

Catchment assessment report Hamesh Koreib
Water for Three States, Sudan

Final report, 23 March 2017



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Summary

The Catchment Assessment study is part of the DFID UK funded “Sustainable access to water, and improved sanitation and hygiene behaviour in the three states of Red Sea, Kassala and Gedaref” project, also known as ‘Water for Three States (Rural)’. This Report provides an assessment of the catchment and feasible options for infrastructure development, looking at the current and future water requirement and availability. This will support catchment-level Water Resource Management Committees in developing catchment-level Water Resource Management Plans.

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1 Introduction

General

This report provides the results of an integrated assessment of Hamesh Koreib Catchment area regarding water resources as well as socio-economic aspects. It includes an analysis of available data related to biophysical characteristics, livelihoods, livestock and natural resources management. This information forms the basis for the development of Water Resources Management Plans (WRMP) plans for the catchment. The current and future water use play an important role in the development of new infrastructure and interventions for water availability.

Due to security regulations, this document relies on data provided by NGOs that operate in the catchment area and analysis of satellite imagery

Objectives

The objectives of this study are:

- To conduct a replicable analysis of the current water balances of the catchment area.
- Compare changes in the catchment water balance and water availability under different scenarios of water infrastructure development for different types of use (Domestic, livestock, cultivation, other use) in different climatological settings.

The catchment report serves as an input for the WRMP that will be developed for the catchment by the Catchment Management Committee (CMC) and other stakeholders, facilitated by the local partner NGO.

Project outputs

This report is part of a joint assessment of 6 catchments. The overall approaches, methodology and background data is provided in the background report. There are three main outputs of the water for 3 states, Sudan project:

A background report, containing:

- A description of methodology explaining how future catchment studies can be conducted;
- A description of key data;
- A description of the model that was used;
- A description of impact of interventions;
- Regional maps indicating suitability of different kinds of infrastructure across the targeted states.

Catchment area reports for 6 catchments (this report):

- Narrative of the activities, thematic maps, water potential maps, model results and recommendations on water infrastructure development;
- Discussion of the outcomes of the analysis of the different options;
- Recommendations on feasible options for intervention.

Catchment database (digital database provided to the project partners):

- Existing literature, collected field data;
- GIS data of the selected catchment areas with suitable locations for water supply infrastructure (ponds, boreholes, etc.);
- Hydrological model with input and output data.

2 Key data

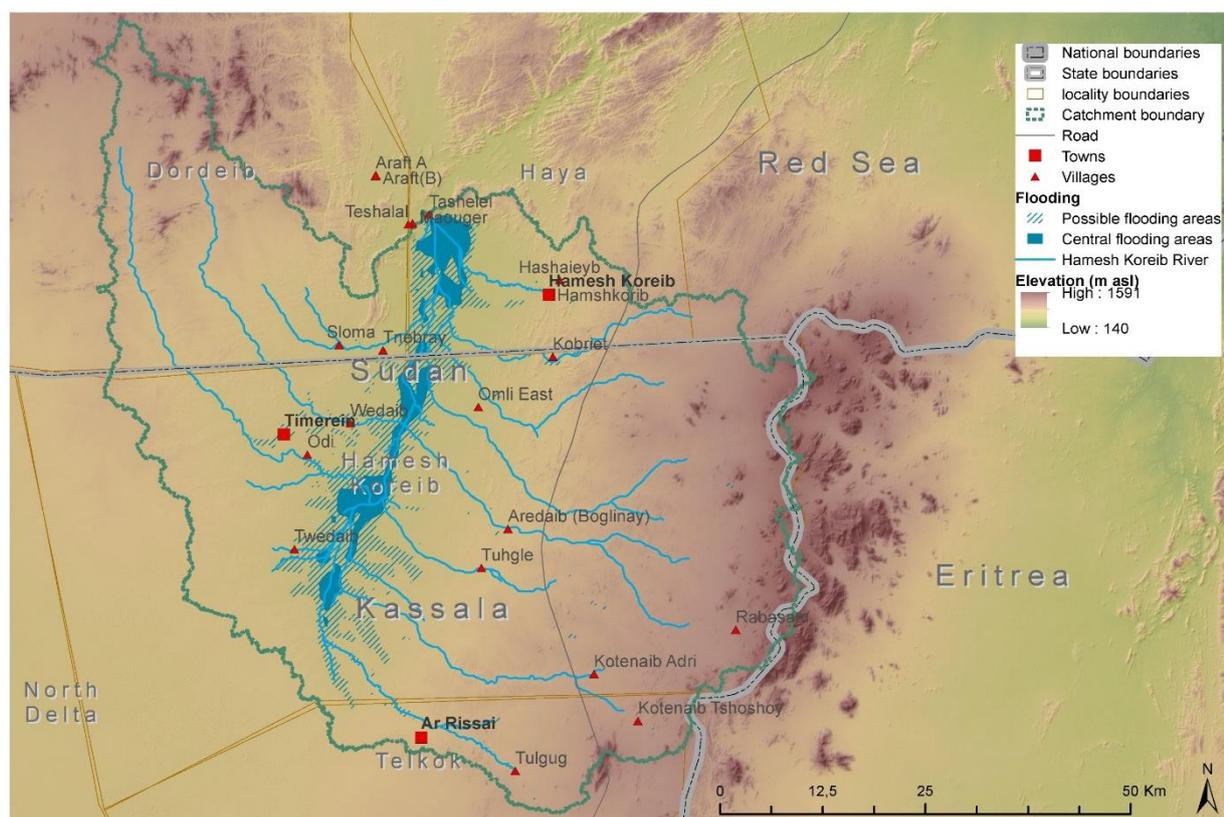


Figure 1. Topographic map of Hamesh Koreib catchment (green line).

Catchment name	Hamesh Koreib Catchment		
State	Kassala & Red Sea		
Administrative locality	Hamesh Koreib, Haya & Dordeib		
Catchment area	4,577 km ²		
Population and density	~30.000 ; 6 capita/km ²		
Important towns/settlements	Hamesh Koreib, Timerein		
Main livelihoods (%)	Agropastoral		
Water access/abstraction	49550 m ³ /year		
Water demand dry year	561225 m ³ /year		
Water demand wet year	554092 m ³ /year		
Water balance averages of modelling output	mm	million m ³	As percentage of precipitation
Average precipitation	184.5	844.4	100%
Average actual evapotranspiration	172.6	789.7	93.5%
Average groundwater recharge	4.3	19.6	2.32%
Average river outflow	2.64	12.1	1.43%

3 Catchment description

3.1 Administrative

The area lies in the Red Sea state and Kassala state. The main town in this catchment is Hamesh Koreib (~9000 inhabitants) and Timerein. The catchment is referred to as Hamesh Koreib catchment.

The area lies in 3 different administrative localities; Hamesh Koreib, Haya and Dordeib. The outlet of the catchment is located at the village of Tashet, in the Haya locality. To the east Hamash Koreib locality is bordered by the state of Eritrea.

3.1.1 Background

The male bias in the water infrastructure and water needs assessments will be a continued point of attention since water use and access for men and women differs. If a water source is located in the village then women and children get the water for domestic use. Children of the age of 10 to 12 often collect water from sources a bit further away from the compounds. If the source is far from the village, the men bring the water in.



Figure 2. Residence in Hamesh Koreib catchment.

3.1.2 Culture and ethnicity

Hamesk Koreib Town is divided into a separate man and women's part. The gender segregation is strong, the voice of the women is hard to hear. There are opportunities by speaking to the wives of the sheighs.

The Beja people are known to prefer to live away from each other. Not only does this make it difficult to estimate the number of residents of an area, they are also mobile and men move around between pasture and their fields.

Tradition does not allow the female labour resource to be used in agricultural production. Women are not part of the agricultural economy, and live almost completely separately from the men. Very few women therefore participate in manual agricultural work, which depletes the workforce further. However, women appear to be active in nomadic and semi-nomadic livestock-keeping (Water for Livelihoods report, 2010).

3.1.3 Livelihoods

The livelihoods of the inhabitants in the area focus around semi-nomadic pastoralism (livestock: goats, sheep and camels), and mixed agro-pastoralists, who are mostly settled (Water for Livelihoods report, 2010)

Agricultural practices

There are some regions in use for agriculture. In the Eastern region of the Hamesh Koreib locality there is no cultivation, but in the western region sorghum is planted.

Around the odil plains, the flooding areas are used for agricultural land. The Teshell dam near the catchment outlet is used for agriculture. In Teshallal dam area there is vegetables and watermelon cultivation in addition to Wedaib Almadrasa about 30 Feddan of sorghum.

In Hamash Koreib town there are newly introduced agricultural/horticultural schemes in the valley or khors. This aquaculture needs further development and support.

The Kassala state is troubled by the Mesquite (*Prosopis* spp.) tree. These are infesting the catchments and reduces crop yield. The tree and shrubs also cause blockages in the water passage to irrigation canals. A master thesis by Nzumira describes the effects of the Mesquite tree in the Kassala state¹. The mesquite trees can also grow in drier areas away from water sites. Even in natural rangelands it is an aggressive competitor and can quickly invade the upland country. Mesquite thickets can out compete other vegetation. The seeds can be transferred by animal movement and dung droppings or water flow from upstream towards downstream areas. Animals like eating mesquite pods because they contain a high sugar content (16%) and protein (12%) which is edible to animals. The Kassala state government stopped planting Mesquite in the year 1990 and launched a campaign to get rid out of it. In 2005 there were several government interventions some of which included the creation of a management mesquite team but all failed to stop the weed.

The trend of mesquite increment has been so fast that it threatens the life of livestock keepers and farmers. However, there are ways to benefit from the Mequite trees. The tree can be used for timber and making charcoal. The edible pods with high protein and large amount of sugar can be converted to flour for making bread and the trees can be used for honey production.

¹ Hamisi Said Nzumira (2014) Mesquite Trees Infestation of the Gash Spate Irrigation system in Kassala state, Sudan. MSc thesis, UNESCO-IHE Institute for Water Education, Delft.



Figure 3. Agricultural land near sand dam.

Grazing areas and livestock migration

Livestock provides an important source of income. Herds consist of camels, goats and sheep. Donkeys and cattle are also present in the catchment, but the majority of the livestock consists of goat and sheep. In the eastern region of the locality there is no cultivation but there is livestock activities of sheep, goats and camels. Available grazing grass are located around Samar, Sangaenib, Dharash, Aelab and Hllo.

3.1.4 Institutional context

Historical Background:

Due to collaboration between government of Sudan represented by National Rural Water Corporation (NRWC) and Netherlands Kingdom represented by (TNO) a bilateral program started on august 1979 and ended in March 1982 to assess the groundwater resources in Gash basin and to develop master plan for groundwater exploitation for all purposes and to promote the governmental institutional setting to assist the institutions to manage the groundwater in the alluvial basin.

The statement of water act as passed by regional assembly in 1984 and as result Water board and Technical Committee were established (TC). The final report of the project (NRWC/TNO 1982) and later published technical bulletin (VanEnk and Mukhtar 1982), Contained the results of the project's investigations. In 1992 this law had been reviewed and the result was a new law called (The Law of Development and Use of Water in Gash Basin 1992) so Water Council had been formed due this law involving different stockholders which had relation with water issues in the basin.

In 1995 (The Law of Development and Use of Water in Gash Basin 1992) had been cancelled by the cabinets ministers of Kassala State and replaced by State Drinking Water Corporation 1996.

This situation has led to create two governmental authorities one is (SDWC) State Drinking Water Corporation which formed due to local law of Kassala State, and the second one is Groundwater and valley administration (Technical Committee TC) in the past which belongs to Ministry of water resources. Since 1996 till now the picture can depicted as:

- Fragmented, scattered and no clear management approach.
- Absence of effective regulatory mechanism to control the exploration and development and management of water resources because as well as no direct coordination between the governmental authorities;
- At the local level in the rural areas there is no clear governmental body responsible for the management, operation and maintenance of the water facilities led to the majority of water

facilities are broken or working with minimum efficiency, most of the water facilities managed by the communities;

- In 2013 the Kassala State governor- Wali decided that, the Rural Water Corporation to be managed under state water corporation;
- Due to many factors, such as lack of funding and lack of enough staffs SWC could not take the whole management of the rural water department, currently the rural water facility managed by the community (source: State Level Assessment).

3.1.5 Development objectives and opportunities

SWOT Analysis (prepared by PLAN):

The SWOT analysis is a widely used as analytical tool to support the preparation of strategic planning. It is mainly used to establish a Framework showing the key internal and external factors that should be confronted during the strategic planning process. This framework is the base used by policy decision-makers in the making of a strategy that ensures a good fit between internal and external factors.

