Mar 30, 2019

Preliminary Results – Wadi Bulbul

Water Resources Assessment for the hydrological catchment area of Taadoud II - World Vision International – SD1

Deliverable 4b.- Final version




ACACIA WATER

Introduction

BUILDING RESILIENCE IN DARFUR THROUGH TAADOUD

“Taadoud” means “working together in solidarity towards one purpose” in Arabic. Taadoud is a 30-month project funded by the UK Department for Internal Development (DFID) under DFID’s Sudan Humanitarian Assistance and Resilience Program (SHARP). Taadoud directly supports 63,924 conflict-affected vulnerable households by applying a holistic approach – simultaneously improving agricultural production to bolster household-level food security, nutrition and income, while strengthening community-level DRR and climate change adaptation through strong community structures that are integrated with local government services.

Here the Preliminary Results of WD catchment are presented. The biophysical context, including climate, landcover, soil and geology, is given, which result in certain potential for water resources, explained in different zones across the catchment. This potential is put into context of water demand and supply and different issues in the catchment, which all together form the base to plan for natural resource management.

Colophon

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1 Catchment area characteristics

1.1 Topography

Wadi Bulbul catchment (4,400 km^2), hereafter named *catchment SD1*, and Kass-*Kundir* catchment (2,400 km^2), hereafter named *catchment SD2*, are situated south of the Jebel Mara in South Darfur. The catchments are intersected in the south by the road connecting Nyala and Idd al Ghanam. Nyala, the state capital of South Darfur, lies 5 km east of catchment SD1 and Idd al Ghanam lies 10 km west of catchment SD2. Another major road intersecting the catchments in their northern half connects Nyala with Kass and Zalingei in Central Darfur.

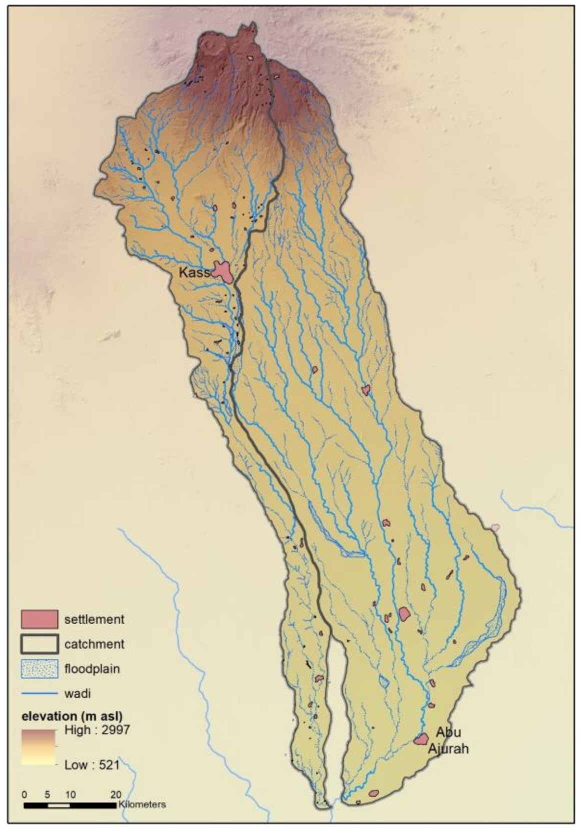


Figure 1. Topographic map of the Bulbul catchment (SD1) & Kass-Kundir catchment (SD2) in South Darfur.

Characterized by a steep terrain that forces the rivers draining the southern flanks of Jebel Mara into relatively narrow, parallel running valleys, the two catchments have an elongated form and large elevation differences. While their outlets are at around 600 m asl SD1 reaches up to approximately 2,300 m asl and SD2, which includes the peak of the Jebel Mara volcano and its caldera, even reaches up to 3,042 m asl. The mountain range acts as an important water tower and produces significant rainfall, especially on its western side. Along this range runs the water basin divide of two large basins: The Lake Chad basin and the Nile basin (Bar el Ghazal sub-basin).

Rivers in catchments SD1 and SD2 are ephemeral and often feature sandy riverbeds. Rivers draining the flanks of Jebel Mara often carry sediment of volcanic weathering material, which has a greyish colour, compared to the otherwise characteristic yellow of the sandy riverbeds (Figure 2).

Figure 2. Confluence of a characteristic sandy riverbed and a river transporting greyish volcanic weathering material at the foothills of Jebel Mara, near Arga at the Kass – Nertiti road (on the left) (Google Earth satellite image)

Especially in the flatter areas in the middle of the catchments broad sand riverbeds can be found. Near the town Tumko in catchment SD1 the riverbed is over 300 m wide (Figure 3).

In the lower reaches of the catchments the streams become smaller again. Much water evaporates or infiltrates on the way from the mountain range to the lower-lying catchment outlet. The landscape in the southern catchment areas shows little relief. Figure 4 shows the main river of catchment SD2 meandering through the sparsely vegetated landscape is merely 10 m wide, much less than in the middle of the catchment.

Figure 3. 300 m wide sand riverbed near Tumko in catchment SD1 (Google Earth satellite image)

Figure 4. The main stream of catchment SD2 near a settlement in the lower area of the catchment is less than 10 m wide (Google Earth satellite image)

1.2 Rainfall

In most of Darfur water scarcity is the limiting factor for crop growth and thereby a threat to livelihoods. Rainfall is not distributed evenly over the area. In order to get an impression of the variability of precipitation, the African Rainfall Climatology version 2 dataset (ARC2) from the NOAA Climate Prediction Centre has been used from the period 1984 to 2016.

Figure 5 shows annual and monthly rainfall averages in South Darfur: nearly 470 mm/year (left) and of 120 mm in August (right).

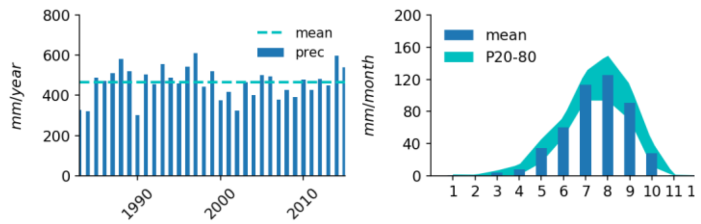


Figure 5. ARC2 and GPCC rainfall data was used to calculate annual precipitation (left) and average monthly precipitation (right) with 20th and 80th percentile.

1.3 Evapotranspiration

Remote sensing data of evapotranspiration was obtained from lobal Land Evaporation Amsterdam Model (GLEAM) for the period 2003-2017.

The differences in the two areas are very small. In both cases the yearly evapotranspiration varies between 120 and 500 mm/year, depending on the water availability. The yearly picks are in the months August-September and accounts for 80-90 mm. There is an average water surplus in the region of about 30-60 mm in August.

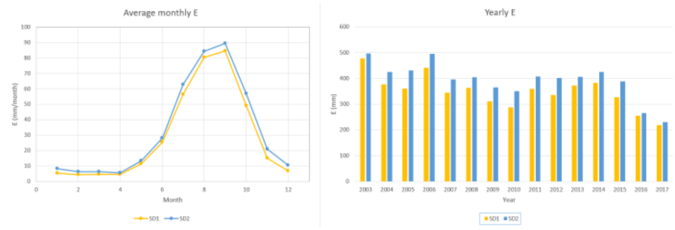


Figure 6. Evapotranspiration averages calculated with GLEAM model in the SD-1 (yellow) and SD-2 (blue).

1.4 Community catchments WVI

The community catchment in Wadi Bulbul is composed of 7 communities: Tembesko, Koli, Talila, Hialbagara, Habania,Mohajerya and Dlalangra. These are given in olive-green colours in Figure 7.

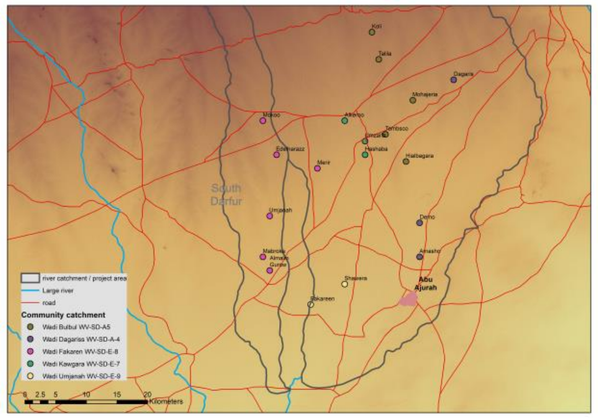


Figure 7. Community catchments of returnees in Taadoud for the WVI area – Southern most of SD1 (Bulbul) & SD2.

A total of 8,736 households have been identified, of which 6,780 are farmers and 1,147 pastoralists. Conflicts are raising among farmers since returnees can not restore their cultivation activities as farmers from the host communities have taken over their cultivation land. The productivity of the forest land is decreasing due to overcutting threes, soil erosion and overgrazing.

