Regeneration measures, to repair damages.

For precaution a detailed master plan is required. The whole city needs a systematical planned extensive drainage concept. The gully system should be included in this concept. The planning must ensure a safe discharge of the storm water to the Voi River or, if this is not possible, a detention storage. In addition to that, there should identified open landscape where the water could be stored or redirected to avoid damages. For example the water which comes from street N4 to Sophia could be redirected directly to the Voi river building a channel near the cost institute. Also the water of the gully which flow through St. Kelvin’s School should not be discharged to habited areas. The natural retention of water at the gully heads is hard to improve, because of the dry season between June and September.

Furthermore the created maps can be used as basic information to develop flood risk maps and an emergency plan for Voi city. Information events in the communities are useful to explain the right way to build up fences and to protect properties.

The city district Tanzania, which is close to the Voi River, is often affected with flood problems. This flood originates from the upper Voi River catchment. The establishment of a People-Oriented Inter-District Operational Flood Warning System for the upper Voi River is recommended. This means on one hand a continuous monitoring of the precipitation and on the other hand the observation of relevant water level at the Voi River. Critical water levels could be identified and warnings and recommendations could be issued clearly.
4.6 Roads and buildings

Authors: Anne Spies, Timo Rauch, Anne Nyabuti, Justus Kimeru

4.6.1 Research questions

Roads in regard to flood risks

There is always the need that a creek or a water channel has to cross a road. In general, several possibilities of creating a “junction” are known, e.g. bridges, culverts, fords. As a result of the field work, three different engineering structures are selected for further investigation:

- Culverts
  Closed conduit for the free passage of surface drainage water under a highway, railroad, canal or other structures.¹

- Fords
  A shallow place where a river or creek may be crossed by traffic or by wading. ¹

- Ditches
  Man-made, small, open channel constructed through earth or rock for the purpose of conveying water. ¹

Question 1: In what condition are the structures found as representative structures during field work?
Question 2: If there is a problem - how can the problem be described and solved?

Buildings in regard to flood risks

There are different flood protection measures for buildings, e.g. walls, dykes, closures and fences.

Research questions:

- Which flood protection measures are already used in Voi?
- Are they working properly?
- Which problems occur with these measures?
- How is it possible to improve these measures?
- Are the measures appropriate to different kinds of buildings?

4.6.2 Methodology

1st step: To get an overview

First there was a need to get an overview of Voi to identify hotspots, storm-water protection measures for roads and different types of buildings.

During the field work in January 2013 study points were marked using a GPS-tool. Photographs of these objects were recorded while taking the relevant notes. Field work surveys were carried out which included observations and interviews of the effected people (referring buildings).

¹ Wasserbau Dictionary
2nd step: Categorisation

The above mentioned culverts, fords and ditches were analysed during field work. Representative examples were selected to get relevant information about the function of the engineering structures. Three different types were differentiated:

A) Culverts
   a. Those that are working
   b. Those that lack maintenance
   c. Those that are not working

B) Fords
   a. Those that are working
   b. Those that are not working

C) Ditches
   a. Those that are working
   b. Those that lack maintenance
   c. Those that are not working

Protection measures for buildings:

Flood protection measures were identified and studied using various categories:

A) dyke
B) fences
   a. out of corrugated sheet
   b. out of sticks
C) walls
D) closures for doors and windows
   a. out of bricks
   b. out of boards
   c. Combination

3rd Step: Assessment

The evaluation of the measurements was made with the help of the engineering knowledge, literature and relevant documents. Furthermore, general approaches to improve the current situation were derived.

4.6.3 Results

A) Culverts
   a. Those that are not working
Example 1

The intake part of the culvert seen in figure 19 is in a good condition, but the damage occurred at the outlet because the erosion protection needed for high flow velocities and shear stresses forces is missing. The culvert itself (diameter: 600mm, surface area: 282.743mm²) is too small for the high amount of water therefore the flood formed another gully aside.