Strong Points:

- Rural Water Corporation had been established by State Water Corporation in 2013.
- Rural Water Supply model created /piloted by JICA – K-TOP Kassala Take off Project.

Weak points:

- Fragmented management of the water resources sector.
- Low human resource capacity in the water resources institutions at the state level.
- Weak financial structure.
- Weak legislative structure.
- Water Governance -institutional barriers
- IWRM is not institutionalized.
- Lack of civil society in water sector.
- Lack of groundwater resources in some areas: North Delta and Aroma localities.

Opportunity:

- Political will for the implementation of IWRM.
- Decentralization of political power.
- Donor will fund project focused on IWRM.
- INGOs work in IWRM.
- Existence of regional educational networks that offers specific training opportunities in IWRM

Threats:

- High dependency on groundwater resources
- Impact of climate change.
- Water conflict

3.2 Biophysical context

3.2.1 Climate

Precipitation is generally quite low, on average around 190 mm/y, with high variation between years (Figure 4, left picture). The rainy season is centred around a three-month period, generally from July to September, with little precipitation outside these months (Figure 4, right picture).

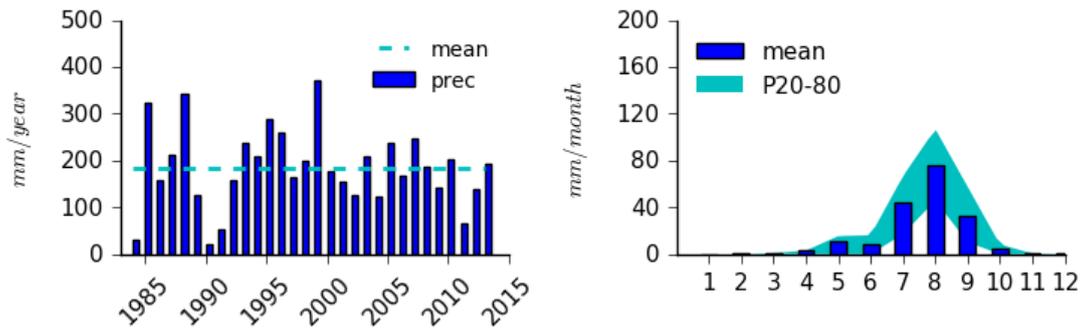


Figure 4. Annual precipitation in the Hamesh Koreib catchment (left) and mean monthly precipitation, as well as the 20th and 80th percentile of monthly precipitation (right) based on ARC2 data.

Table 1 presents some statistics for precipitation and precipitation events for two locations. The number of precipitation events is low, just 18-21 days per year on average. Rainfall is higher in the middle of the catchment, with extreme maximum events: up to 260 mm in one day, which is higher than average annual precipitation.

Figure 5 shows a graph for return periods. A return period, also known as a recurrence interval is an estimate of the likelihood of an event, such as a flood or a river discharge flow to occur. It is a statistical measurement based on historic data denoting the average recurrence interval over an extended period of time. This information can be used for risk analysis or planning (e.g. to indicate how often an area will flood, or to design the storage capacity of water infrastructure). For example, T=10 (also expressed as T10) of rainfall means that the total annual rainfall in this year statistically occurs once every 10 years. In Figure 5 return periods are produced for rainfall events. In this graph rainfall intensity of an event for a specific return period (T) can be found by interpolating between points (like T15 in Table 1).

Table 1. Precipitation statistics for two locations

	Mid catchment	Upper reaches
Average daily precipitation (mm)	0.5	0.4
Average event (mm)	8.9	7.9
Average yearly number of events (#)	21	18
T15 event (mm)	40.5	25.3
Average yearly maximum event (mm)	91.1	48.0
Maximum event (mm)	259.5	66.9

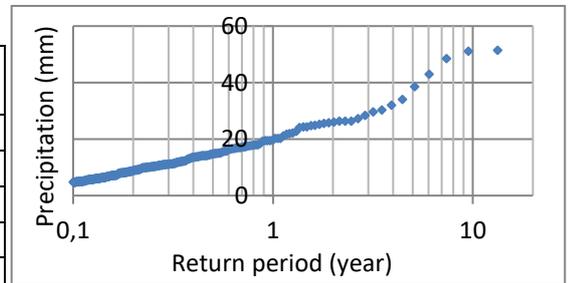


Figure 5. Return periods for precipitation events. Note the logarithmic scale

Evapotranspiration patterns resemble precipitation patterns, although peak years are a little less extreme and dry season shows somewhat higher values (Figure 6).

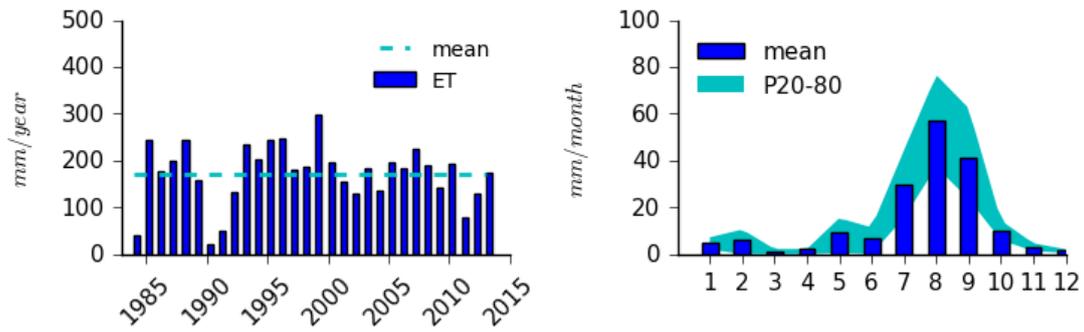


Figure 6. Annual evapotranspiration in the Hamesh Koreib catchment (left) and mean monthly evapotranspiration, as well as the 20th and 80th percentile of monthly evapotranspiration (right) based on SWAT model.

3.2.2 Hydrology

A map with the rivers, streams and flooding areas is presented in chapter 2. Hamesh Koreib or Odi Plain catchment consists of a number of sub-catchments discharging into the central valley with large flooding areas. The central flooding area (Odi Plain) is enclosed by mountains. The outflow of the catchment is determined by a dam place in a narrow corridor, which only occasionally overflows. It is unknown how often, and how much water leaves the catchment over the dam

Large floodplains are present within the catchment. Through analysis of NDVI data (2000-2016), floodplain areas were determined in two ordinal classes: areas where flooding occurs regularly and maximum area where flooding has occurred in this period. Using a Digital Elevation Model, and field survey data, an approximate depth was determined for these floodplains, which was used to calculate total flooding storage. Regular floodplains cover an area of 114.1 km² with a storage capacity of 17.9 million m³, while floodplains at a maximum stage cover 397.9 km² with a storage capacity of 62.9 million m³.

Table 2. Storage volumes of wetlands (million m³)

Wetland type	Flooding area (km ²)	Flooding storage (million m ³)
Catchment regular floodplains	114.1	17.9
Catchment maximum floodplains	397.9	62.9

All major floodplains are located in the middle of the catchment, towards the north boundary where the catchment outlet lies. Figure 7 shows NDVI values of this area for the rainy season of 2007 and after. Here the progression of vegetation of the central part of the catchment can be seen. Blue spots indicate areas of much vegetation, mostly flooding areas. The white colour indicates open water. Values are high for a large part of the area in the rainy season, and it takes a long time for values to decrease, some small parts present high values after a full year. This indicates long term availability of soil moisture and possibly shallow groundwater. Three hotspots can be seen where NDVI values stay high the longest. At the catchment outlet, a lake appears during the rainy season (indicated by the white colour in the first image). The formation of this lake is enhanced by the dam located at the catchment outlet. The lake is almost disappeared in the next image (after 100 days), and NDVI values in this area decreases much faster than in the other two hotspots. This is most likely due to the absence of permanent vegetation (trees and shrubs) in this area. The other two hotspots are the flooding areas in the middle and upper (southern) part of the Odi Plain. These flooding areas have recharge from different parts of the catchment, but the upper part also feeds the central and lower part during years of high discharge.

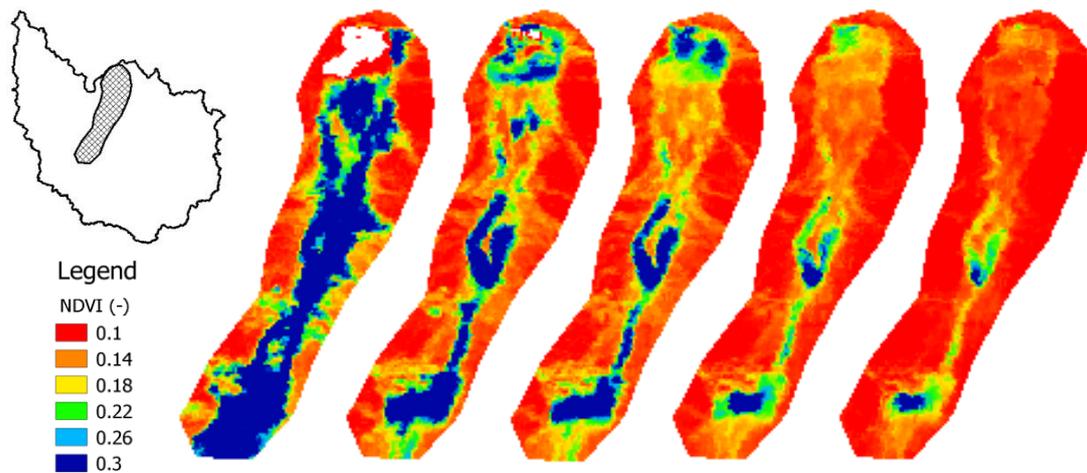


Figure 7. NDVI time series for July 2007 till August 2008, 90 days interval, of the central part of the Hamesh Koreib catchment. White areas within the catchment indicate open water.

3.2.3 Geology and hydrogeology

The eastern part of the catchment gives rise to a mountain range of basement rocks. Streams originating in this area have sandy river beds that could be a source of shallow groundwater. The western part of this range is bordered by an elongated formation of volcanic rock, perpendicular to the general westward flow direction of the streams. Further westwards of the range, flow diverges into a broad valley, mostly filled by alluvial fans.

The western part of the catchment consists of impermeable basement as well. The oval shaped landscape features, with a diameter in the order of 10 km, are the only notable changes in the geology on this side of the catchment. From the shape of these features it can be assumed that they origin from intrusive rocks, that erode more easily than the surrounding basement.

Flow from both sides of the catchment accumulates in a wide gently sloping valley. All water in this valley flows to the north, where a dam is constructed in a narrow passage in a ridge of impermeable basement. On the western side of this valley, sandy material from the headwater areas of the eastern tributaries forms an interconnected range of alluvial fans. The bottom of the wide valley is likely directly underlain by impermeable basement rock.

A refined geological/lithological map was made for the catchment based on the field data collected and classification of satellite imagery (Landsat 8), see the water recourses potential map at chapter 4.4

3.2.4 Soils

A refined soil map was developed for the catchment area based on Landsat 8 satellite imagery and field survey data (Figure 8). This map is used for the hydrological model and can be used for selection of soil and water conservation interventions.

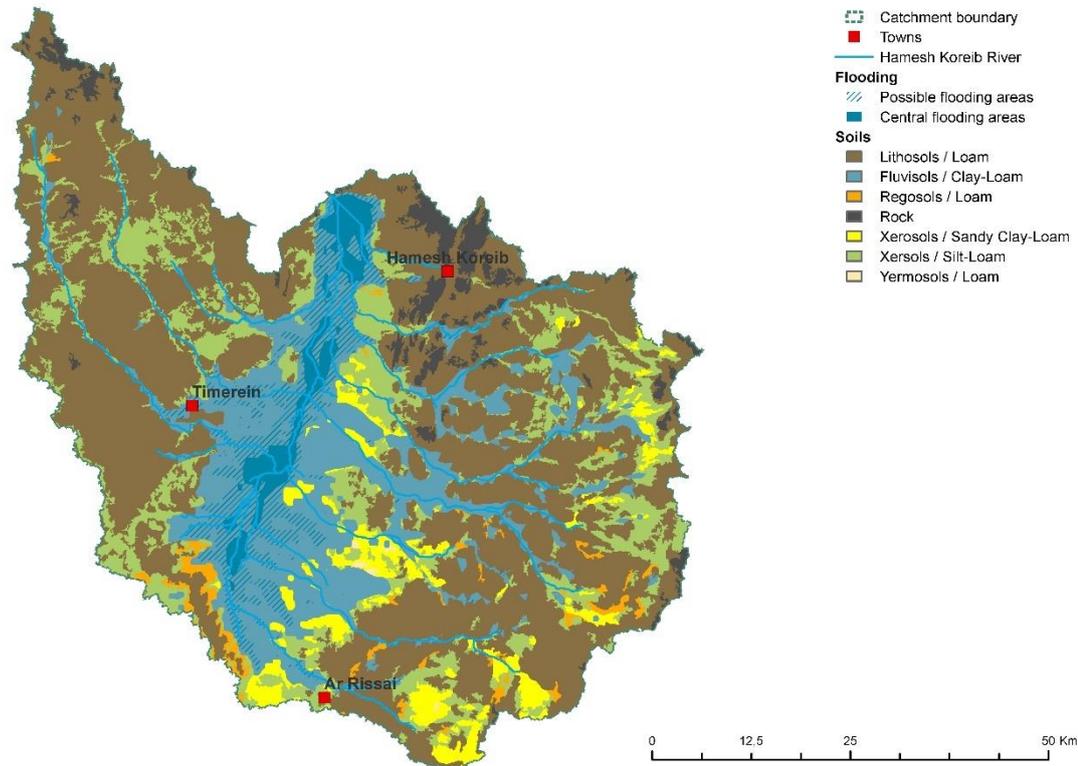


Figure 8. Soil map of Hamesh Koreib catchment

In the mountainous and gently sloping parts of the catchment soils are shallow sandy or loamy with rock fragments (lithosols and rock). These shallow soils are not well developed due to a low presence of weatherable minerals. There is hardly any soil formation and they have a high erosion hazard. Moreover, these often-bare soils have low fertility and soil moisture holding capacity and are therefore not suitable for agriculture.