2 Soil and Geology

2.1 Soil

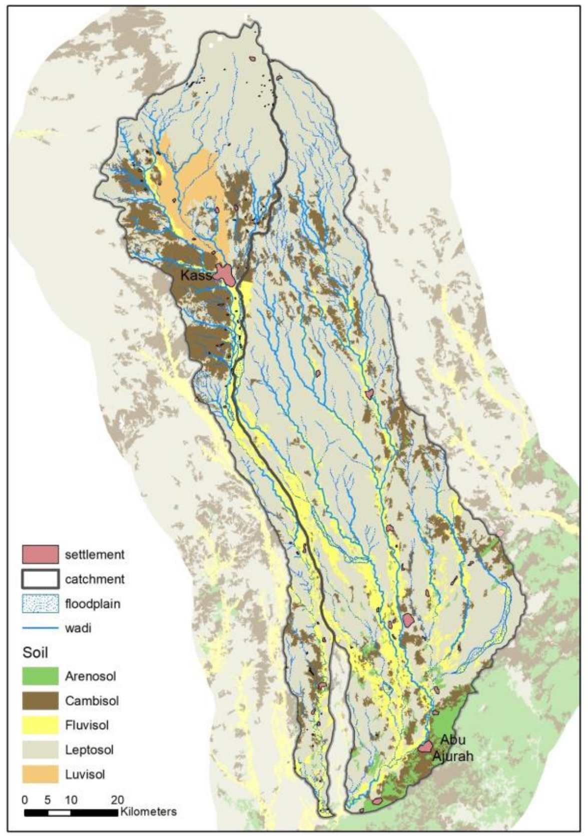


Figure 8. Refined soil map of catchments SD1 (Wadi Bulbul) and SD2 (Kass-Kundir)

The two project catchments in South Darfur are dominated by thin leptosols that are only sparsely vegetated (Figure 18). Only in the high catchment region on the flanks of the Jebel Mara vegetation on the leptosols is more abundant.

In catchment SD1 agriculture takes place on leptosols throughout the entire catchment, especially in the upper and lower regions. Patches of more fertile cambisols are spread out throughout the catchment.

Fluvisols are present along river courses in both catchments. Fluvisols are alluvial deposits, i.e. sediments that were transported by rivers from upstream erosion processes and which are generally deposited in valleys and floodplains. In South Darfur, these soils are also used for agriculture. In the higher catchment regions, fluvisols can contain weathering products of volcanic material, visible as a more greyish colour. Fluvisols in the middle of the catchment are likely sandy. The presence of finer silt fractions increases further downstream in the catchment where flow volumes and flow velocities of rivers decrease.
In the south of catchment SD1, around Abu Ajurah, arenosols (Goz soils) are present. Even though some agriculture can be found here, the soil's agricultural potential is estimated to be low.

In catchment SD2, much rainfed agriculture takes place in the upper half of the catchment below the slopes of Jebel Mara around the town of Kass. Agricultural activities here coincide with the presence of cambisols and luvisols. Furthermore, crops are grown on fluvisols along the large wadis.

2.2 Geology

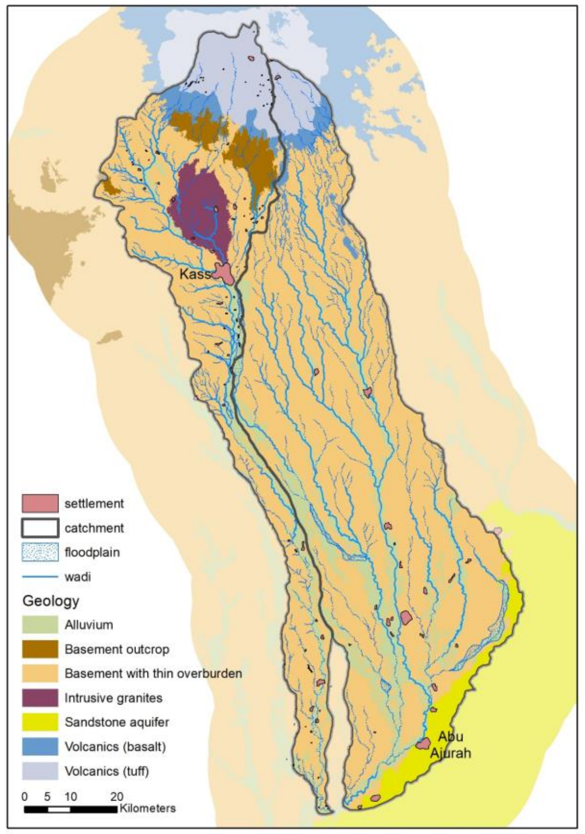


Figure 9. Geology of catchments in South Darfur

*A*lmost the entire project area is underlain by the Basement Complex of Precambrian age (4600 – 540 million years ago), covered by a very shallow overburden with some small outcrops. The very upper catchment consists of volcanic rocks, originating from the young formation of the Marra Mountains (Jebel Marra), of which the last volcanic eruption occurred about 3,500 years ago.

The Jebel Marra complex displays the highest *precipitation* quantities of the entire region. Firstly, this causes substantial runoff carrying loose sediment (colluvial) into *wadis* situated at the base of the hillslopes. Secondly, this high amount of precipitation could lead to large water storage in combination with a suitable geology. This is indeed the case for a part of the Jebel Marra complex where rhyolitic tuffs (volcanic rock or lavas with glassy fragments) and ignimbrites (hardened tuff with crystal and rock fragments) create good aquifers and probably store large amounts of water around the crater (Gachet, 2006). Besides this area, a large portion of the volcanic complex consists of basalts, which have a low *permeability* resulting is poor quality *aquifers*. The *weathering products* of these basalts decreases even further the permeability due to production of colloids (mixture of insoluble particles). Nevertheless, the basaltic complex includes many fractures that show high water bearing capacities.

Multiple straight and parallel running *dikes* (also called *dyke* swarms. Go to the **Glossary** for the explanation) are located in the central a part of catchment SD-4, all generally with a NW – SE trend. A *dyke* is a sheet of rock that formed in a fracture These *dikes* are associated with a fracture patterns perhaps related to the Jebel Marra volcanic activity. There are different types of dikes and each type will have a different effect on the geohydrology of the area. Clastic dikes are formed when sediment fills a fracture. Magmatic dikes form when magma intrudes into a crack and then crystallizes. A field visit to the dikes in catchment SD-4 can provide more information on the type of dyke and the implications for the *hydrogeology*.

Downstream of the catchment, in its central and southern parts, most streams have sandy stream beds where runoff concentrates. As a result of the impermeable (impenetrable) basement rock, water infiltrates poorly outside the sandy stream beds.

2.3 Landcover and land use

In the project catchments in South Darfur, the predominant land use is rainfed agriculture (Figure 7), especially along wadis but also on flatter terrains between river courses. The rocky upstream areas of catchment SD2, including large parts of the vegetated slopes of Jebel Mara, are unused.

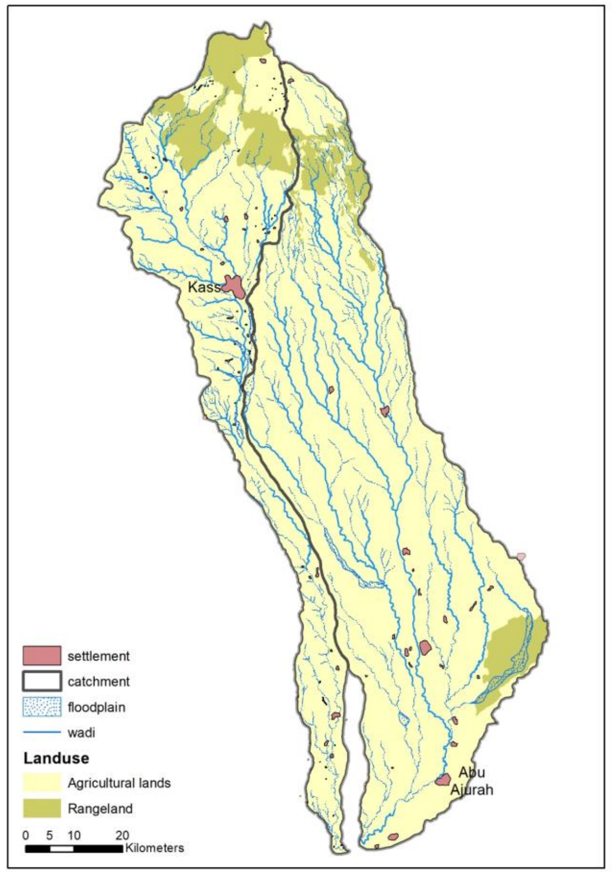


Figure 10. Land use / land cover map of catchments SD1 (Wadi Bulbul) and SD2 (Kass-Kundir)