![Fig. 19: Culvert that is not working](image1)

Example 2

The erosion protection was built in the rainy season when the sand under the protection measure downstream was soaked with water. In the following dry season, the water evaporated thus changing properties of the sand. Consequently changing the volume of the soil, hence destabilising the protection structure lead into the collapse of the structure as shown in the figure 20. The materials used for the erosion protection structure are too weak to handle the shear stresses during flood events. Rips appeared; the storm water increased the rips and washed parts of the structure away. Scours were formed at the damaged parts and the structure become ineffective.

![Fig. 20: Culvert (diameter: 600mm)](image2)

b. Those that lack maintenance
Figure 21 is showing a typical example of culverts partly filled with sediment. During a storm water event, the discharge capacity is reduced and the calculated amount of water cannot be discharged. Runoff water floods the road and makes the road impassable. The storm water also damaged the structure.

**Dimensions:**
- Height: 2.38m
- Width: 5.06m

**Surface Area:** 565486mm²

---

c. Those that are working

Figure 22 shows the front part of the inlet where the storm water enters the structure. The inlet part is in a good condition, as compared to the outlet part (figure 23). The downstream end requires maintenance and need to be repaired, otherwise the structure can be collapse during the next heavy flood event. Figure 25 shows the problem: Intensive erosion was the source of the collapse of the erosion protection measure.

**Dimensions of the culvert:**
- Height: 2.38m
- Width: 5.06m

---

The following drawings 1 and 2 give an illustration of a possible improvement of the culvert structures that could be adopted.
Figure 24 and Figure 25 show a possible solution for the erosion problems in the outlet area of the culvert (downstream end).

A ramp should be built with concrete and rocks to ensure discharge the runoff.

A stable and deep substructure should also be put in place to make the culvert resistant against erosion.
B) Fords

The few fords we located during field work were not properly working (figures 26 and 27).

![Fig. 26: An overview of a ford](image1)

Fig. 26: An overview of a ford

![Fig. 27: A study member showing the direction of](image2)

Fig. 27: A study member showing the direction of

High erosion is also taking place at the upstream end of the fords and lead to instability of the whole structure.
Figure 28 and 29 show ford which is working properly. Nevertheless the erosion protection of the downstream end of the ford could be improved.

The fence as indicated in figure 30 should be removed in the downstream end of the ford to reduce accumulation of silt, sediments and surface runoff waste.
B) Ditches

a. Those that are not working

Figure 31: Illustrates a ditch that is not connected with another ditch to discharge water from the gully system further downstream. Consequently it will contribute to the flooding of the road making it impassable. In this particular example the ditch was filled with sediments.

Fig. 31: Not connected ditch filled with sediments

b. Those ditches that lack of maintenance

Figure 32 shows a ditch filled with construction debris which may block the passage of stormwater. It needs to be removed.

Fig. 32: Ditch filled up with debris
c. Those that are working

Buildings:
Protection measures for the buildings:

A) Sandbag-dyke

A dyke made out of sandbags that are fixed by soil. If there is high intensity of the storm water, the soil will be washed away and the sandbags might lose their positions.

High sandbag-dykes prevent the floodwater from entering houses or properties.
Low sandbag-dykes with one or two layers can be used to reduce the power of the flood.
This picture shows an example of a correctly built sand sack wall within a German city.

Additional suggestions:

- Fill the bags only to two-thirds, to ensure closure of the bag all the time.
- Keep a distance of 2 – 3m between buildings and dyke
- The lowest layer in direction of the water side has to be parallel to the current
- The sandbags have to be layered overlapping each other.

B) Fences
   a. Those made out of corrugated sheets

It is a good idea to use a combination of stakes, corrugated sheets and accumulation of soil. A proper illustration is shown in figure 36. It is important to ensure that the construction is resistant to floodwater, and this is achieved by fixing the stakes in the soil while using struts for the enhancement of the framework. The struts should be built on the non-water side of the wall and positioned between 30-45°. The corrugated sheets should be buried more than 10 cm into the ground and soil is recommended to be used on the flood water side to stabilize the construction.
b. Fences made out of sticks

A fence like this does not protect water from getting into the property. It can just reduce the power of the current. To reduce the velocity of the flood water it is necessary that the fence itself is stable. Therefore, sticks should reach more than 20 cm into the ground and they also need struts on the non-water side.