The valley in the middle of the catchment is covered with fluvisols. These relatively young soils are developed in alluvial deposits of periodically flooded areas. Textures can vary from coarse sand in levee soils to heavy clays in basin areas. The infiltration capacity will mainly depend on the texture. The fluvisols usually have high soil moisture holding capacities favourable for agriculture.

3.2.5 Land use and land cover

Hamesh Koreib catchment mostly consists of bare soils and rock outcrops, with locally sparse shrubland or grassland, especially along the wadis. In the middle of the catchment valley along the floodplains, vegetation is locally more abundant.

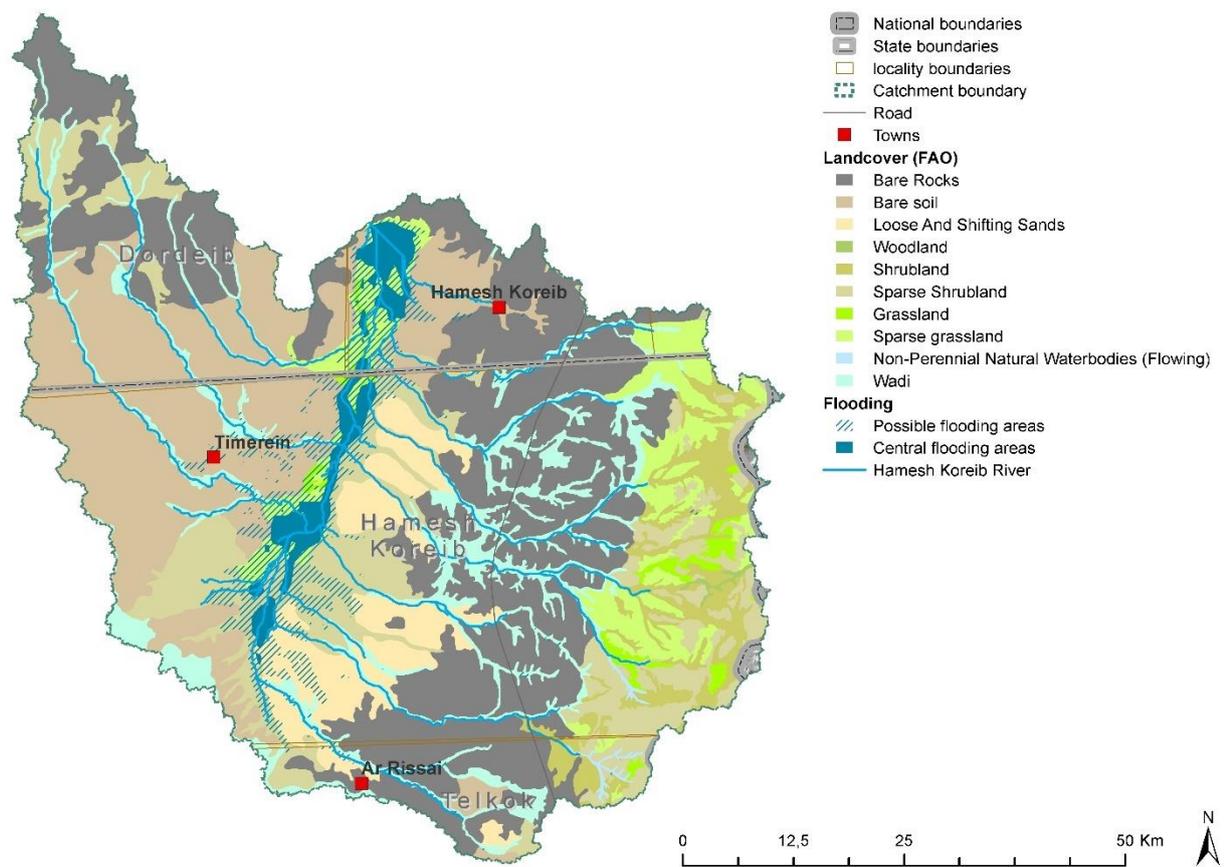


Figure 9. Land cover map of Hamesh Koreib catchment



Figure 10. Vegetation in Hamesh Koreib catchment



Figure 11. Landscape in the Hamesh Koreib catchment

4 Current water situation

4.1 Policy and regulation

4.1.1 Policy

Hamsh Koreib locality, as a rural area, faces many challenges in term of Water Governance, Water Policy and Regulation. By law the state water corporation (SWC) is responsible for the management, operation and maintenance but due to lack of budget and staffs the management is difficult. This influences the locality and community.

4.1.2 Current water resources management

Since 1996, water resource management can be depicted as fragmented, scattered and no clear management approach. At the local level in the rural areas, there is no clear governmental body responsible for the management, operation and maintenance of the water facilities. This has led to the majority of water facilities being broken or working with minimum efficiency. There is no effective regulatory mechanism to control the exploration, development and management of groundwater resources and no direct coordination between the governmental authorities and local bodies. In 2013 the Kassala Sate governor Wali decided that the Rural Water Corporation was to manage as state water corporation, but due to many factors SWC could not take the whole management of the rural water department. Effectively, most of the still active water facilities are managed by the local communities.

4.2 Water supply, access and demand

4.2.1 Existing water infrastructure

The existing water infrastructure is shown in Figure 12, which is based on the water infrastructure assessment (WIA) carried out by the partners under the WF3S program. Most water points are hand dug wells in and around the stream beds. Besides wells, the only other water infrastructure present is one water yard.

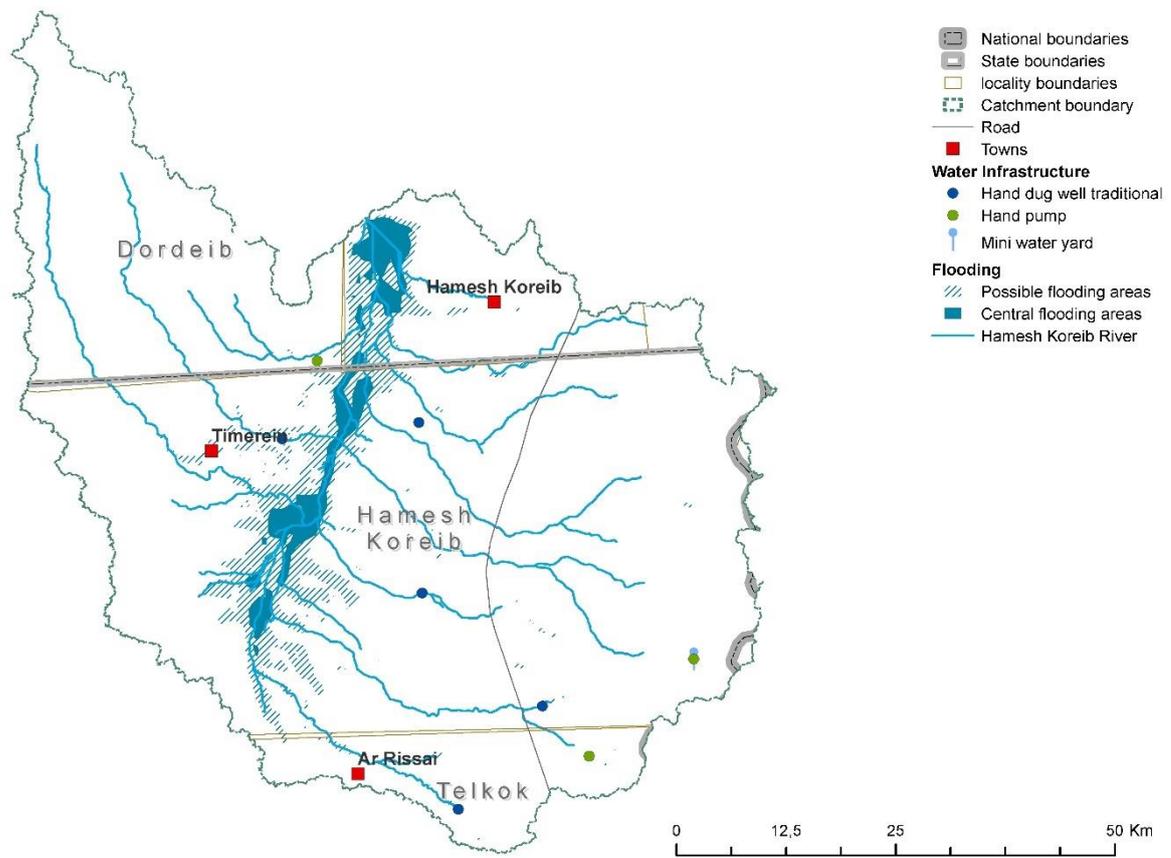


Figure 12 Map of existing water infrastructure

There are 13 water points in the catchment, of which 1 non-operational at the moment. But according to the dataset one of these water points can easily be repaired.

It is very likely that the WIA is not complete. During the workshop in December 2016 a hafir was indicated in the centre of the catchment. Also 6 shallow wells around Hamesh Koreib town have been mentioned in documents. During the following analysis, the information from the water infrastructure assessment was used.

4.2.2 Domestic water demand

The water infrastructure in the catchment (based on the WIA) is used to make estimates for the water availability and water demand. The dataset is post-processed and some unrealistic values have been adjusted. The WI database indicates the number of people and livestock per day that make use of the water points in a wet and dry season. The domestic water demand in a wet and dry season is calculated using a daily water demand of 20 l/capita/day

The water infrastructure dataset states high numbers of users per water point. According to the dataset, in total 20,430 people make use of the water points in the dry season and 18,000 in the wet season. The reliability of these values is uncertain, but these are most likely rough estimates. Other population data is not available and therefore these values will be used for calculations. The water availability is calculated based on estimated yields of the water points. Handpump abstraction rates were set to a maximum of 5 m³/d. These assumptions result in the following table:

Table 3. Domestic water gap in m³/d for Hamesh Koreib catchment

	m ³ /d
Total domestic water demand in wet season	100
Total domestic water demand in dry season	409
Total domestic water availability	70

This results in a water gap of 339 m³/d for a dry situation and 290 m³/d for a wet situation.