3 Water resources development potential

3.1 Landscape potential

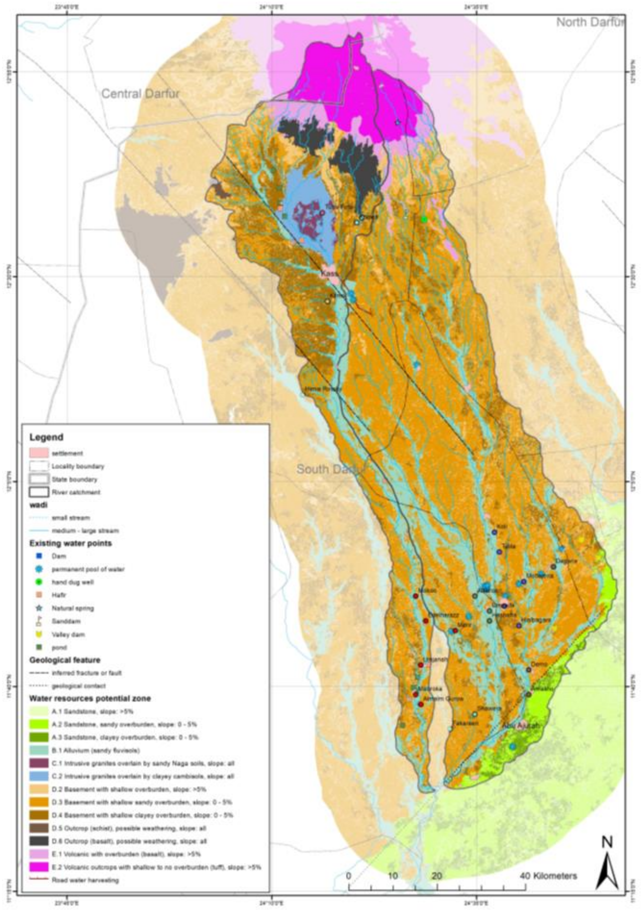


Figure 11. Potential for water harvesting techniques in the landscape for catchment SD1 & 2 (legend table 1A, 1B).

Vulcanic (E.1 & E.2) is formed by basalt and riolite rocks. E.1 (basalts) seems to have a more developed highly porous overburden present. Nevertheless, dense forests and intensive agricultural fields have been observed from aerial images on the Jebel Mara, also on the “fresher” E.2 Volcanic tuffs with shallow to no overburden. Classification 9ground truthing needed for confirmation). This rock type is expected to generate more sandy soil layer.

Table 1A. Combined water resources potential map units

Zone	Hydrogeological unit	Sub category 1	Sub category 2
A.1	Nubian sandstone	Shallow overburden, slope >5%	Mixed type of soils
A.2	Nubian sandstone	Developed sandy overburden	Arenosols, leptosols
A.3	Nubian sandstone	Developed clayey overburden	Cambisols, luvisol
B.1	Alluvium (sandy wadi’s, sandy to clayey fluvisol)	Underlain by shallow basement rock, higher potential for harvesting	Arenosols, sandy to clayey fluvisol
C.1	Intrusive granite	Overlain by sandy soils, slope: all	Leptosols,arenosols
C.3	Intrusive granite	Overlain by clayey cambisols crust,	Cambisols, luvisol
D.2	Basement with thin overburden	Shallow overburden, outcrop, slope >5%	Mixed types of soils
D.3	Basement with thin overburden	Shallow sandy overburden, outcrop, slope 0-5%	Mixed types of soils
D.4	Basement with thin overburden	Shallow clayey overburden, outcrop, slope 0-5%	Cambisols
D.5	Outcrop (Schist)	Possible weathering product, slope: all	n/a
D.6	Outcrop (basalt)	Possible weathering product, slope: all	n/a
E.1	Volcanic (basalt)	With overburden	Basalt
E.2	Volcanic (tuff)	Outcrops with shallow / no overburden	tuff
	N/A	Road water harvesting	Poor drainage

Table 1B. Overview of potential of different intervention groups based upon landscape features

Zone	Shallow groundwater	Deep groundwater	Water harvesting
A.1	Medium	Moderate	Recharge dams, infiltration ditches, ponds), hillside dams, ponds, stone bunds
A.2	High	High	Pond infiltration, tube recharge, floodwater spreading
A.3	Medium	Low-medium	Pond infiltration, tube recharge), open water storage
B.1	High	Medium-high (high fractured aquifer)	riverbank infiltration galleries, floodwater spreading, spate irrigation (main wadi’s), subsurface dams, sand dams, hafirs, micro-basins
C.1	Low	Low (moderate along fractures)	Rock catchments on bare rock, permeable dams, gabions, trenches and contour bunds where overburden present
C.2	Very low	Very low	Rock catchments, hillside valley dam, sand dams, permeable check dam (e.g. gabion), loose stone check dam (for gully plugging)
D.2	Low	Low (moderate along fractures)	valley or permeable dams (. gabions), (stone) contour bunds, microbasins, hillside terraces
D.3	Low	Low (moderate along fractures)	hafirs, valley or permeable dams (e.g. gabions), microbasins, trapezoidal and contour bunds
D.4	Low	Low (moderate along fractures)	hafirs, and valley, microbasins, earth or permeable dams (gabions), trapezoidal and contour bunds
D.5	Very low	Very low	rock catchments, charco / valley dams (depressions)
D.6	Very low	Very low	rock catchments, permeable check dams, gabions, stone contour bunds, hillside terraces
E.1	Very low	High	Permeable dams (gabions, check dams, gully plugs), hafirs, small ponds (subsurface dams)
E.2	Very low	Moderate	Permeable dams (gabions, check dams, gully plugs), small ponds, stone bunds, hillside terraces
	Medium	Low	Floodwater spreading, hafirs/ponds, supply via improved culverts under road downstream

The wadi just south of the intrusive granite area seems to be related with an inferred fracture. If the wadis are located on fracture zones, it needs to be better understood if the fracture is contributing to the alluvium or infiltrating runoff from upstream might be recharging and contributing to the groundwater storage in fissural aquifers. In both cases, constructing infrastructure such as sand dams and gabions is probably not the most efficient way of enhancing water resources availability in this wadi. For a better assessment of the situation, groundwater monitoring data is needed.

Due to the flatness of the area southern of Kass, and very probably also due to sediment accumulation in the wadis, there seems to be superficial exchange of flood water during (intense) rainfalls between SD-2 into SD-1. Interestingly, and due to presence of permanent pools of water just across in the upstream part of SD-1 catchment, there might be (at least a semi-permanent) subsurface connection between the two catchments. That would mean that developing infrastructure just downstream of these water pools might help to ensure and increase the water levels in those pools.

In downstream part of SD-1 existing permanent pools of water seem to be on a straight NE – SW possibly line; related to a dyke structure, fracture or geological faults. Orientation of this line also is exactly perpendicular on most inferred fracture and fault lines in this area, although it runs parallel with the inferred geological contact between the sandstones and basement rock formations. In case of a dyke structure can be confirmed during ground truthing activities, it will most likely offer opportunities for upstream water harvesting, and can this intervention possibly sustain and increase water resources availability at downstream target communities.

The change of course of the wadi along the Nubian sandstone formation in SD-1 from a NW – SE, to a sharp NE – SW direction basically confirms the change and influence of geology, and presence of this geological contact (zones A.1 and A.2). It is important to see if this sandstone formation also acts as infiltration area or also outflow/’leakage’ area. This can also be inferred when information is made available about the existence of springs.

Wide wadi’s and related floodplains (zone C.2) start downstream of Kass town (SD2). This is also the main pattern in the Bulbul community catchment (SD1). Interventions such as floodwater spreading, and spate irrigation are recommended in this area to sustain the existing livelihood activities, and other water harvesting opportunities such as subsurface dams, hafirs and micro-basins (eye-brow basins/half-moon bunds, etc. in combination with agroforestry/fruit tree plantation for example). Allocation of infrastructure such as sand dams are most unlikely to be feasible in this area since the wadis are wide and basement depth is uncertain.

It is known that after rain season, some pools retain water for some time. We advise on the possibility of expanding the capacity of these pools and invest in the construction of hafirs along the wadis for water harvesting in the dry season. In the upper parts of the hydrological catchment area there is some opportunity for contour bunds and valley dams. That will increase grass production for livestock and increase water storage and infiltration. Since this area is near Oxfam’s Taadoud project area, the implementation of these interventions will be discussed with that organisation and allocated in the implementation plans for Kass-Kundir.

3.2 Potential for in-stream water harvesting techniques

The characterization of the individual river (Figure 12) reaches along these factors was done by visual analysis of the satellite images. The classification of the segments into the classes listed in Table 2 was done by scoring and ranking the analysed factors.

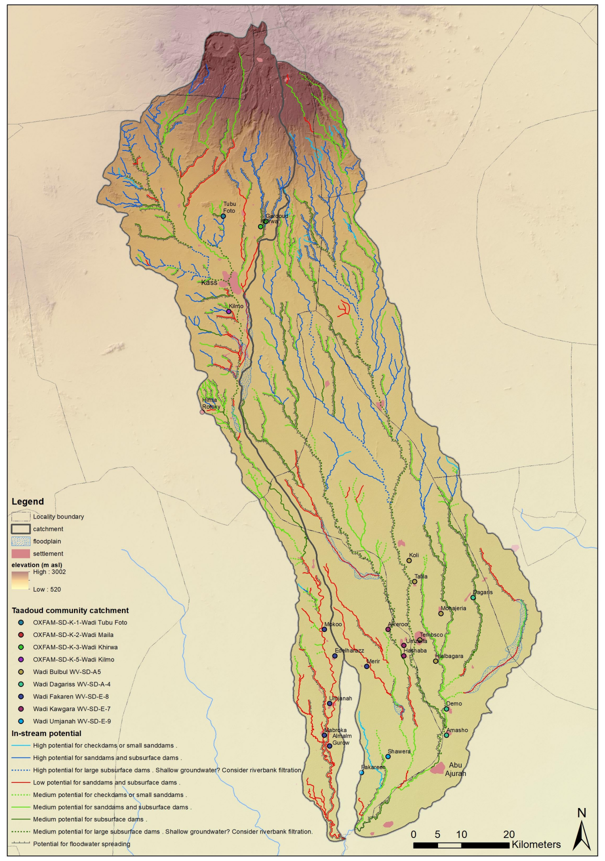


Figure 12: Potential map for in- water harvesting solutions in-stream for catchment SD1 & SD2.