Fig. 37: Fence made of sticks

C) Walls

A wall can be a good protection against flood water. It is necessary that the wall surrounds the building completely. In this example (fig. 38) the water can pass the school from the non-water side. Therefore they built a dyke out of soil. If the water is higher than the dyke it can get into the school compound. So we would recommend an extension of the wall to surround the entire school compound.

Furthermore, there are good experiences with elevating walls with natural stones, because natural stones are more resistant against water than bricks.

Fig. 38: Wall at the St. Kevin Hill Primary School
D) Closures for doors and windows
   a. Out of bricks

   To have a closure in front of doors can be useful. To prevent a building from flood water, the closure has to be high enough. Otherwise, it just protects the house from sediments. High closure does not make sense in front of a door. It is recommended to raise the closure with woods before the flood is arriving.

   Fig. 39: Closure out of bricks in front of a door

   b. Out of wooden boards

   Closures made of wooden boards have the advantage in that their volume increases when they are put into water. Thus the boards fill little gaps between themselves and the wall by itself straight away when flood is coming.
c. Combinations of different materials

In figure 40 a combination of corrugated sheets and accumulation of soil is to be seen. If you work with corrugated sheets as a closure, you need to fill the gaps between sheet and wall with soil. We also recommend fixing the sheet with sand bags. They are heavy and cannot be displaced with that ease.

Fig. 40: Closure made of different materials

There are different kinds of buildings which use different kinds of protection measures.

A) Residential house
   d. Single-storey building
      i. Out of bricks
Single-storey buildings out of bricks can use all kinds of the described flood protection measures. It is important to protect the walls from soaking. If they are standing in water for a long time they are prone to collapse. It is also a good idea to elevate the house by using natural stones, because they are resistant to water.
ii. Out of mud

Buildings out of mud are not resistant to floods. They will take quite a short time standing in water and then collapse. The described protection measures cannot totally prevent such buildings from water. If the storm water is only passing by the house and is not that high, the building can be elevated with stones, bricks or boards.

Muddy houses should not be built in a valley with stagnant water or in a flood-prone area.

Fig. 42: Muddy house

e. Multi-storey building

In a building like the one shown in fig. 43, it is important to protect the ground floor from damages by flood water. If the ground floor gets damaged, the entire building will bent towards one side and eventually collapse. In addition, the buildings constructed next to it will likewise get damaged.

Fig. 43: Multi-storey building
B) Petrol station

There is one important safety aspect for petrol stations relating to flood: the gas tanks. If gas tanks float, they can be damaged and the petrol can pollute the environment. So it is very important to make sure that the tanks are not able to float. There are good experiences with cementing the tanks under the ground so that they cannot move and float.

Fig. 44: Petrol station (Source: ARENDT 2013)

4.6.4 Discussion of the results

During our field work we found that different storm water protections already exist in Voi town. The problem is that the amount of measures is too low. The estimated dimensions are too small and there are different problems in the way how to build the storm water protection measures.

4.6.5 Recommendations

To build storm water protection measures in the right way it is necessary to use the common codes, to stick on the right preparing of the material. Also it is necessary to inform the inhabitants how to use the available sandbags in the right way.
4.7 Floodwater Harvesting

Authors: Ayhan Celebi, Michael Eiden, Angela Wairimu Kimaru, Joyce J. Kong’a

4.7.1 Research questions

Concerning Flood Water Harvesting some questions emerged – answers to these questions are answered in later parts of this report. First it is important to know what Flood Water Harvesting means to get an understanding of the topic. According to the Food and Agricultural Organization of the United Nations Flood Water harvesting is the development of water resources in case of flood water.

The main research questions which were picked for the field work are:
1) Is there already an existing strategy for Flood Water Harvesting in Voi?
2) What appropriate strategies should be used in Voi?
3) What measures can be implemented for water storage and for flood protection?