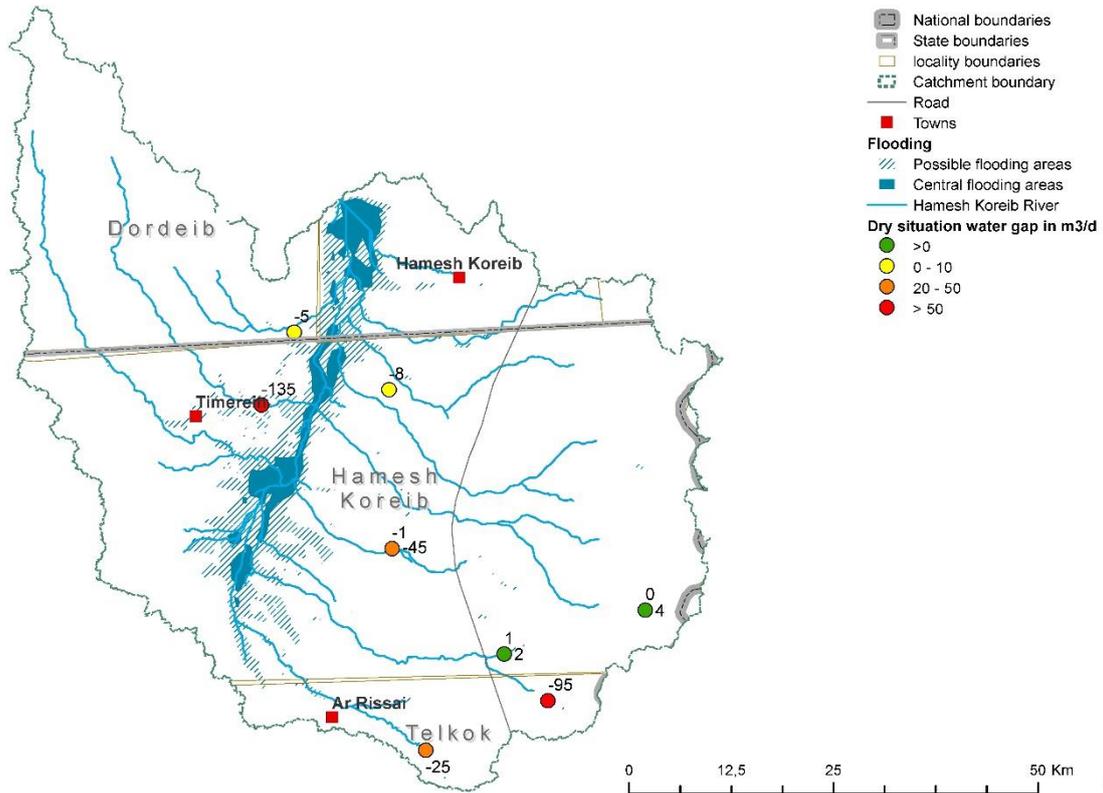


Figure 13 The map shows the domestic water gap per water point for dry conditions in m³/d. A negative value indicates a water gap and a positive value abundance of water. Several water points are located at the same geographical location and might overlap in the map.

The domestic water gap is mainly around the town of Timerein.

4.2.3 Livestock water demand

Livestock water demand is calculated making use of the Sub Saharan Livestock unit. One Sub Saharan FAO Livestock Units (LU) = 250 kg of livestock. One LU uses 50 l per day. The water infrastructure dataset states the number of livestock making use of the water points in a dry and wet season.

The additional livestock water demand during migration is added to the water demand in the dry season.

Table 4. Livestock water demand standard values of the FAO. One Sub Saharan FAO Livestock Units (LU) = 250 kg of livestock. One LU uses 50 liter per day.

2	cattle	=	1	LU	1	cattle	=	0.5	LU	1	cattle	=	25	l/d
10	goats	=	1	LU	1	goats	=	0.1	LU	1	goats	=	5	l/d
10	sheep	=	1	LU	1	sheep	=	0.1	LU	1	sheep	=	5	l/d
0.91	camel	=	1	LU	1	camel	=	1.1	LU	1	camel	=	55	l/d
1.67	donkey	=	1	LU	1	donkey	=	0.6	LU	1	donkey	=	30	l/d

The livestock water demand is different during dry and wet seasons and during dry and wet years. In a wet season, other water sources might be present in the catchments like water in rivers or puddles. During a dry season, livestock is dependent on the available water sources like hafirs and water yards and hafirs do not contain water year-round. There are no hafirs indicated in the WIA, but there was one hafir mentioned during the workshop in December 2016. Therefore, one hafir with an estimated volume of 24,000 m³ is used in the calculations.

During a normal year, there is migration from livestock towards the catchment for grazing areas and water mainly in the wetter months. Hafirs are assumed to replenish at least once a year in normal years (although this varies per hafir and in dry years there is no significant runoff). Therefore, the migrating livestock is added to the livestock numbers for some months to calculate the livestock water demand in a normal situation. Based on the water infrastructure assessment, the water demand can be calculated for a dry situation and a wet situation per day. During a normal year, there are more or less 9 dry months and 3 months with a wetter situation (circa 50 mm/month) for Hamesh Koreib catchment. With the following situation, the water demand and water gap is calculated and presented in Table 5

Situation in a normal year:

- Hafirs are replenished once a year
- Additional livestock water demand for 2 months of the year.
- ~9 dry months
- ~3 months with a wetter situation

Precipitation data analysis of very dry situations show that there are years without rainfall. This means that the hafir in the catchment does not get recharge during very dry situations. In such a situation, the potential for grazing is low in the catchment and therefore part of migrating herders could take their livestock elsewhere. The migration routes depend on the water availability in and outside the catchment.

Situation in a dry year:

- Hafirs are replenished once per two years
- Additional livestock water demand for 3 months of the year.
- ~12 dry months

Table 5. The livestock water availability includes a hafir volumes (minus an evaporation and seepage loss)

	Normal year (m ³ /year)	Dry year (m ³ /year)
Total livestock water demand	345,898	345,898
Total livestock water availability	129,625	87,625
Total livestock water gap	203,863	258,239

There is a large water gap for livestock in Haya catchment in a normal year and in a dry year. In chapter 4.2.2 the total water gap is calculated also looking at the domestic water demand.

4.2.4 Water supply gap

The following table presents an overview of the yearly water gap for Haya catchment in a normal situation and a very dry situation.

Table 6. Water demand, availability and gap for Hamesh Koreib catchment in m³/year

Yearly totals	Normal year (m³)	Dry year (m³)
Domestic water demand	142,722	123,589
Domestic water availability	25,550	25,550
Domestic water gap	-117,172	-98,039
Livestock water demand	465,863	465,863
Livestock water availability	21,810	9,810
Livestock water gap	-444,053	-456,053
Total water gap	-561,225	-554,092

For domestic use, there is a major water gap in normal and dry situations. It is likely that not all water infrastructure in the catchment is included in the water infrastructure assessment or that the domestic water use is less than 20 l/capita/d. Another possibility is that the yield of several water points does exceed 5 – 10 m³/d. This would decrease the water gap.

There is also a large water gap for livestock in a normal and dry year, mainly due to the high numbers of livestock and almost no water infrastructure for livestock. The additional water demand due to livestock migration was taken into account in the calculations. It is possible that in the real situation, the livestock migrates also between water points close to the catchment borders.

4.3 Catchment water balance

4.3.1 Model set-up

A hydrological model was developed for the catchment to create insight in the water balance of the catchment. SWAT uses spatial data of catchment characteristics (DEM, land use, soil, stream pattern), combined with climate data series and water use to simulate water flow through the catchment. The input data is generated using remote sensing, open source data and the results of the field surveys. Rainfall was obtained from the FEWS-Arc2 data and all other climate parameters from the CFSR database. More information on SWAT, the input data and methodology used is provided in the background document.

Figure 14 gives an overview of the catchment as input for SWAT. The catchment is divided into sub-catchments based on stream pattern. Each sub-catchment has one stream (or reach). Runoff leaves the catchment as outflow at the outlet in sub-catchment 3. The main flooding areas in the central plain are modeled as reservoirs. Reservoir 17 includes all the flooding areas in the upper and middle catchment. Reservoir 3 simulates the flooding area and water body at the outflow of the catchment.

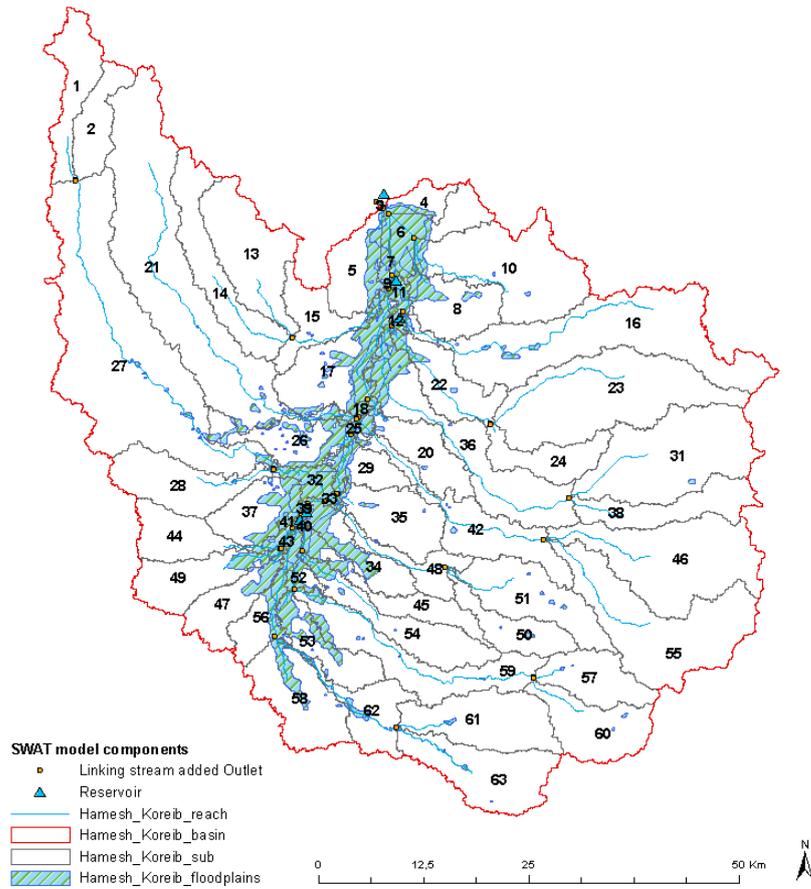


Figure 14. SWAT model setup for Hamesh Koreib Catchment

4.3.2 Model outputs

The model was run for 30 years (1984–2013), simulating daily time steps, while writing monthly output data.

Figure 15 gives an overview of SWAT outputs, providing the average yearly water balance of the catchment. On average 94% of the precipitation leaves the catchment in the form of evapotranspiration, while 3% becomes surface runoff.

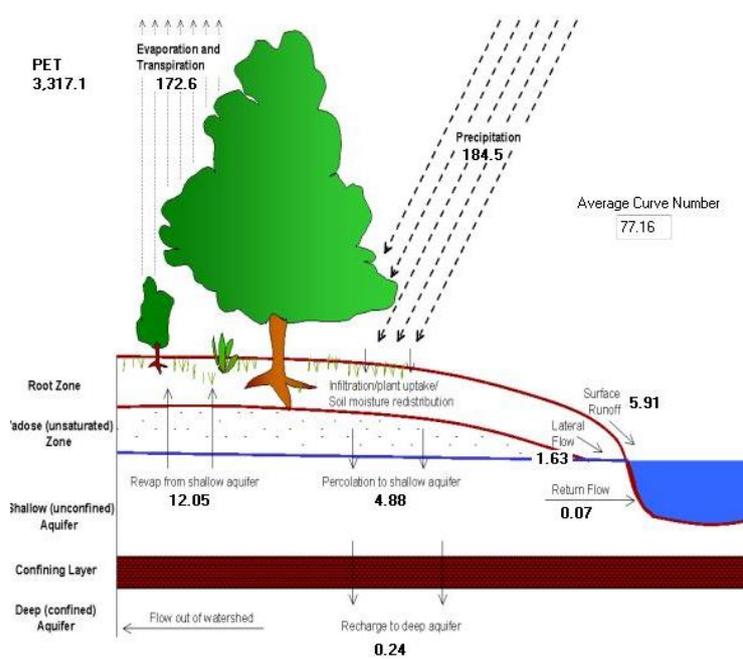


Figure 15. SWAT output: Water balance in mm for Hamesh Koreib Catchment

Table 7 gives output of the main processes of the water balance for normal, dry and wet years, based on their return periods (for definition of return period see chapter 3.3.1).

Except for wet years, evapotranspiration is equal to or higher than precipitation, while the other components are very small. Runoff and groundwater recharge are much increased in wet years, although actual outflow is still low.

Table 7. SWAT output: Values of water balance components based on their return periods for a wet, normal, dry and very dry year (mm and million m³)

	Normal (T2)		Wet (T10)		Dry (T5)		Very dry (T15)	
	mm	Mm ³	mm	Mm ³	mm	Mm ³	mm	Mm ³
Precipitation	176	805	324	1484	127	582	30.5	140
Evapotranspiration	182	835	245	1122	131	598	41.5	190
Runoff	1.53	7.01	29.2	134	0.11	0.51	0.00	0.00
Groundwater recharge	1.01	4.64	19.9	91.1	0.29	1.34	0.00	0.01
River flow into the flooding areas (reach 3 and 17)	2.22	10.16	29.6	135.4	0.92	4.20	0.15	0.69

Figure 16 presents the average yearly runoff in mm as simulated by the SWAT model. Table 8 presents outflow for normal, dry and wet years, for the most important reaches. The reach numbers are corresponding to the sub-catchment number as provided in Figure 16. Runoff is lower in the north-western part of the catchment, which can largely be attributed to a lower precipitation in that region.