Table 2: Legend for in-stream water harvesting potential

Overview of potential for in-stream water harvesting techniques		
	Potential	Suitable types of interventions
	High	Check-dams and small sand dams
		Sand dams
		Large sub-surface dams; riverbank filtration if shallow groundwater is present
	Medium	Check-dams and small sand dams
		Sub-surface dams
		Large sub-surface dams; riverbank filtration in alluvial aquifers
	Low	Sand dams and sub-surface dams
		Flood-spreading weirs

A wadi with a high potential for sand dams, for example, would feature shallow sedimentary deposits of sandy texture with some hard rock outcrops and have a bed of medium width (5 – 50 m).

Additionally, this river stretch should not show signs of flooding or a frequently changing course. If some of the criteria are not met, this affects the score. If the bed material consists of sedimentary deposits only, i.e. there is no visible sign of an impermeable basement rock underlying the (shallow) sediments (no visible rock outcrops), this reduces the potential for sand dams. Sand dams profit from underlying hard rock that form a natural reservoir and prevent the stored water from infiltrating to deeper layers. Where such a lining is not present, the potential for a sand dam is decreased and it has to be evaluated carefully whether a sand dam is suitable at this location. Similarly, the potential for sand dams is decreased to the category "low potential" if the riverbed sediments are too fine (silt or clay, darker colour on satellite images, should always be verified in the field). Vegetation density along the river course can be a good indicator for the water holding capacity of the sediments carried by the river and is also incorporated in the scoring. Overflowing or flooding of a river are also considered; if this is the case it decreases the potential for sand dams as they have to be built in a clearly defined river bed with pronounced banks that will act as reservoir walls. If the overall score of described factors is too low, a river segment is classified as having low potential for sand dams, sub-surface dams or check dams.

Where a wadi is too wide to construct a sand dam (threshold set here at 50 m width) it might still be possible to build a large sub-surface dam across the wadi. Similar to a sand dam, a sub-surface dam stores the water upstream in the riverbed, only that no artificial deposition of sediments takes place. The dam is built into the present river sediment and ideally sits on the underlying basement rock. This way it is less susceptible to being washed away by floods. Sub-surface dams are also a potential water harvesting technique where the texture of the wadi sediments is unsuitable for sand dams (silt) or where the overall score of the other factors results in a unfavourable potential for sand dams.

Where there is a potential for large sub-surface dams because of a relatively wide wadi, it should also be investigated if there is shallow groundwater close to the wadi. If this is the case, riverbank filtration might be an option for improving the local water supply. Shallow wells can be installed at a short distance from the river. The existing sediments in the broad riverbed are a good reservoir for river discharge and wells along the river will induce a groundwater flow from the saturated riverbed to the shallow wells. For this, there must be a hydraulic connection between the riverbed and the adjacent underground. A well placed in a thick clay layer, for example, will hinder the groundwater flow and make riverbank filtration impossible.

Next to the potential for sand dams, check dams, sub-surface dams and riverbank filtration, the potential for floodwater spreading was assessed. It should be noted that floodwater spreading includes a wide range of techniques (including spate irrigation), however, here we focused on flood-spreading weirs as a potential in-stream intervention. Flood-spreading weirs are dams of varying height built across a river that aim to spread the river discharge during high-flow events the targeted floodplain should not be occupied by a settlement, should consist of sedimentary deposits (no hard rock) and have sufficient width to allow a considerable area to be inundated (>100 m wide).

Wadi Bulbul has a varied potential. The best potential for intervention such as sand dams and large subsurface dams is found in the middle section of the catchment area. In the lowest part of it, the potential for such interventions is medium since wadis are wider. The potential identified in Figure 12 has to be confirmed in the field.

3.3 Groundwater potential

In general, the groundwater potential for the basement complex is low because the rocks are impermeable. Nevertheless, along fractures and fracture zones weathering causes the rocks to become permeable which increases the potential of water presence in these zones. Such (fractured) *aquifers* are however far from ideal, they have low storage capacities and produce low well yields (litter/second) (UNEP, 2007). Thereby, the aquifer properties strongly depend on the fracture orientation and geological processes that took place by that time.

Information obtained from local geologists confirms that some of the fractures surrounding the Jebel Marra complex are groundwater bearing. The percentage of successful boreholes is very low, though. The hydrogeological dynamic of this fractures is very difficult to assess and predict since there is almost no monitoring data available and a field work for attesting their location has not been possible (yet).

Very often groundwater is also stored in the *alluvium.* In most of the cases recharge of alluviums occurs during the rainy season by runoff. Certainly, there are also some cases whereas *alluvium* is recharged by groundwater arising from geological faults interconnected with the volcanic formations or other groundwater bearing formations.

However, there are other aspects then the presence of water which might influence the potential of an *alluvium* for groundwater exploitation. Upstream erosion plays an important role in feeding the aquifer with either high or low potential sediments (sand or clay respectively). Thereby, the slope is also an important aspect in assessing the *alluvial* storage and *aquifer productivity*. Low slopes (less than 1/1000) can result in large clay and silt deposits where high slopes (higher than 0.4%) cause erosion of the *wadi* bed.

The underlying geology of the *alluvial aquifer* is another important aspect in determining the potential of the alluvial aquifer. The thickness of the sedimentary deposition is determinant for the storage capacity and the abstraction rates (yield).

In the case of sandstone or fractured basement as underlying geology the aquifer can be recharged from beneath increasing the storage capacity. This recharge is the dominant factor for aquifer potential in alluvial aquifers because the storage capacity is generally low making the alluvial aquifer vulnerable to dry years.

Quality of the groundwater in alluvial aquifers is generally high but can be affected by volcanic hydrothermal seepages and mineralized contents of clay deposits, as well as human activity such as *livelihood* in the vicinity of the wadis or pit latrines. Local knowledge is essential to better understand the hydrogeology of Darfur and collect data that might help in the interpretation and inferring location for groundwater storage. Yields are always another point of attention, it is hard to predict yields until a borehole-test can be conducted. Siting groundwater wells is often difficult and, in some regions, (whereas monitoring data is not available), the rates of success can be very low.

4 Catchment water balance

4.1 SWAT model

A hydrological model called SWAT (Soil Water Assessment Tool) was developed for the catchment to create insight in the water balance of the catchment. SWAT uses spatial data of catchment characteristics (the topographic map, land cover/land use map, soil map, and stream patterns), combined with climate data series and water use to simulate water flow through the catchment. The input data is generated using remote sensing, literature, open source data and the questionnaires. Rainfall was obtained from a combination of the Africa Rainfall Climatology version 2 (Arc2) and Global Precipitation Climatology Centre (GPCC) satellite data, while all other climate parameters were obtained from the Climate Forecast System Reanalysis (CFSR) database.

4.1.1 SWAT model setup

Figure 13 gives an overview of the catchment as input for SWAT. The area is divided into sub-catchments (or sub-basins) based on the stream pattern. Each sub-catchment has one stream that is connected to the main wadi. Runoff leaves the catchment as stream outflow in the south, at the outlet in sub-catchment 28. The model was run for 27 years (1986-2013) simulating daily time steps, while writing monthly output data. Table 3 and Table 4 give an overview of SWAT output, providing the average yearly water balance of the catchment overall years, and specifically for dry and wet years. The model was built so that for each community in the South, there is a water balance available.