To answer these questions, some auxiliary questions were developed. In the specific area, the water pathways and the origin of the water need to be figured out. Another aspect that has to be investigated is the state of art, so what has already been implemented and what measures are not yet available. Related to this, it is important to identify what the water will be used for and where it can be stored. In order to make suggestions for further measures, it must be found out which possibilities are there in the study area and a good starting point for the implementation of such measures. The contact with local inhabitants is very important in order to access information about the general social acceptance, motivation and response of Flood Water Harvesting and to ensure that they all work together for the success of the measures.

4.7.2 Methodology

For the investigation area in Voi we found no documentation of Flood Water Harvesting measures available even where basic harvesting methods exist.

The satellite images and the maps created by Christopher Raab and Steffen Lehmann from the Free University of Berlin are useful to get a general overview (maps 9 and 10). Three study areas with different conditions are chosen and the following maps are used (look up in the appendix):

- sub area south west
- sub area hot spot 1
- sub area hot spot 2
- sub area hot spot 4

Preliminary visit to the selected areas were conducted first, observations and follow ups done to verify sources of water and flow paths and also search for measurements that are already implemented. For documenting the investigation in the field, photographs were taken.
For detailed investigations, some measurements using the Leica DISTO™ D8 were taken at various study points to get information about the widths, depths and height of flood water flow. The local residents were interviewed to get responses for the questions and to find out if they were open for new measures. Also the interviews assisted to document any steps are taken.

4.7.3 Results

Study area 1

In this area two possible flood water harvesting points are identified based on the amount of water that was flowing through these points. They are categorised as sub area 1 and sub area 2 and details of each were discussed on the basis of suitability for possible implementation of construction of flood water collection tanks. Details of these areas are to be seen in figure 45:

![Study area 1 map](www.earth.google.com, edited)

Sub area 1:

This is one of the initial places where we found it reasonable to build a water storage facility. It is located right above the Voi stadium. There was already huge amounts of water concentrated within it. The presence of huge sediment deposits around it suggests of a high amount of water passing through it. With this information, this area is considered as an ideal place for flood water storage in order to control the amount of flood water that flows through it and which consequently ends up eroding at the edges of the stadium and damaging the road next to it.
Sub area 2: This area is an open land closer to the hilltop with no ongoing agricultural activities nor nearby constructions or buildings. This seems to be a more convenient area for water harvesting because of the convergence of water from different directions. The culverts at this point are too small to handle the large volumes of water flowing in it due to the sediment that is covering the culverts halfway. Most water comes from gullies in this sub area, converging at one point which becomes of interest if some kind of harvesting would be done to act as a flood control and at the same time serve the community’s domestic usage.

It is however imperative to mention the great challenge posed by sediments that are carried along with the flood water. Sediment barriers should be put into consideration when decision for construction is underway.

![Fig. 47: Proposed area](image)

![Fig. 46: Proposed area 2](image)

**Tab. 6: Local prices for water tanks in Voi 2013**

<table>
<thead>
<tr>
<th>Volume in liters</th>
<th>Price in KES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,500</td>
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<tr>
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<td>31,000</td>
</tr>
<tr>
<td>4,000</td>
<td>38,000</td>
</tr>
</tbody>
</table>
Study area 2 is one of the critical areas considered in the study. There are some deep and wide gullies running from the hill. It consists of settlements and other social amenities e.g. hotels, schools located on the slope of the hills in the area. The people carry out small scale farming. The area experiences intense rainfall during some selected months of the year. The rain water collects in the hills and flows down its slopes with a high velocity due to the high slopes of the hilly terrain. This water flows as storm water into the settlements and the schools and also creates the deep and wide gullies in the area. Some of the residents living in these settlements have tried to build some terraces to control the flow of the flood water and use some of the water to irrigate crops on their lands. They also dug deep trenches to collect the water that flows downstream when it rains but the rate of infiltration is very high due to the high hydraulic conductivity of the soil thus the water cannot be stored for long. To channel the water from the gully to the field, a depression in the side wall of the gully is dug so that a part of the water above a certain water level flows to the field.
Therefore storage needs to be constructed in the area to collect the flood water to be used for agriculture and by the schools around. An underground storage tank can be built in the North-West of St Agnes primary school, where there is already a little embankment to concentrate the water and redirect it so that the water does not flow directly into the buildings. The school could use that water in the nearby kitchen to cook or wash. Because of the huge amount of sediments, a sediment barrier should be constructed before the tanks, otherwise sediments would be deposited in to the tanks which would decrease the storage capacity after every rainfall event. Another storage tank can be built as a large water storage pan in the area around the gully shown on the map. The storm water would be channeled to this water pan. This water from the pan can be used for agriculture in the area and can also be treated and used by the nearby school St Kevin. In the settlements, where some terraces are already built, every resident could build terraces so that the flood water may be slowed down and the water used to irrigate the nearby farms. Therefore it is really important that all the residents work together, because one single terrace would not achieve the desired effect.