This can also be seen in the outflow data, where reach 21 and 32 representing north-western tributaries, show relatively low values compared to southern and eastern tributaries like reach 40 and 42. Lowest outflow values are however in reach 3, where the catchment outlet is located, only shows some outflow in wet years. The outflow of reach 17, represents the outflow from the upper and middle flooding areas into the flooding area at the outflow of the catchment. In the current model simulation, the volume of water is zero, in other words, all streamflow remains in the flooding areas. Hamesh Koreib town is located in subcatchment 10, where outflow is medium. This catchment is an important contributor to the flooding area at the catchment outflow.

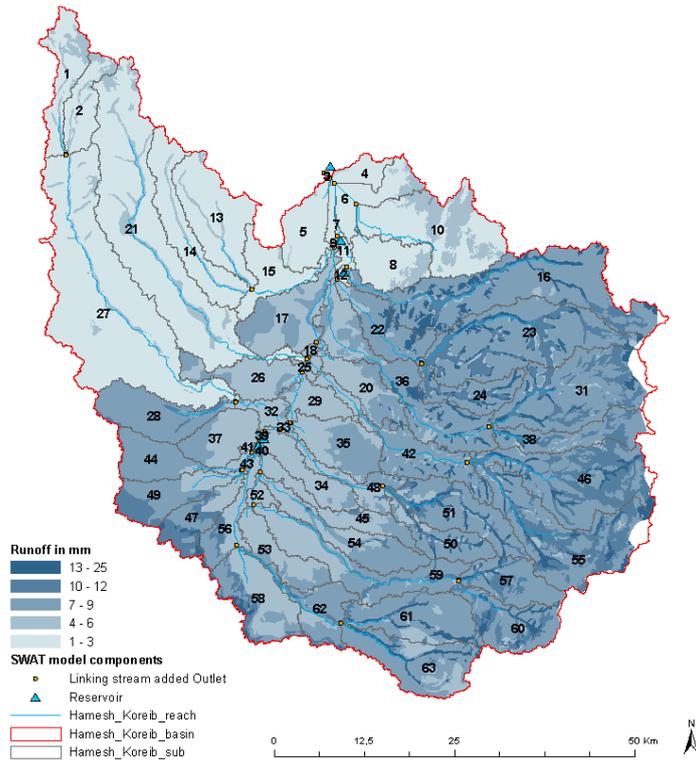


Figure 16. SWAT output: Simulated Runoff in mm for Hamesh Koreib Catchment

Table 8. SWAT output: Outflow data (mm and million m³) for a wet, normal, dry and very dry year for specific reaches, for return periods T₁₀ of high reach outflow and T₂, T₅ and T₁₅ of low reach outflow. Note that values in mm are calculated using upstream area from the end of the reach

Sub catchment	Wet (T ₁₀)		Normal (T ₂)		Dry (T ₅)		Very dry (T ₁₅)	
	mm	Mm ³	mm	Mm ³	mm	Mm ³	mm	Mm ³
3 (catchment outlet)	0.20	0.93	0.00	0.00	0.00	0.00	0.00	0.00
4	11.7	53.0	1.00	4.51	0.47	2.14	0.08	0.37
7	9.22	38.9	0.95	3.99	0.43	1.83	0.07	0.31
10	14.9	2.25	2.77	0.42	1.44	0.22	0.30	0.04
17 (wetland outlet)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	27.1	77.5	1.87	5.35	0.69	1.97	0.11	0.31
21	7.42	2.37	1.31	0.42	0.73	0.23	0.17	0.05
30	25.0	47.9	1.53	2.94	0.45	0.87	0.06	0.11
32	11.6	6.85	1.44	0.85	0.70	0.41	0.14	0.08
40	22.1	12.9	1.96	1.14	0.35	0.20	0.02	0.01
42	32.2	14.2	4.35	1.92	1.99	0.88	0.37	0.16

Figure 17 presents the yearly outflow of the reaches with the highest outflow, i.e. reach 7, 18 and 30, plotted together with precipitation. These reaches provide an image of flow of the main river in the mid-part of the catchment. Water accumulated in the tributaries in the upper catchment first reach the main river at subcatchment 30 and more downstream in subcatchment 18. There, the accumulated water flows into the floodplains, which do not reach full capacity at any time during the modelling period, and no flow reaches the catchment outlet from upstream of this subcatchment, which covers the majority of the total catchment. However, directly downstream of these floodplains water accumulation starts again from more northern tributaries (the lower catchment including Hamesh Koreib Town). This water

collects in subcatchment 7. Here flow enters the lower floodplain at the catchment outlet. Here floodplain capacity is only exceeded in really wet years.

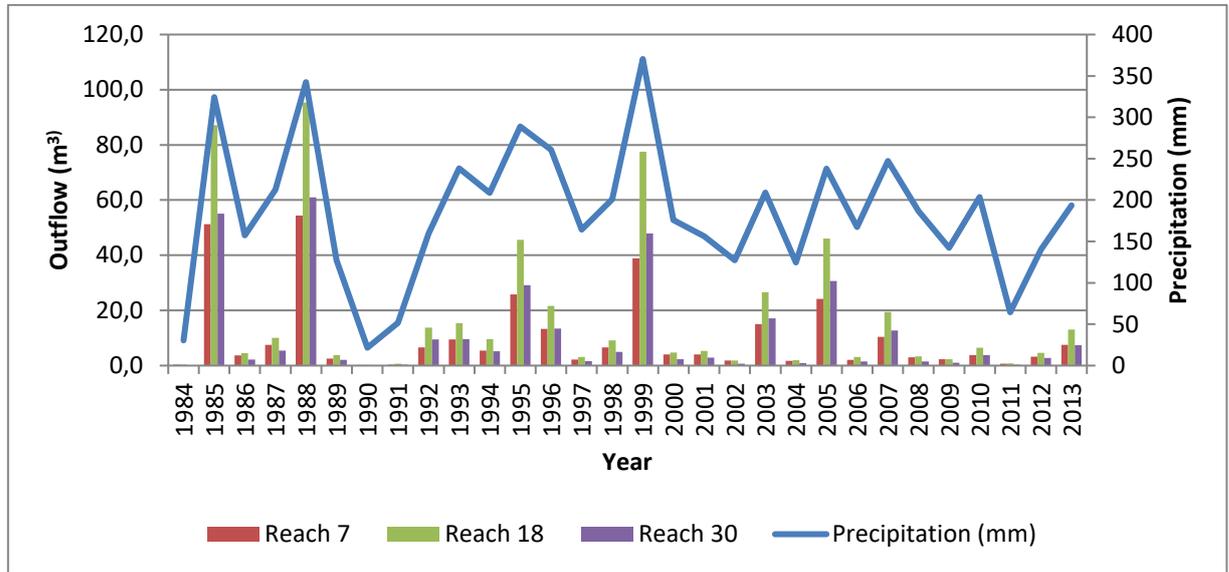


Figure 17. SWAT output: Total yearly streamflow (in million m³) at three locations, plotted with precipitation (mm)

Figure 18 provides the monthly inflow statistics for reach 3, indicating flow into the floodplains at the catchment outlet. These statistics are determined on return periods of monthly inflow values for normal, wet and dry months.

The wet and dry period are pronounced very strongly in this figure. Basically, all inflow occurs between July and August, with a strong peak in August, even in wet circumstances. In very dry years this peak is only 0.08 Mm³, hundred times lower than in wet circumstances.

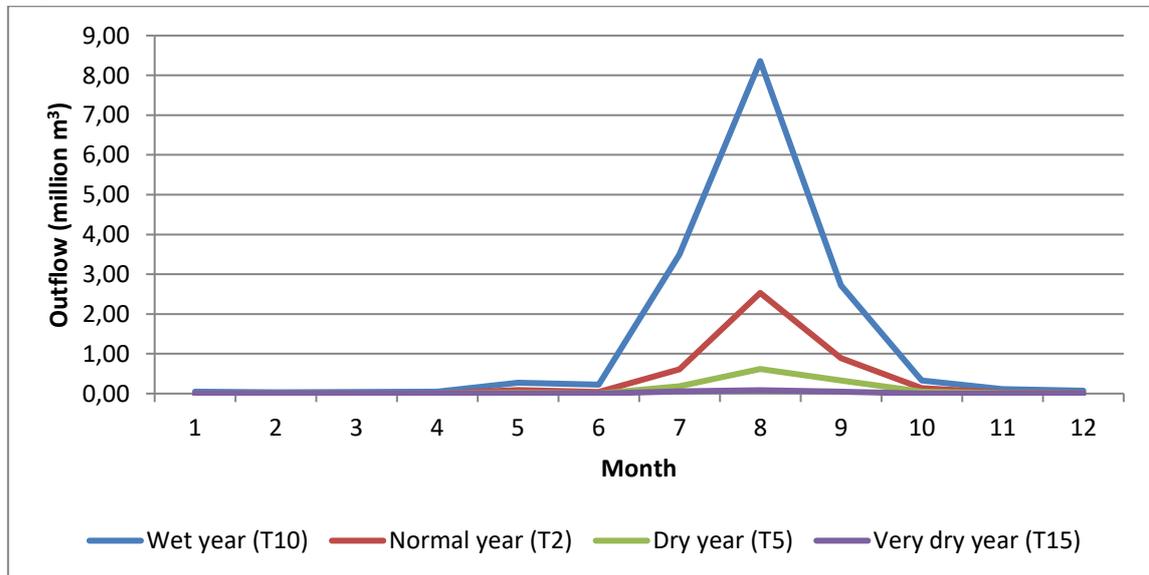


Figure 18 SWAT output: Outflow values (million m³) for monthly outflow return periods of river flow into the floodplain at the catchment outlet (reach 3), for T₁₀ of high outflow and for T₂, T₅ and T₁₅ of low outflow

4.3.3 Assessment of model outputs

The model outputs indicate a high variability in rainfall which is even stronger reflected in runoff and stream flow. Runoff only occurs in the short time span of the rainy season, although periods of low streamflow can last over 5 years. The wet and dry periods are pronounced very strongly in this catchment.

Runoff is collected in the floodplains where it is stored. Only in extreme cases runoff will flow out the floodplains at the catchment outlet. The location of the floodplains dominates the distribution of water in the central part of the catchment. The flooding areas are large and have an enormous impact on the water balance. Eventually the majority of the stream flow disappears in the floodplains due to evapotranspiration and infiltration, a total of 10.16 Mm³ flows into the floodplains in an average year, while in a wet year (T=10) this is 135.4 Mm³.

To address the water shortages in the dry and very dry years, part of the peak flow in the wetter years can be used for recharge of water resources and sources. The water gap for human and livestock water demand in dry years is 1518 m³/day or 554092 m³/year. If 0.5 % of the discharge in the wet years (T=10) could be captured, the water gap in a dry year could be bridged. Resources for bridging long term droughts should preferably be groundwater resources. Paragraph 4.4 provides the potential for water storage in the catchment.

4.4 Water resources development potential

The water resources potential in the catchment was mapped based on the lithology and stream characteristics, see Figure 19. The map provides generalized potential for shallow groundwater, deep groundwater and water harvesting.

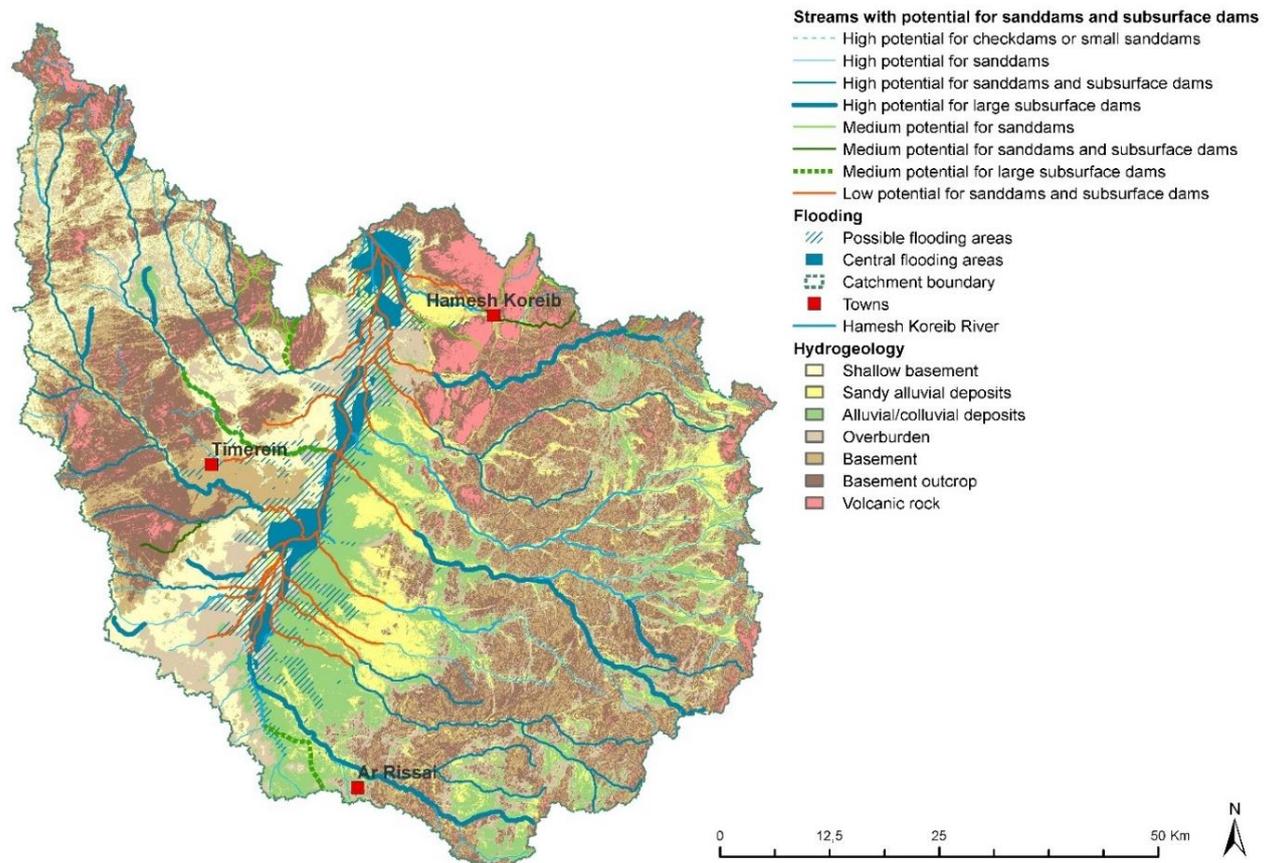


Figure 19. Water resources potential map for Hamesh Koreib catchment (large version presented in Annex 2).