4.1.2 Model results

The model shows that on average, there is considerable precipitation in the catchment (467-500 mm). ~80% of this precipitation is lost by

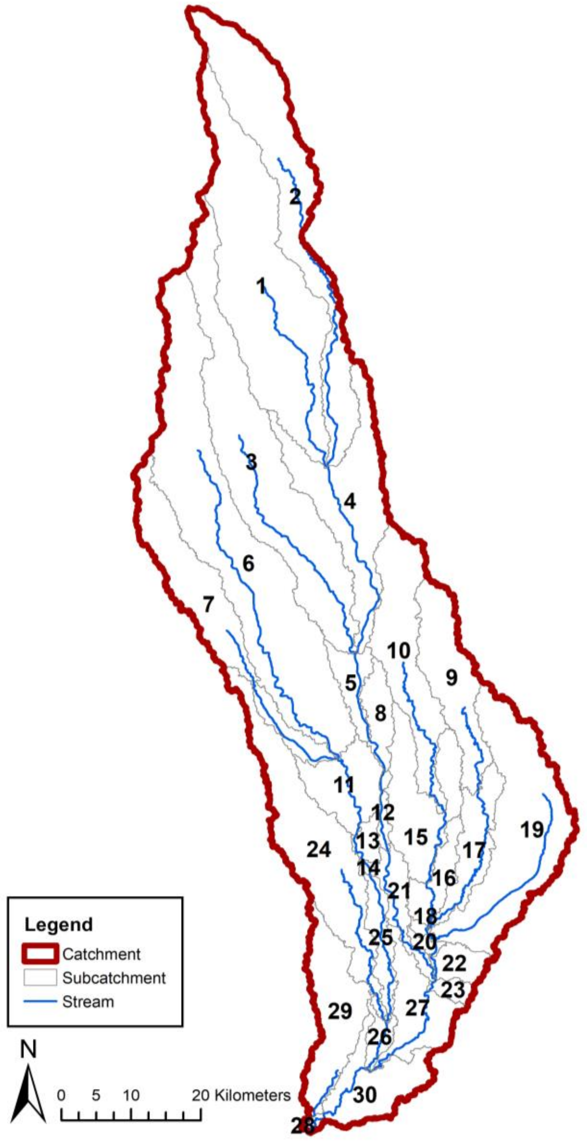


Figure 13. SWAT model setup for Wadi Bulbul. The catchment outlet is located at subcatchment 28 in the south.

evapotranspiration. In normal years, this leaves quite a lot of water for infiltration or surface runoff for water harvesting. The amount of infiltration in wadi Bulbul is quite high, due to the sandy wadi beds and the low slopes. Infiltrated water may be held in the soil and later evaporated, or it may slowly make its way to the surface-water system via underground flow. Return flow (or base flow) from the shallow aquifer to the wadi is very low, due to the flat landscape. For Wadi bulbul, revaporation (evaporation of soil moisture) is quite high, likely due to the widespread rain fed agricultural lands. The percolation to the deep aquifer is low, as no wadis are known that lose their groundwater in fracture systems (See table 3 for values in mm).

Table 3. Summary of the different elements of the hydrological cycle in mm, and in percentage compared to precipitation.

Element of hydrological cycle	mm	In %
Precipitation	477	100
Evaporation and Transpiration	387	81
Surface runoff	61	13
Lateral flow	1	0
Return flow	3	1
Percolation to shallow aquifer	52	11
Revap from shallow aquifer	45	9
Recharge to deep aquifer	3	1

Table 4 shows the water balance for a normal year (T2, a year that likely occurs once in every 2 years). The table shows values in mm and in Million cubic meter. The table shows great variation in numbers, showing that the water balance and therefore water availability strongly depends on the amount of rainfall. During wet years, there is a lot of generated surface runoff, groundwater recharge and outflow. During dry years and very dry years (occurring once every 5 or 25 years resp.) groundwater recharge and river outflow is very low compared to the rainfall. If you consider the outflow in Mm3 in these years, there is still water that could be captured in surface water infrastructures. Also, if the generated runoff could be slowed down, more groundwater recharge would take place.

Figure 14 shows stream outflow. Outflow from the undulating range lands in the east is lower compared to the northern part including the footslopes of the Jebel Marra. Google earth imagery showed that the wadi bed of subcacthment 5, 8 and 12 is most clear and wide compared to the other subcatchments. This wadi section shows a high stream flow.

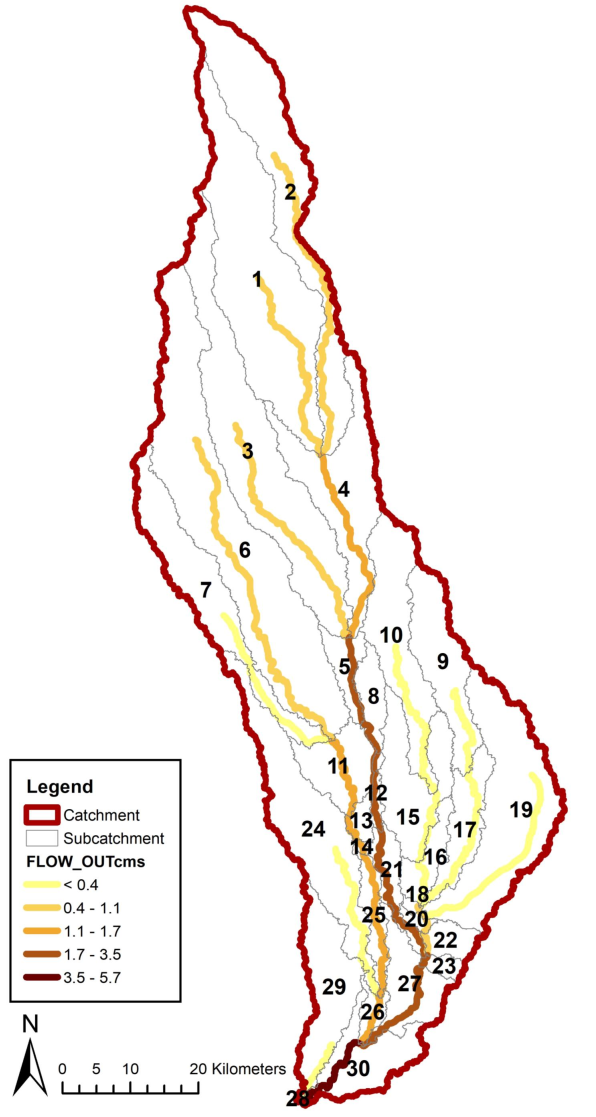


Figure 14. SWAT output: Outflow in m3/s. The colour of the outflow per reach indicates the annual average discharge in m^3/s.

Table 4. SWAT output: Water balance in a wet very wet, normal, dry and very dry year (mm and million m^3) for the catchment outlet, at subcatchment 28.

	Normal (T2)		Wet (T10)		Very wet (T25)		Dry (T5)		Very dry (T25)	
	mm	Mm^3	mm	Mm^3	mm	Mm^3	mm	Mm^3	mm	Mm^3
Precipitation	467	2002	613	2623	635	2718	381	1633	304	1302
Evapotranspiration	380	1628	453	1940	455	1947	357	1528	294	1258
Generated runoff	30	127	72	307	93	399	12	49	4	16
Groundwater recharge	22	93	63	272	74	319	1	3	0	0
River flow at outlet (sub 28)	33	135	83	344	97	400	13	55	4	18

Figure 15 indicates the annual average generated surface runoff by SWAT. The runoff is quite high throughout the catchment. All wadi systems show lower runoff values, indicating infiltration in the wadi systems and wadi banks. On the western, and southern side, annual average rainfall is a little bit higher, indicating even higher runoff rates. Also, the areas where (rainfed) agricultural lands are present, runoff is high. SWAT likely has an overestimated surface runoff for the agricultural lands in the northern part of the catchment because google earth imagery showed great terrace structures. Due to these terrace structures, surface runoff is slowed down, creating more time for infiltration. Rangelands in the east show a little less runoff, indicating higher infiltration rates to the shallow groundwater.

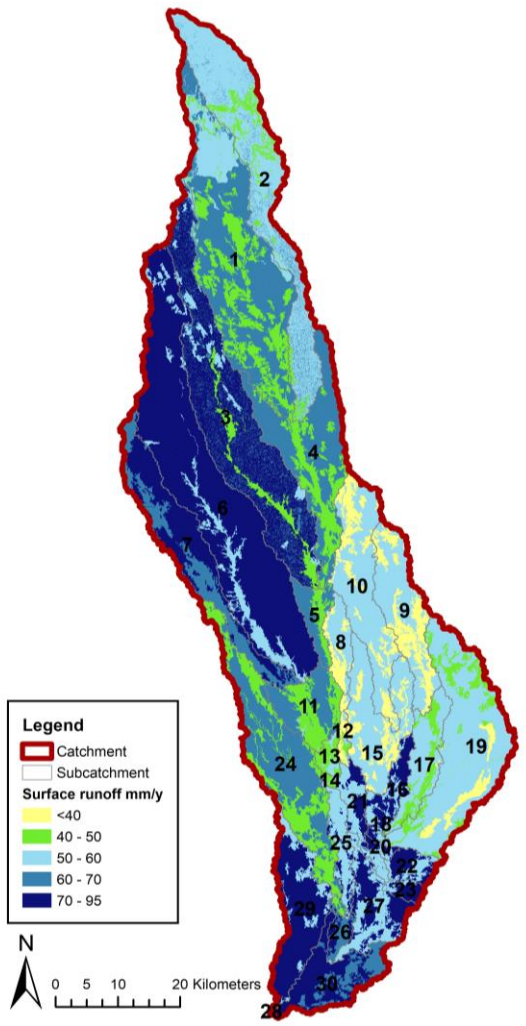


Figure 15. SWAT output: annual average generated runoff (mm) throughout the catchment. The colour indicates the surface runoff per area.

The depth to bedrock will also plays and important role in how much shallow groundwater can be stored.