![Fig. 50: Proposed terracing, 2013](image)

![Fig. 49: Tranches](image)

**Study area 3**

The third investigated location was the area around the Scripture Mission of Voi. This location is of great importance because of the gully on the west end of the property, which is discharging huge amounts of water and causing huge damage on the settlements and infrastructure next to the Coast Institute of Technology. In the Scripture Mission of Voi, there are already several measures of Rain Water Harvesting put into practice. Little earthen embankments lead the water to fruit trees, roof catchment and buckets with small holes filled with water buried in the earth which irrigates the plants slowly. The collected water from the roofs is diverted into 3 fish tanks. Generally, the use of land is already much more efficient than the surrounding area of Voi and therefore this is a good example for possible duplication by the Voi people.
To gain more intense agriculture on the 32 ha land of the Mission, more water is needed which can be gathered by Flood Water Harvesting. In contrast to the other investigated areas in Voi, the discharge of flood water which is flowing in southern direction towards the Voi River does not move in centered gullies but constantly on the whole range of surface. Therefore it would make sense to lead the flood water by earthen embankments or water spreading bunds to a centered place where it can be stored as illustrated in figure 52 and 53. The consequent reduction of the stream velocity will increase the infiltration rate, which will regenerate the ground water level and further enhance the capacity of the already existing well. Due to the semi-arid climate and the high evaporation rates it’s necessary to collect the water in an underground storage, so that the water can be used even in the dry season to ensure a certain constant amount of water for agriculture. Another way of collecting water for agriculture in this area would be to divert some water from the flanking gully to the ground of the Voi Mission, which would also reduce the damage of flood water discharges in the settlements near to the Coast Institute of Technology.
4.7.4  Discussion:

To realize Flood Water Harvesting methods in Voi, it is suggested to start with the first measures on the ground of the Scripture Mission Voi. Not only do the topographic aspects favor such interventions but also the fact that the Scripture of Mission of Voi is an interesting place from a social point of view. Flood Water Harvesting methods which will be realized on the ground of the Mission can be used together with the already realized Rain Water Harvesting methods to develop a pilot project of Water Harvesting methods for the city of Voi. Other residents could learn from the pilot project either through workshops to implement the techniques for their own or common use. It is more reasonable to face the problem by starting with small measures like Rain Water Harvesting methods and afterwards implement Flood Water Harvesting methods in a step by step process. Due to the high evaporation rate, the best solution for storage in semi-arid areas like Voi is an underground tank although this could be prohibitive due to the costs involved especially in putting a tank. It is imperative for one to consider the purposes for which the water is used. For irrigation, a pan would be fit to construct than an underground tank because of the cost element. Measures like the construction of terracing systems would only be reasonable if they are realized in the whole area. It is for this reason that it is important to have a remarkable pilot project like the Scripture Mission of Voi to convince the people of the importance and benefits which will result from their investment, so that Flood Water Harvesting can be an option for Voi residents in the future.
5 Discussion of the Results

After one week of joint German Kenyan student field work in Voi we are glad to summarize that the approach of the students project was very successful to work together and interdisciplinary. The students gained methodological competence and sociocultural experience during field work. During this week they stayed together on the campus of Taita Taveta University college, worked together to create the field study report and took the opportunity for sociocultural exchange in a more private atmosphere.