Table 9. Water resources potential of hydrogeological units

Hydrogeological unit	Shallow groundwater	Deep groundwater	Water harvesting
Outcrops (volcanic)	poor	fractured aquifers only	-
Outcrops	poor	fractured aquifers only	Rock catchments
Basement	poor	fractured aquifers only	Hafirs
Overburden	poor to moderate	fractured aquifers only	Hillside dams, valley dams, terracing
Alluvial/colluvial deposits	moderate	fractured aquifers only	Hafirs, MAR, floodwater spreading
Sandy alluvial deposits	good	moderate	MAR
Shallow basement	poor	fractured aquifers only	Hafirs

4.4.1 Surface water

The catchment is bordered on the eastern and western side by a mountain range of impermeable basement rock, with a gently sloping valley with large floodplains in between. This valley is locked by a dam at the northern boundary, built into a narrow passage in the basement rock. The dam causes a lake to form in periods of high rainfall.

Hamesh Koreib catchment has no natural permanent surface water sources. All streams, flooding areas are seasonal and only discharge water during and shortly after rainfall events. Surface water has low potential for supply of drinking water. Surface water is used for irrigation through flood recession agriculture. This is mainly practiced in the lower catchment, and could also be practiced in flooding areas and along streams in the middle and upper catchment.

4.4.2 Ground Water

The exposed basement rocks on both sides of the catchment are considered poor aquifers. Deep groundwater may be found in large open fractures and shallow groundwater is likely to be only found in sandy beds of streams running through the valleys. Most of the sandy stream beds are found on the eastern side of the catchment. The wide range of alluvial fans running along the eastern valley side are considered potential sources of (shallow) groundwater; where streams emerge from the eastern hills, recharge of the alluvial and colluvial deposits takes place.

The stream that runs past Hamesh Koreib town from the eastern ranges has a relatively small sub-catchment area. The stream directly to the south from this town has a larger catchment area and well developed sandy river beds, as gathered from remote sensing data. This stream has a high potential for shallow groundwater, especially if recharge is augmented, e.g. by blocking groundwater flow where the stream passes a narrow valley in the eastern ranges, before it emerges in the main valley.

4.4.3 Water harvesting, storage and conservation

As described in the model outputs, increased water harvesting and recharge of existing water resources is essential for bridging the water gap in the dry years. The physical characteristics of the catchment provide a number of opportunities for rainwater, runoff and stream water harvesting. These options were mapped based on the lithology and stream characteristics, see Figure 20.

Four main categories of water harvesting, storage and conservation can be distinguished based on their functioning, location in the landscape and main purpose.



Figure 20. Different types of water harvesting categories and examples (more examples and details are provided in Annex 1)

Each category of interventions has its own purposes, strengths and weaknesses. Whether interventions aim at improving vegetation cover and biodiversity, promoting soil formation, storing water or any other purposes, and the rate at which this happens differs per category, and even per specific intervention. For

example, where small tanks store small volumes to bridge for example a short dry period, large surface storage and particularly groundwater storage can help to bridge an unusual dry year or a series thereof.

Landscape characteristics dictate which water harvesting interventions are most suitable for a certain location. Contour bunds and terraces, for example, can be best applied on cultivated slopes, whereas sand dams can best be applied in areas where sandy seasonal streams with shallow hard rock are available.

Protection, restoration and management

Protection and management refers to the active protection of ecologically sensitive and valuable areas, so that these can recover and achieve their full-potential in terms of ecosystem system services provided. It also includes water system management interventions such as flood control interventions.

Opportunities for protection and restoration in the catchment include: rangeland management, protection of forests, protection of riverine vegetation, tree planting, and protection of central flooding areas. The feasibility and specific location of such interventions has not been part of this assessment and would need further study.

Floodwater spreading can be used for strengthening of croplands, rangelands and reducing floods.

Soil and water conservation (SWC)

SWC targets the conservation of soil, water and related natural resources on agricultural land—the land used to produce food, forage, fibre and other products. Soil and water conservation measures entails the implementation of land use changes, farming practices, or physical structures, which often also counteract erosion, crust formation or breakdown of soil structure. All of which also increase infiltration, and hence contribute to water conservation. Examples of SWC-techniques include mulching, contour bunds, terracing, trenches and application of permanent crops and agroforestry.

Opportunities for SWC in the catchment are present in the current croplands in the flooding areas, but also near villages in other parts of the catchment. Away from the main flooding areas soil and water conservation can enable increased agricultural productivity. Runoff from hillsides (areas indicated as outcrops on the map) can be collected through collection channels and or bunds and diverted to a lower laying farming area with good soils and limited slopes. Within the farming area, water can be diverted and infiltrated into the soil.

SWC techniques that can be used include: terracing, contour planting, intercropping and mulching to increase soil moisture holding capacity and soil fertility. Often manure is available in the villages from the night shelters of livestock. The accumulated manure in the settlement could provide an opportunity by providing a precious resource for fertilizing the land. Where possible annual crops could be combined with permanent crops or trees. *Compost pits or Zai pits* can be used to plant trees. These should be relative deep pits in which soil is mixed with manure and other organic material, to increase fertility and soil moisture storage. These pits should be protected with thorns, and will allow rapid growth of natural vegetation, but can also be used for crops or tree planting such as fruit trees or pasture shrubs. Compost pits could be combined with tied ridges or V-shaped collecting drain to increase soil moisture storage and infiltration.

Off-stream water storage

includes many typical water recharge, retention and reuse interventions. Off-stream water storage includes all on-land interventions that collect water from surface run-off for storage in either open or closed reservoirs or in the ground. Rock catchments, closed tanks and ponds are examples of off-stream water storage interventions.

Possible off-stream storage interventions in the catchment include: dams, hafirs and rock catchments. However, open water storage is not recommendable for sources that need to supply water throughout the year, because of the long dry periods and high evaporation rates. Similarly, closed storage tanks are

rather inefficient due to the long dry period. Another option is **road water harvesting**. Roads can create runoff water that can be harvested and stored. During road construction and mining activities, opportunities for water supply and management are created. For example, borrow pits can function as ponds, and river crossings (Irish bridges) can function as sanddams.

Increased groundwater storage through **Managed Aquifer Recharge (MAR)**, could be an alternative option that does not have the limitations of the earlier mentioned off-stream storage interventions. Table 10 provides an overview of different MAR interventions.

Table 10. Different MAR technology groups.

MAR technology groups		Example interventions
1.	Diffuse land surface infiltration	floodwater spreading, spate irrigation and dune infiltration
2.	localized land surface infiltration	infiltration ponds, trench/ditch infiltration and infiltration pits
3.	Direct aquifer infiltration	infiltration wells/tube recharge

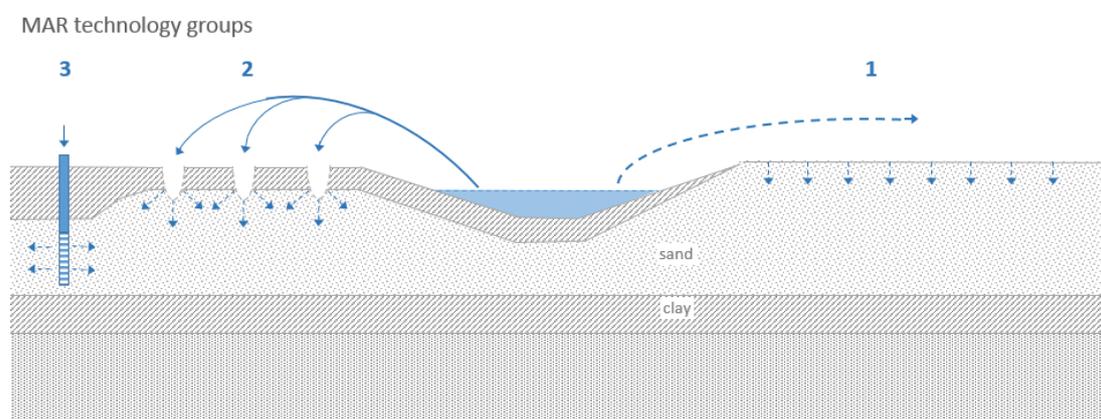


Figure 21. MAR technology groups

Both local runoff and floodwater can be used as source for MAR. Areas that are most feasible are the alluvial deposits and possibly areas indicated as shallow basement in the map. The most feasible technology depends on the characteristics of the local aquifer for storage and the type of demand. In the catchment of Hamesk Koreib Town a number of sanddams are present. These dams are located on top of fractured volcanic formations. Although these dams might not store water at the dam site, they recharge deeper groundwater in fractures and increase downstream well yields. This knowledge could be used to apply MAR at other locations in the catchment. Another option is to increase storage at existing well fields that abstract water from the riverbeds through construction of subsurface dams. Wells that are located away from the wadis that are experiencing water shortage or salinity problems in the dry season could be recharged through trench/ditch infiltration.

Floodwater spreading can also contribute to MAR when the infiltration soil infiltration capacity is sufficient and the underlying formations have good storage capacity. It should be noted that this can have a large impact on the water balance and have a negative impact on downstream water availability.

In-stream water storage

This aims at water storage in riverbed sediments of seasonal rivers (shallow groundwater) or in open water reservoirs build across flow accumulation areas (surface water). As with off-stream water storage interventions, these are typical water recharge, retention and reuse interventions aimed at collecting runoff during the rainy season to make it available in dry periods. An additional advantage of water storage in riverbed sediments is that water quality is improved, so that it is relatively safe for domestic use. Examples of in-stream water interventions include sand and subsurface dams, and valley dams.

Within the upper and middle catchment there are streams with high potential for sanddams and/or subsurface dams. Sanddams can be simple stone walls that accumulate sand and only slow down water flow or concrete (impervious) structures that block water.

When different water harvesting, interventions are implemented in one catchment, they increase in effectiveness. For example, when sanddams are cascading in a river, recharge and leakage from the upper dams recharge lower dams and increase the water availability in the dry season. Or when in the upper catchment infiltration is increased through land and water conservation measures, such as contour bunds, terraces or re-forestation, the recharge of groundwater to the riverbed increases and a sanddam downstream becomes more effective.

5 Input for WRMP development

5.1 CMP development

This Chapter provides input for the development of the Water Resources Management Plan (WRMP), based on the assessment of the catchments by the consultant. The actual WRMP will be developed by the CMC and stakeholders facilitated by the partner. This process will follow the WF3S programme guidelines ('Checklist for the catchment-level water resources management plan' and the 'format for Water Resources Management Plan').

5.2 Main issues and trends

This subchapter provides a summary of water related issues in the catchment. The summary is based on the previous chapters and combines socioeconomic and hydrological data.

5.2.1 Water resources related problems in the catchment area

The catchment is very dry, with low vegetation cover, except for the wadis and flooding areas.

There are problems with with the water quality. Salinity is a problem around Hamesh Koreib town and in Windi, Omlil east, Odi west, Kibreet. Contamination of 6 open wells in Hamesh Koreib town is also mentioned. The water infrastructure also refers to bacteriological contamination and worms in wells.