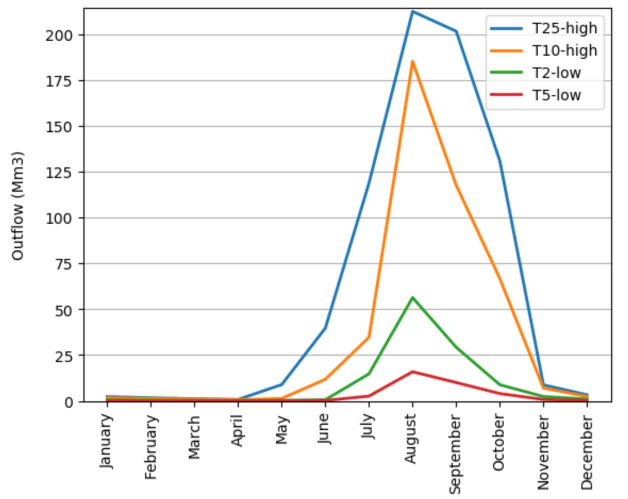


Figure 16. SWAT output: Outflow values (million m³) for monthly outflow return periods of river flow out of the catchment (reach 28), for T10 and T25 of high outflow and for T2 and T5 of low outflow.

Figure 16 shows the calculated peak flows at the catchment outlet for different types of years. The actual peak flow is likely somewhat lower due to overflowing water on wadi banks. The peak flow takes place between May and November, with no outflow in the dry season. Peak flow in normal years (T2-low) is relatively high. 50 Million m³ could fill approximately 500 large valley dams. This shows that at least several valley dams using peak flow can be constructed without negatively affect water users downstream.

The (T25) high peak flow near the catchment outlet that occurs once every 25 years, is 3 times higher than a normal peak flow. New water infrastructure in the southern part of the catchment should be able to withstand such a peak flow to ensure sustainable plans.

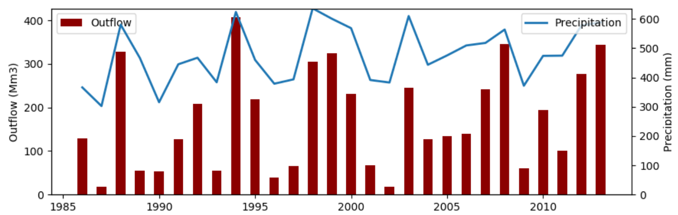


Figure 17. SWAT output: Total yearly streamflow (in million m³) at the catchment outflow, plotted with precipitation (mm).

Figure 17 shows the total annual outflow for the years included in the simulation, compared to the total annual precipitation. Annual variation in precipitation is quite high, and outflow is highly respondent on the precipitation values.

4.2 Model trends and analysis

During model setup, channel delineation was difficult due to the flat landscape. This indicates that wadi streams can easily divert their course. During the rainy season, water can carry large amounts of sediment. When the velocity is reduced, sediment is deposited and if this blocks a channel, the wadi can divert. Chance on diversions can be reduced by capturing sediment upstream with for example sand dams and gabion weirs. Also measures to reduce soil erosion (upstream) would benefit the catchment and sustainability of planned interventions

In the upper part of the catchment, a large area is covered with terrace systems along the contour lines. These terrace systems improve the infiltrated volumes of water towards the shallow aquifer. This groundwater recharge system should be well maintained to ensure the groundwater availability, also downstream in the catchment.

In the downstream part of the catchment, there are some locations with quite high runoff rates. These areas (figure 15) could be used to capture surface runoff and peak flow in valley dams. These valley dams would improve the water availability along the livestock migration corridor. If seepage losses take place, this would improve the groundwater recharge. Backfilled hafirs combined with a water yard, could provide a solution to bridge the dry season water demand. When the hafir is backfilled with sand, the effective storage capacity reduces to about 35% of the volume. But this water could be abstracted only during the dry season. Additionally, groundwater quality can improve as the sand acts as a natural water filter.

Peak flow throughout the catchment is quite high and could be well used to improve the water availability. Annual variation in precipitation is quite high, and outflow is highly respondent on the precipitation values. Taking the future decreasing precipitation trend into account, it would be good to design the new water supply systems, so it is properly functioning in the normal and dry years.

Looking at the water balance and SWAT output, opportunities in this catchment for improved water availability lie in the reduction of surface runoff to increase groundwater recharge. The smaller wadis upstream could capture peak flow and store more groundwater using gabion weirs, sand dams and subsurface dams. Also, peak flow can be captured in surface water storage in the downstream area.

5 Water resources development analyses

5.1 Catchment issues

The soil in this catchment is mostly sandy and closed to the wadis it turns more clayey. The fertility of soil at present is low, during the dry season; the soil is not cultivable except the soil along the wadis, but in the rainy season most of soils (sandy or clay) are cultivable.

The soil fertility is going down and soil moisture is very low given the low level of rainfall in the last few years. Soil erosion is also contribution to degradation. There is sign of erosion on the top of the soil mainly in the forest land and grazing areas, but some initiatives are made to increase reforestation and those are already improving the situation

There is conflict between returnees and the host community on farm lands, the returnees already had farm lands before they were displaced. Now, by their return they face problems to return to their former farmland since it already being cultivated by host farmers.

There is conflict between farmers and nomads due to damage of crops when nomad inter the crops farms before harvesting (particularly in the farmers of rainy season).

The grazing land is available and accessible but poor pastures are not sufficient for all livestock. The communities keep cows, goats and sheeps. Therefore, there is a decrease in livestock numbers, specially the numbers of cows.

The water trend is decreasing because the low level of rainfall and low level of underground water. During the rainy season the communities rely on the wadis but in the dry season the main source is groundwater.

5.2 Current water demand x supply

Most of land in this catchment area is gently flat, majority of land is non-irrigated (the community mainly depend on rain cultivation system).

In the sandy soil they crop millet, okra and watermelon. And in the clay soil sorghum, potato, radish, onion and tomato

For cropping practice; the farmers depend on monoculture as main cropping technique.

According to information gained, the main water resource in the catchment area is the wadi in the rainy season and in the dry season depends on groundwater (by use submersible pump hand bumps "for drinking, HHs and livestock" and hand dugs wells "for drinking, HHs, livestock and irrigated farming land") and pond (Hafeir) for drinking, HHs, livestock and brick making.

5.3 Opportunities for allocating interventions

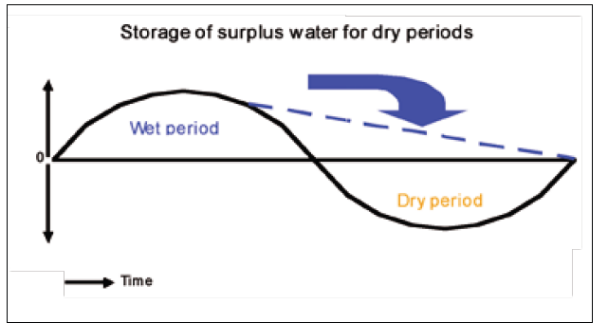
Floodwater exchange between the two catchments and the visible accumulation of sediments in the wadis could also be a consequence of land degradation upstream and more intense flash floods. Especially if this is the case, water resources development and interventions should upstream more focus on landscape restoration (SWC measures), runoff reduction and enhancement of infiltration.

Due to the many clayey cambisols this might be difficult, but the sandier (Goz) soils on basement rock and the wadi's offers opportunities to implement permeable structures upstream, such as valley dams (gabions) or impermeable such as sand dams or subsurface dams on the lower parts of the catchment.

During the wet season and in the period after, many locals make use of scoop holes ('Meshish'). Water is plenty for livestock and domestic use. However, for domestic water use, water supply from shallow groundwater should be preferred over surface water or meshish due to the better quality and lower chances on polluted water.

Also, separating livestock supply from domestic is a good measure to ensure lower contamination and degradation of the water resources.

The main strategy for ensuring supply in the dry season is to store the water when its plenty. Not only livelihoods activities shall benefit from this strategy but also ecosystem recovery will benefit.



5.4 Integrated solutions

In order to improve water availability, it is key to improve vegetation cover in the area, combined with the right measures to make that the vegetation flourishes. The vegetation is vital for different reasons:

They keep the soil open so that more water can infiltrate, they improve the soil fertility and they provide food for livestock and sources of income.

Because there is a pressure on land, integrated solutions are needed, one example of this is an integrated farm.

Fully-integrated farming systems focus on the interdependencies between water, soils and vegetation. Experience shows that by addressing these parameters in an integrated manner crop production can increase tremendously, erosion can be reduced, and water availability improved. Fully-integrated farms support interacting biophysical processes, and the need for soil and water conservation measures. Attention is paid to water infiltration and evapotranspiration (e.g. soil bunds, trenches, hafirs), soil formation and fertilization (e.g. mulching, nitrogen fixing, application of manure), and vegetation management (e.g. variation of plants with different heights, variation of crops).

The well-designed integrated farm will increase water storage in the soil, increase soil fertility and thus increase crop yields and livelihoods for the farmers.

These problems can be helped with simple measures, especially soil and water conservation measures. However, these problems are not just fixed by implementing measures without changing the people's mindset as well.