The student field work results are analyzed and summarized in a project report. The report yield a contribution to the understanding of the geo scientific processes (interpretation of satellite data, flood risk mapping of flow paths and gullies, gully investigation and soil characteristics), and describes basic engineering approaches (flood risk versus use, flood risk management strategies, roads and buildings and flood water harvesting). The specific results are summarized in each subchapter of the report. The investigations are considered as a basis for a comprehensive monitoring that should be preferably implemented by Taita Taveta University College.

6 Recommendations

The student research was carried out during a few days in January 2013. The investigations on the ground could give a broad overview and in some cases detailed information were received. But this does not substitute a comprehensive research approach considering all relevant aspects in the investigation area. Neither can it substitute the necessary efforts for a Master plan of city development which need to have a drainage concept included.

Although, some recommendations as a result of the field work can be derived:

1. Flood seems to be the most dangerous natural hazard for Municipal Council of Voi. It is continuously damaging individual houses and public infrastructure during the rainy seasons. Therefore there is an urgent need for a comprehensive and holistic approach to understand the natural processes of the problems as well as predicting the negative effects.

2. The soil erosion protection and flood risk management strategy need to be incorporated in a Master plan for the development of the city.

3. There is no existing drainage system within the Municipal Council of Voi which is able to carry storm water in a non-hazardous way to the Voi river. The gully system as well as the natural creeks we found during our field work are not stable and change with the flow conditions. Without an efficient drainage system, storm water will continue to inundate vulnerable parts of the city and cause damage during flood events.

4. Generation of surface water runoff combined with soil erosion occur frequently in the headwater areas uphill. This is the most important source area for the flood and erosion related
processes in Voi. Effective erosion protection measures need to focus on those regions. Water retention in the headwater areas will be most efficient.

5. We see a lot of possibilities for water retention including infiltration. Because water is a valuable resource in semiarid regions, storage of water can be used for different usages. Flood water harvesting measures should be strongly supported and put into practice on different places and at different scales.

6. Storm water cause damages on roads in the investigation areas mostly by soil erosion which affects the engineering structures (culverts, fords, ditches). The necessary engineering knowledge to avoid these problems is available and need to be applied properly. Therefore it is necessary to monitor the damages after rainfall events and react properly.

7. There is a variety of possibilities to protect individual and public buildings against storm water. Individual protection measures have to follow the regulations of the Master plan (see 2) otherwise it can create bigger storm water problems downstream. We found some examples of building precaution measures which can be used as positive examples.

8. It seems to be necessary to raise the awareness of storm water and soil erosion problems within the whole community because many citizen might be affected and everybody is able to contribute to solutions. Workshops and other capacity building measures are appropriate tools. They should also include best practice examples which we have seen within the city for example rain and flood water harvesting measures.

9. The Municipal Council of Voi should make benefit of their scientific institution. The Taita Taveta University College can contribute with knowledge and engagement and for example install and operate a monitoring system.

7 Outlook

The joint German – Kenyan student project ends with the workshop in Voi on January 14th 2013. The students of the Freie Universitaet Berlin will continue their field work until the end of January 2013. Their master thesis will be available in autumn 2013. After intensive preparation in spring 2012 the VOIRICA proposal referring further scientific investigations was submitted to the Federal Ministry of Education and research (Germany) in June 2012. The assessment about the success of the application is to be expected at the end of January 2013. We are looking forward to be financially supported to be able to return to Voi and continue our investigations.
Appendix
Map 13: Hotspots of Voi

Legend:
- Type of Boundary:
  - Watershed
  - Main Street
  - Subsidiary Street
  - Border of National Park Tsavo East

Waterways:
- Voi River

Vegetation:
- Woodland
- Scrub
- Scattered Trees
- Palms
- Sisal

Scale:

Basic Information for Mapping:
- Topographical Map of Voi
- Spheroid: WGS 1984
- Scale: 1:50,000
- Projection: UTM
- Sheet 190/3
- Grid: Zone 37 N
- Kenya Government 1961

Design and Mapping:
- B.Sc. Steffen Lehmann

Lead Partner:
- Prof. Dr. Achim Schulte
- University of Kaiserslautern
  Civil Engineering
  Hydraulic Engineering and Water Management