Floods are a problem in Hamesh Koreib catchment and causing damage around Hamesh Koreib town.

5.2.2 Water supply related issues

Socio economic issues

There is insufficient water supply for human needs in the catchment. The current water infrastructure is not sufficient to provide in the domestic water demand. People have to walk far distances to fetch water. The limitation of water also affects the movement of pastoralists. Also water quality is an essential problem, due to saline resources, as well as bacteriological contamination at the source. It is recommendable to separate domestic water sources and livestock water sources. There is a lot of contamination in the water points in the catchment.

The Dron Dron dam and the Teshell dam provide water for livestock. There are problems with siltation. Also there is probably not enough fodder and grazing areas around the dams for livestock. For some water points, there is no one responsible for maintenance. It would be good if a person from the community would be made accountable.

Domestic water gap:

The analysis of the WIA shows that the largest water demand is situated close to Timerein town.

The water infrastructure of Hamesh Koreib town was not in the WIA, but there is a clear shortage of domestic water for Hamesh Koreib town and surrounding villages.

Livestock water gap:

The main water shortage is in livestock use. The livestock water gap is approximately 4 times higher than the domestic water demand. For livestock, there is hardly any proper water infrastructure like hafirs of water yards. The total water supply gap is 561225 m³ per year in a normal rainfall situation.

5.3 Water management and water allocation principles

Based on the information obtained from the field and common principles for water allocation, the following principles are used for scenario assessment. This has to be validated and completed with the stakeholders, during the development of the Catchment Management Plan.

Stream and flood control principles

Stream discharge priorities

- Increase local baseflow and instream storage in riverbed
- Reduce flash floods by reducing runoff and slowing down streamflow
- Interventions that reduce peak flows (T=5) should be stimulated

Requirements for flooding areas

- Interventions in the upper and middle catchment should not reduce the amount of water discharging to the flooding areas by more than 5% in normal years
- Flooding required in lower catchment for agriculture and grazing
- Optimal flooding situation equals the wet years (T=2 - T=5)

Priorities for water allocation

- Rainwater can be harvested locally, river water abstractions fall under regulations
- Downstream use has priority
- Water use priorities
 1. Domestic water
 2. Livestock
 3. Flooding areas – rangelands
 4. Flooding areas - agriculture
 5. Irrigated agriculture
 6. Other uses

Water supply requirements

Design criteria water supply:

- Domestic water sources
 - o Reliability during drought: Sources for domestic water supply should be able to supply the demand at least 2 year without recharge
 - o Quality: Sources for domestic water supply should supply safe water without further treatment
 - o Groundwater is preferred for drinking water use
- Livestock
 - o Livestock water sources should be separated from sources for domestic water supply
 - o Water sources for livestock in wet season grazing areas should not be permanent
 - o Water sources for livestock in dry season grazing should be controlled, only to be opened during dry season, and only supply for as long as grasses are available
 - o They should be suitable for use by nomads, but must not encourage settlement
- Agriculture

- Sources for small scale irrigation should be able to supply sufficient water for crops planted after onset rains to mature without any further rainfall.
- Preferably use surface water or separate shallow groundwater sources

5.4 Feasible IWRM interventions

This part provides a list and description of possible IWRM interventions in the catchment area. It includes both 'soft' and 'hard' interventions. Examples of soft interventions are: regulation, awareness creation, training and facilitation of management processes. Examples of hard interventions are: infrastructure development, implementation of SWC measures and tree nurseries. This list of interventions is based on the water resources assessment, water allocation principles, and options identified through the field work.

5.4.1 Water supply infrastructure

Domestic water supply

It is recommendable to separate domestic water sources and livestock water sources. There is a lot of contamination in Hamesh Koreib catchment. There is an approximately a daily domestic water gap of 300 m³/d, additional boreholes and shallow wells could be placed to lower the water gap. However, current groundwater availability is not sufficient at all locations in the catchment, this can be increased through:

- Construction of sanddams with protected wells in the feasible rivers with slopes and firm banks
- Construction of subsurface dams with protected wells in the feasible rivers, with wider banks with gentle slopes
- MAR for the wells and well fields with low yields

Livestock water supply

There is an approximate shortage of 450,000 m³ in normal years, mainly due to large numbers of livestock. This water gap could be overcome by placing additional boreholes with a total daily yield of 1500 m³/d. Placing hafirs is also a possibility but siting should be done taking grazing areas in consideration. It should be noted that hafirs do not help to bridge the very dry years, while boreholes might not be feasible for migrating livestock, because of O&M considerations. Alternatives could be sanddams or subsurface dams with shallow wells or scoopholes for livestock. The following options could be considered:

- MAR and wells for permanent water supply
- Subsurface dams with wells in the middle and upper catchment
- Specifically investigate water options for nomads which neither encourage settlement nor cause environmental degradation (boreholes are not appropriate)

Agriculture

Additional sources of income and livelihood diversification are needed in the catchment. Currently farming is mostly focussed on the flooding areas, but alternative options are available (see Figure 19). The following activities can stimulate improved agricultural practices:

- Promote household farming with improved SWC and crop diversification at the villages at the main flooding areas as well as those more upstream in the catchment
- Small scale supplementary irrigation for vegetables at village level
- Establish and/or strengthen existing farmer field schools.

5.4.2 Water management

Water resources management

Water resources management will become an important responsibility of the CMC. The CMC has the following instruments for IWRM, strengthening these instruments could be undertaken as part of the capacity building of the CMC:

- Administrative changes: multisector stakeholder involvement (institutional power, negotiations, indigenous knowledge), institutions for decision making and planning. Important is that communities get involved in water resources management. Often this is done through establishment of community management committees on micro-catchment level. Mobilization of communities for micro-catchment management is an important element. Developing guidelines for community based micro-catchment management.
- Research, increasing the knowledge base of the catchment:
 - o assessment of risks,
 - o impact monitoring,
 - o use of available (scientific) data
 - o Implementing a monitoring network for monitoring of water resources, climate data and river flow gauging
- Technology and infrastructure: water supply, reforestation, erosion control SWC measures, reduction pollution (see next paragraph)
- Social change instruments: information, education, communication
- Regulatory frameworks and legal instruments, regulations
- Investment and financial instruments
- Economic instruments: e.g. pricing of water
- Capacity building, training professionals and other

Water infrastructure development and O&M

- Introduce a more robust handpump for abstraction from shallow wells, that can be produced and maintained locally, such as the rope pump
- Explore the opportunities for manual drilling and introduce it in the region. This could be done as part of local business development
- Provide training in the technical and financial aspects of community water supplies such as handpumps
- Stimulate ownership and management systems that have proven effective in the area, and that is preferred by the users. This can be the community, private or the Locality.
- Make clear arrangements for O&M and management and assign tasks and responsibilities to ensure that the water facilities are kept functional. The arrangement and agreement should be part of the MoU.
- Improve financial viability of the water services by analysing the total costing (both capital and recurrent costs (including the direct institutional costs)) and identify and agree on sources for financing. The latter including user fees and tax and transfer subsidies.
- For the more complex systems (such as water yards) the CMC and/or locality could provide structural support to the WMCs, to prevent problems rather than solving them (rehabilitation), ensure sustainable and reliable water supply, this can include:
 - o Regular technical inspection of the water supply system.
 - o Monitoring of water services, including, volume supplied (water meters) review of logbooks of revenue and expenditure, and O&M activities.
 - o Communication system through which the operators provide regular updates (daily or weekly) about the system.
 - o Communities pay a small monthly fee for this support.
 - o Providing easily accessible means for repairs, including:
 - Local technician with a toolbox and a motor cycle.
 - Local supply chain for spare parts. Possibly the private sector can be involved.
 - Communities pay for the services and parts provided.

5.5 Impact assessment of interventions

Table 11 *Table 11* provides an overview of the impact of different water management and water supply intervention categories on the water balance, water availability. The impact was determined based on literature, catchment specific knowledge, and for some interventions hydrological modelling.

This is a general indication of impact on catchment level, before actual implementation of interventions the local and downstream impact should be assessed. When the WRMP are developed, the model could be used to assess the impact of large scale infrastructural and water management interventions.

Table 11. Overview of impacts of different intervention groups (detailed overview provided in Annex 1)

Intervention groups/categories	Impact on water balance	Impact on water availability
Protection and restoration (Forest, rangeland management, wetland protection)	+ Increased infiltration + Increased recharge + Reduced peak flow +/- Reduced runoff (50-99%) +/- Reduced flooding	+ Increased soil moisture for agriculture, rangelands and natural vegetation
Soil and water conservation (Interventions to improve agricultural practices, such as terraces, bunds, contour planting, agroforestry)	+ Increased infiltration + Increased recharge + Reduced peak flow +/- Reduced runoff (60-100%) +/- Reduced flooding	+ Increased soil moisture for agriculture
Instream storage (sanddams, subsurface dams)	+ Increased riverbed storage + Increased baseflow +/- Reduced peak floods +/- Limited impact on downstream flooding	+ Increased storage for water supply + Increased water availability in dry season
Off-stream storage – open water reservoirs	+ Increased recharge - Increased evaporation +/- Reduced streamflow +/- Reduced downstream flooding	+ Increased storage for water supply
Managed aquifer recharge	+ Increased recharge + Possibility to use only peak flow +/- Reduced peak flow +/- Reduced flooding	+ Increased groundwater availability + Increased water availability for dry periods

Protection and restoration

Protection and restoration of forests, rangeland management, wetland protection, can significantly reduce runoff when it effectively results in an increased vegetation cover. For example, when bare soil is transformed into forest runoff can reduce approximately 75-90%, or when grasscover is improved from poor to good, runoff can reduce approximately 40-65%. Impact of increased vegetation on flooding in the middle and lower catchment will only be significant if large areas of land have a increase in vegetation cover. Currently only approximately 32% of the catchment area has a vegetation cover, mostly sparse grassland and shrubland which equals 1467 square kilometre. When conservation and water management interventions are implemented within the streams and flooding areas, such as wetland/flooding area management and floodwater spreading, downstream impact can be more significant.

Soil and water conservation

Impact of SWC on runoff can be significant. On average runoff is reduced with 60-90% by properly implemented soil and water conservation interventions. When terracing, soil bunds, or trenches are applied, runoff can be reduced to zero in arid regions. In addition, runoff from upstream areas can be collected and infiltrated.

Instream storage (sanddams and subsurface dams)

Impact of instream storage on downstream discharge is generally limited. Sanddams store relative small volumes, while subsurface dams are below the existing riverbed and only block groundwater. If storage would be created to supply all the domestic and livestock water demand in the area, the impact on the catchment water balance would be minimal (less than 5,5% of the average yearly discharge into the flooding areas in the lower catchment).

Large open water reservoirs could have a significant impact on the water balance. Although they could be feasible at some places in the catchment, it might not be a feasible intervention because of the high evaporation losses in the arid climate.

Off-stream storage

Impact of offstream storage on downstream discharge is generally limited. Sanddams store relative small volumes, while subsurface dams are below the existing riverbed and only block groundwater. If storage would be created to supply all the domestic and livestock water demand in the area, the impact on the catchment water balance would be minimal (less than 5,5 % of the average yearly discharge into the flooding areas in the lower catchment).

6

Conclusions and recommendations

This report provides the results of an integrated assessment of Hamesh Koreib Catchment area regarding water resources as well as socio-economic aspects. It serves as an input for the Water Resources Management Plans (WRMP) that will be developed for the catchment by the Catchment Management Committee (CMC) and other stakeholders, facilitated by the local partner NGO.

The main socio-economic issues in the catchment are gender segregation, depleted workforce, and conflicts over resources, especially related to nomadic tribes. Food aid, and more recently food-for-work has been a major feature of livelihoods in this part of Sudan. Agricultural production is hampered by the erratic climate and the invasive species Prosopis, the Mesquite tree, is taking over the agricultural land.

The current water infrastructure is not sufficient to provide in the domestic water demand in the catchment area. People have to walk far distances to fetch water. The limitation of water also affects the movement of pastoralists. Also water quality is an essential problem, due to saline resources, as well as bacteriological contamination at the source. It is recommended to separate domestic water sources and livestock water sources. There is a severe shortage of water supply for livestock, the total water supply gap is 561,225 m³ per year in a normal rainfall situation.

Rainfall is low on average (190 mm/y), but has a very high inter-annual variability which is even stronger reflected in runoff and stream flow. Runoff only occurs in the short time span of the rainy season, when rainfall events are intense, although periods of stream flow can last throughout the year in wet years. The flooding areas are large and have an enormous impact on the water balance. Streamflow is collected in the floodplains where it stored. Eventually almost all stream flow collected in the floodplains (10.16 Mm³) and disappears due to evapotranspiration and infiltration. Only in very wet years flow out of the floodplains at the catchment outlet occurs.