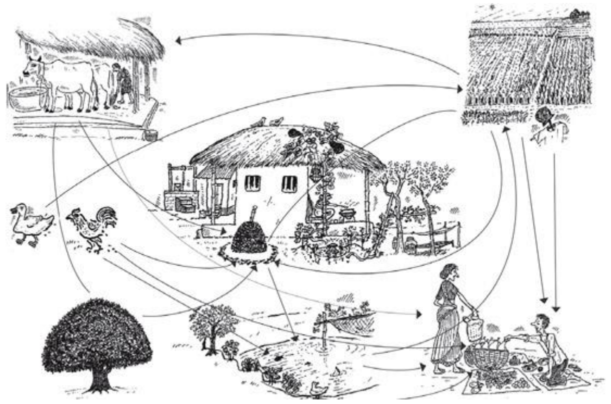
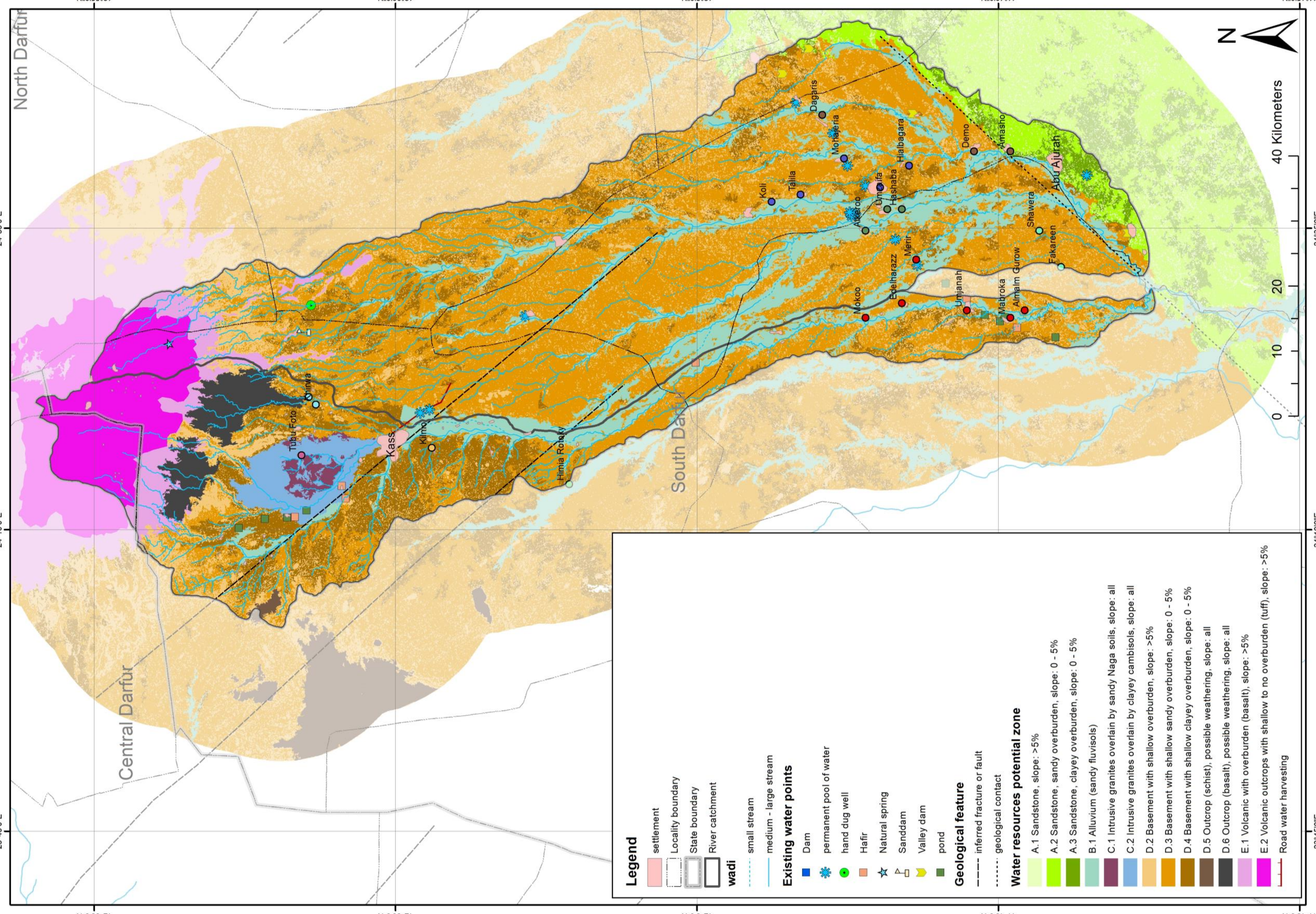


Figure 18 Integrated farming to increase water availability for agriculture.

Annexes

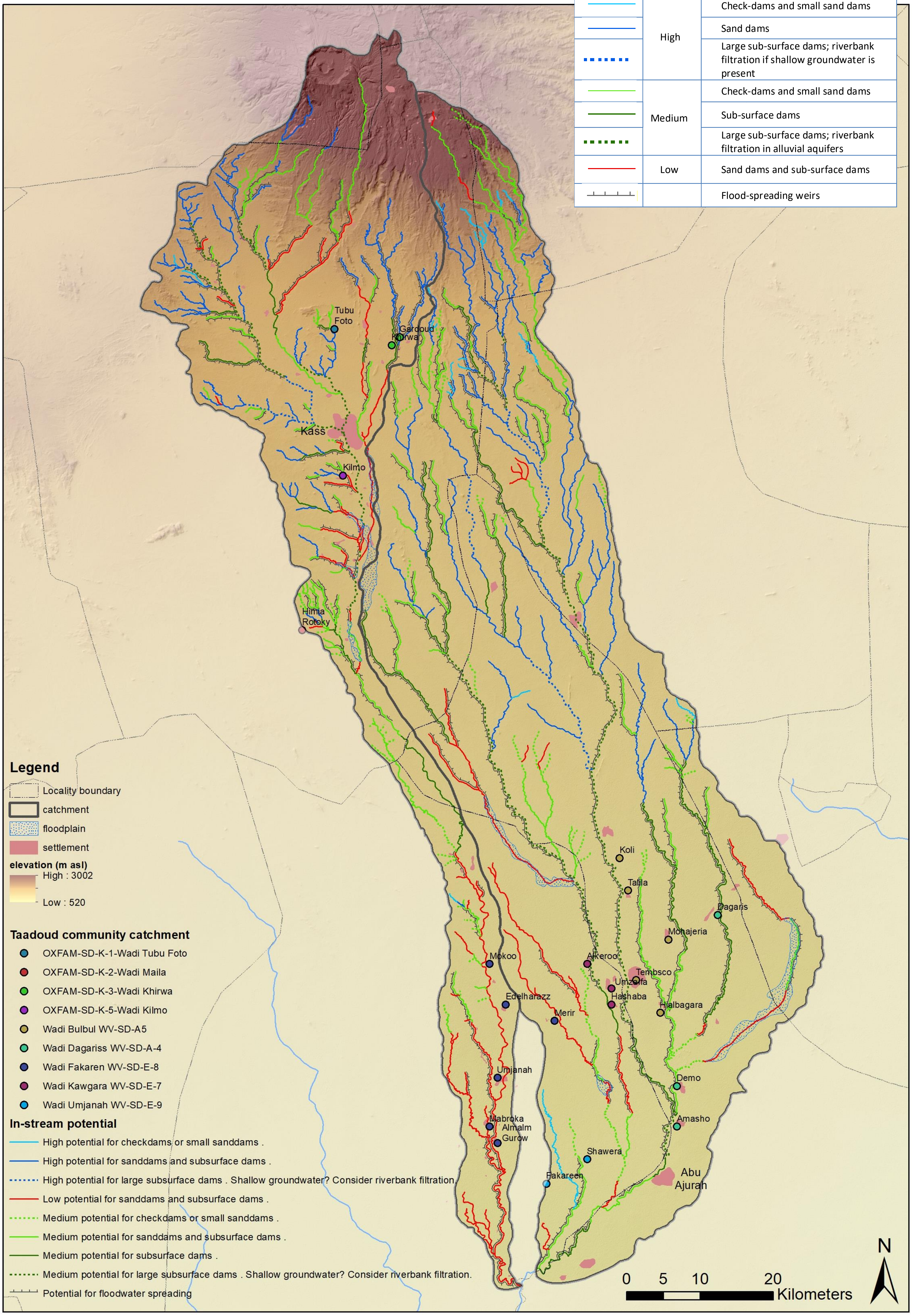
larger format maps for better visualisation