To address the water shortages in the dry and very dry years, part of the peak flow can be used for recharge of water resources and sources. If 0.5 % of the discharge in the wet years (T=10) could be captured, the water gap could be bridged for one year. Resources for bridging long term droughts should preferably be groundwater resources including underground storage.

The catchment has low potential for deep groundwater, and locally moderate to high shallow groundwater potential, especially in the stream sediments. Water available can be improved by increased recharge and retention, the most feasible techniques include: sanddams, subsurface dams and managed aquifer recharge (MAR). Soil and water conservation (SWC) techniques could be used to improve water availability in the agricultural areas in the lower catchment, but also to enable agriculture in the middle and upper catchment. Rangeland and forest management, can be improved to increase infiltration and recharge, and availability of grass and fodder for livestock and produce availability of natural products for the communities. It should be noted that SWC and activities that lead to an increased vegetation cover can reduce or even stop local runoff. However, this will only have a significant impact on the flooding

areas in the lower catchment when large areas are affected by these activities, >5% of the catchment area (> 230 km²).

For the development and implementation of the WRMP specific attention should be given to 'soft' measures, such as regulation, awareness creation, training and facilitation of management processes. Due to the low capacity for labour and O&M, water supply technologies should preferably be low-cost and low-tech. In Hamesh Koreib catchment agro-economic activities in the flooding areas (Odi Plain), strongly depend on streamflow originating from runoff in the catchments of the tributaries. Increased use of runoff and floodwater in the upper- and middle catchment, has a downstream impact. Therefore, water resources management will become an important responsibility of the CMC. The CMC has a number of instruments for IWRM, strengthening these instruments could be undertaken as part of the capacity building of the CMC.

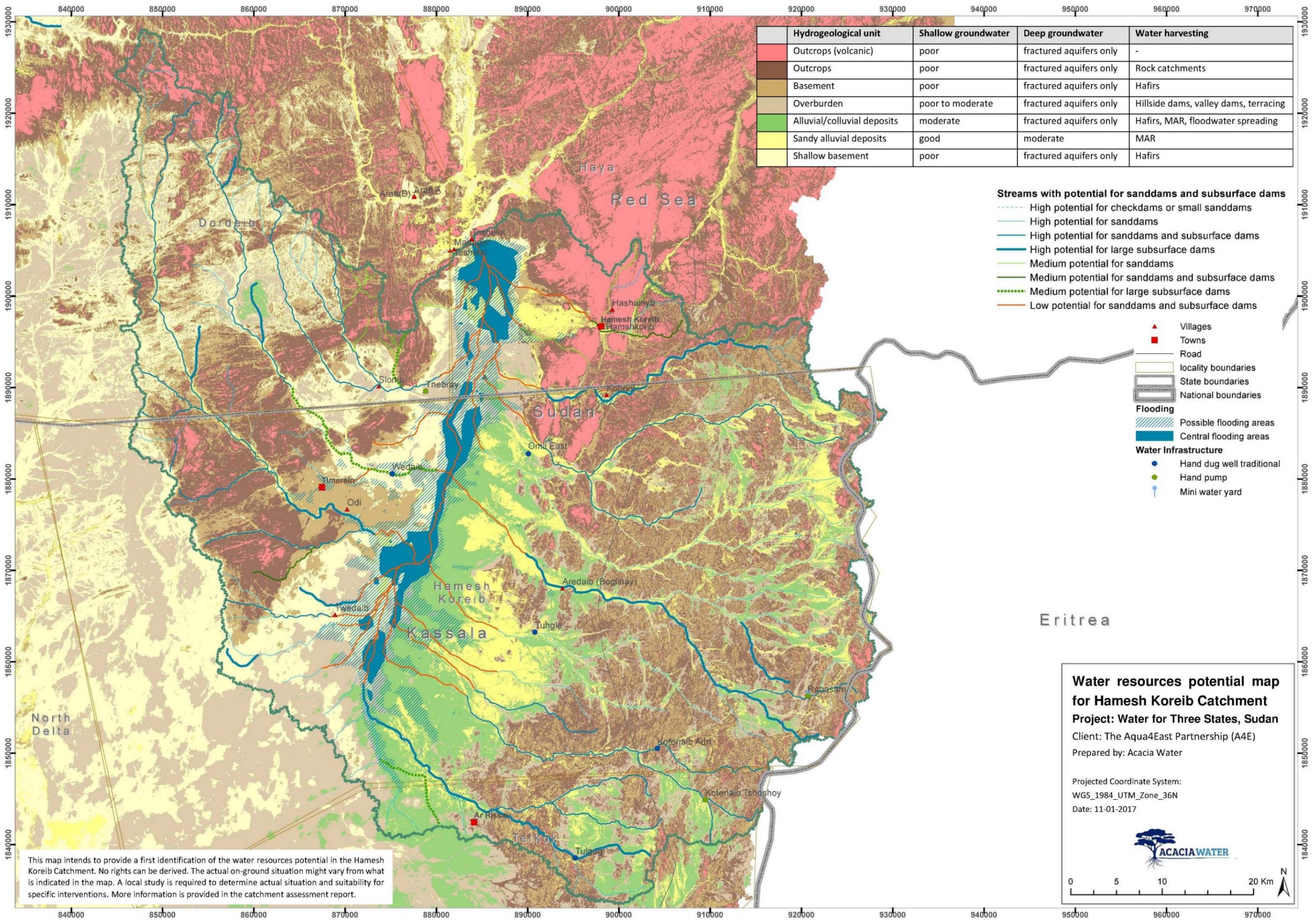
For effective implementation of IWRM measures, local stakeholders and especially communities are essential. Mobilization of communities for micro-catchment management and developing guidelines for community based micro-catchment management and farmer field schools are examples of 'soft' interventions on community level. For all interventions, it is important that the process and implementation has full stakeholder participation, based on self-motivation. Stakeholders should be enabled and stimulated to deploy the approaches and implement the measures themselves. Only then interventions are sustainable and can be up-scaled to have impact on catchment level.

Annex 1: Water harvesting intervention overview

Explanation of land use types and 3R intervention groups and used terminology

Types of interventions	Categories of interventions	Explanation and examples	Benefits	
			To local users	To the catchment
Protection and management	Riverbank protection	Protection of riverbanks and flooding areas against overgrazing, arable farming, tree cutting and water erosion. In the case of artificial reservoirs also protect the inflow area.	Erosion control, increased production of forage and other natural products	Improved groundwater recharge, flow regulation, biodiversity, (micro)climate regulation
	Area closure	Protection of an area against degrading activities, such as grazing, agriculture and/or tree cutting. Often cut-and-carry systems and fruit harvesting are allowed. Sometimes closures function as back-up grazing area for emergencies. The closure can be realized by fencing or by (community) agreements		
	Forest management	Agreements on sustainable use of forested areas, including controlled harvesting of wood and other natural products. Increasing the ecological and socio-economic value through tree planting, wildlife management, control of invasive species, etc.		
	Rangeland management	Agreements on grazing patterns, assignment of wet/dry season and emergency grazing areas, sustainable wood harvesting, wildlife management		
	Urban water and waste management	Collection and safe disposal of waste(water)		
	Discourage agriculture	Limit agricultural practices in these areas. Ensure that in crop production areas due measures are taken to control erosion		
Soil and water conservation	Basic SWC	Mulching, grass strips, soil bunds	Higher yields, more reliable yields. Possibility to produce crops with a higher market-value	Improved groundwater recharge, water flow regulation and soil formation. Increased biodiversity
	SWC to control wind erosion	Tree planting, tree strips (wind breaks), life fencing, agroforestry		
	SWC for slopes	Terracing, contour bunds, contour ploughing, tied ridges, grass-strips, contour trenching		
	SWC for very steep slopes	Stone structures above ground such as stone bunds, trenches, hillside terracing, check dams, tree strips		
	SWC for weak soils	Soil moisture management, mulching		
	Conservation agriculture (CA)	The three main CA principles are: minimal soil disturbance, permanent soil cover and crop rotations		
	Permanent agriculture	Production of permanent crops such as fruit trees, tea, coffee		
	Flood-adapted agriculture	Produce crops outside the flooding period, or flood resistant crops. Apply flood control interventions, such as soil bunds and diversion ditches. Apply spate irrigation or floodwater spreading		
	Biological interventions	Revegetation, afforestation, reforestation and protection of trees. Planting of species that promote soil stability. Controlled grazing		
	Erosion control structures	Small and larger scale structures constructed with manual labour to control erosion, such as gabions		
Off-stream water storage	Hafir dams	Also known as valley tanks. Larger excavations for water storage on flat to gently sloping lands	Improved water availability	Groundwater recharge, flow regulation
	Ponds	Small natural depressions in which runoff concentrates made impervious to prevent leaking		
	Hill-side dams	Small hill-side half-moon shaped embankments on medium-steep slopes used to promote infiltration and store water		
	Rock catchments	Open water reservoirs build to trap water coming of bare rock areas		
	Birkads	Underground cisterns dug out and lined to store water, keep it cool and (when covered) prevent evaporation		
	Managed aquifer recharge	Infiltration of surface water into an aquifer via infiltration wells to store water and improve its quality		
	Roof rainwater harvesting	Use of suitable roof surface – tiles, metal sheets or plastics – to intercept rainfall, and conduct it to a storage tank		
In-stream water storage	Check dams	Small dams across a waterway that counteract erosion by reducing flow velocity	Improved water availability and water quality	Groundwater recharge, flow regulation
	Micro-dams	Very small open water reservoirs consisting of a wall (earth or concrete) in a narrow valley aimed at storing water		
	Valley dams	Small open water reservoirs consisting of an earthen or concrete wall on a concave location to store water		
	Sand dams	Reinforced concrete walls across seasonal rivers capturing coarse sediments, thereby storing shallow groundwater		
	Subsurface dams	Reinforced concrete walls across seasonal rivers that store shallow groundwater		

Annex 2: Water resources potential map



Hydrogeological unit	Shallow groundwater	Deep groundwater	Water harvesting
Outcrops (volcanic)	poor	fractured aquifers only	-
Outcrops	poor	fractured aquifers only	Rock catchments
Basement	poor	fractured aquifers only	Hafirs
Overburden	poor to moderate	fractured aquifers only	Hillside dams, valley dams, terracing
Alluvial/colluvial deposits	moderate	fractured aquifers only	Hafirs, MAR, floodwater spreading
Sandy alluvial deposits	good	moderate	MAR
Shallow basement	poor	fractured aquifers only	Hafirs

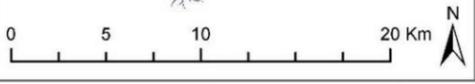
Streams with potential for sanddams and subsurface dams

- High potential for checkdams or small sanddams
- High potential for sanddams
- High potential for sanddams and subsurface dams
- High potential for large subsurface dams
- Medium potential for sanddams
- Medium potential for sanddams and subsurface dams
- Medium potential for large subsurface dams
- Low potential for sanddams and subsurface dams

- ▲ Villages
- Towns
- Road
- locality boundaries
- State boundaries
- National boundaries
- Flooding**
- ▨ Possible flooding areas
- Central flooding areas
- Water Infrastructure**
- Hand dug well traditional
- Hand pump
- ⚡ Mini water yard

Water resources potential map for Hamesh Koreib Catchment
Project: Water for Three States, Sudan
 Client: The Aqua4East Partnership (A4E)
 Prepared by: Acacia Water

Projected Coordinate System:
 WGS_1984_UTM_Zone_36N
 Date: 11-01-2017



This map intends to provide a first identification of the water resources potential in the Hamesh Koreib Catchment. No rights can be derived. The actual on-ground situation might vary from what is indicated in the map. A local study is required to determine actual situation and suitability for specific interventions. More information is provided in the catchment assessment report.

Annex 3: Catchment database content

A catchment database is prepared for the catchment, which will be provided to the Partners and is meant as knowledge base for the Catchment Management Committee. This database contains the following information:

- Database manual. Explanation of database and guidelines for usage of the content.
- Thematic maps (jpg or pdf format), indicative:
 - Topography, elevation, rivers, gazetteer
 - Rainfall
 - Geology
 - Soil
 - Land cover including flooding areas
 - (NDVI, landsat, bing)
 - Existing water infrastructure
 - Water gap (demand vs access and water related problems)
 - Runoff coefficient
 - Model setup, sub-catchments, nodes/outlets, reaches
 - Environmental problems (flooding, erosion, land degradation)
 - Water resources potential
 - Scenarios
- Arc GIS data
- KMZ/KML files of the main catchment features
- SWAT model files
 - Input data (Access)
 - Output data (Access)
- SWAT Software and guidelines
- SWAT Output Viewer

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