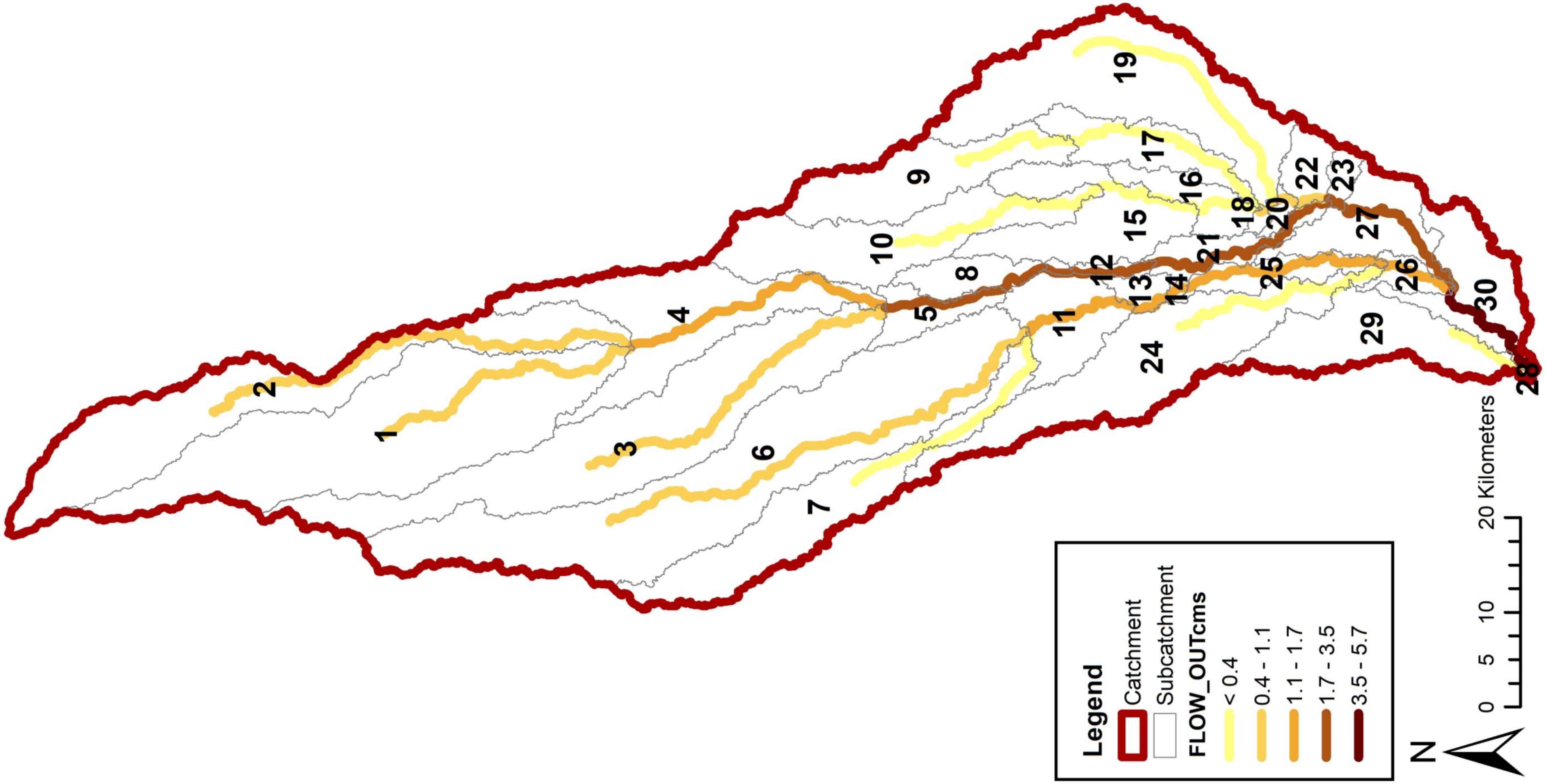


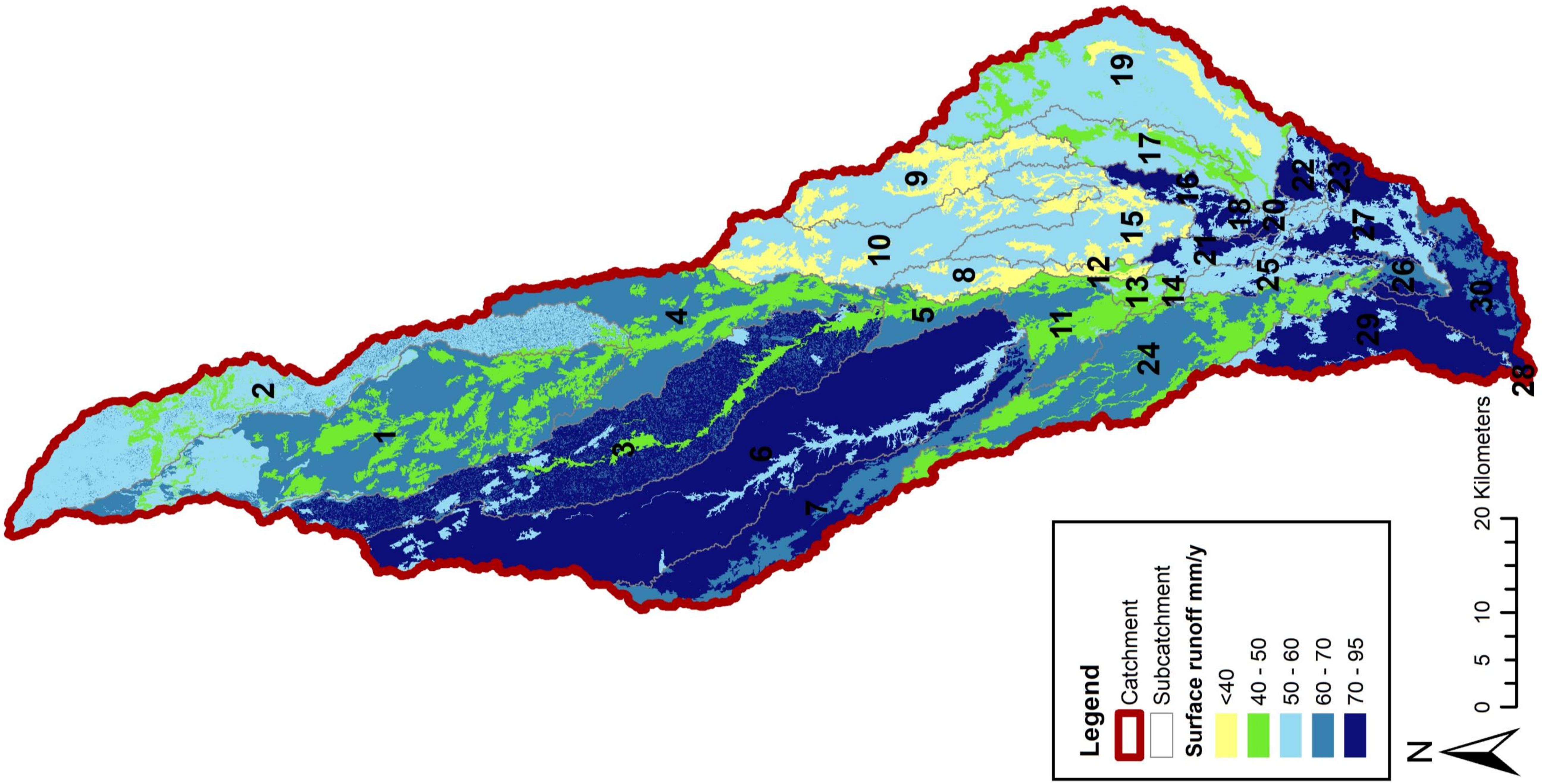
Legend
settlement
Locality boundary
State boundary
River catchment
wadi
small stream
medium - large stream
Existing water points
Dam
permanent pool of water
hand dug well
Hafir
Natural spring
Sanddam
Valley dam
pond
Geological feature
inferred fracture or fault
geological contact
Water resources potential zone
A.1 Sandstone, slope: >5%
A.2 Sandstone, sandy overburden, slope: 0 - 5%
A.3 Sandstone, clayey overburden, slope: 0 - 5%
B.1 Alluvium (sandy fluvisols)
C.1 Intrusive granites overlain by sandy Naga soils, slope: all
C.2 Intrusive granites overlain by clayey cambisols, slope: all
D.2 Basement with shallow overburden, slope: >5%
D.3 Basement with shallow sandy overburden, slope: 0 - 5%
D.4 Basement with shallow clayey overburden, slope: 0 - 5%
D.5 Outcrop (schist), possible weathering, slope: all
D.6 Outcrop (basalt), possible weathering, slope: all
E.1 Volcanic with overburden (basalt), slope: >5%
E.2 Volcanic outcrops with shallow to no overburden (tuff), slope: >5%
Road water harvesting
North Darfur
Central Darfur
South Darfur
Kass
Abu Ajurah
40 Kilometers
0
10
20
N
12°55'0"N
12°30'0"N
12°5'0"N
11°40'0"N
11°15'0"N
24°35'0"E
24°10'0"E
23°45'0"E

Overview of potential for in-stream water harvesting techniques

	Potential	Suitable types of interventions
(light blue line)	High	Check-dams and small sand dams
(blue line)		Sand dams
(blue dotted line)		Large sub-surface dams; riverbank filtration if shallow groundwater is present
(light green line)	Medium	Check-dams and small sand dams
(dark green line)		Sub-surface dams
(dark green dotted line)		Large sub-surface dams; riverbank filtration in alluvial aquifers
(red line)	Low	Sand dams and sub-surface dams
(ticked line)		Flood-spreading weirs




Legend
Catchment
Subcatchment
FLOW_OUTcms
< 0.4
0.4 - 1.1
1.1 - 1.7
1.7 - 3.5
3.5 - 5.7
N
0 5 10 20 Kilometers


Legend
Catchment
Subcatchment
Surface runoff mm/y
<40
40 - 50
50 - 60
60 - 70
70 - 95
0
5
10
20 Kilometers
N
1
2
3
4
5
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