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Development and Application of a Groundwater Model for Gedaref-Adigrat Aquifer

Report B

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1. Background

In Report A of this study (Report A) the construction of the conceptual and numerical groundwater models of the Gedaref–Adigrat aquifer were discussed. The report identified the data and information needed for the model, namely, the physical boundaries and appropriate boundary conditions, distribution of the hydro-geologic characteristics, water level information and initial head distribution within the aquifer, recharge source and quantification as well as the groundwater abstraction from the aquifer. Also the spatial and time discretization of the model were discussed as well as the GMS modelling software used. The following packages have been used in the model:

- Well Package
- Recharge package
- Drain package.

Data for the above packages has been prepared as GIS layers / raster and introduced to the GMS, as well as the distribution of aquifer parameters, time and space discretization.

Initially, a steady state simulation run was performed using the initial heads of the aquifer. The resulting head distribution from the steady state simulation was used as input to the transient simulation and the following trial simulation runs were been carried out:

- 5-years simulation using the existing pumping and recharge rates.
- 5-years simulation with 50% increase in pumping
- 5-years simulation with 50% increase in pumping and 10% decrease in recharge.

For each simulation run the following results were presented:

- Water level variation at selected points.
- Water budget
- Zone budget for Gedarif and Adigrat areas.

The purpose of the above trial runs was to test the performance of the model and to make sure that it runs without problems and gives consistent results.

Generally, very limited data is available in the Adegrat side of the basin. Model calibration is an important step in the modelling process to ensure that the model is a reasonable representation of reality. This step has not been carried out due to lack of historic water level information to be used for the calibration process. However, parameter adjustment has been carried out till a reasonable groundwater flow trend is obtained. More effort needs to be exerted by the national consultants to obtain some historic water level information for the calibration process. The three trial simulation scenarios presented were just examples, the purpose of which is to test the performance of the model and to make sure that it runs without problems. The results show that the model is running smoothly without problems and gives consistent results. It should be emphasized that the developed model is just indicative of future trends and must be thoroughly calibrated as more data become available.

In this report (Report B), the results of application of the developed model will be discussed considering the following:

1.Test the socio-economic impact on the aquifer due to population increase and the resulting increase in water demand up to year 2050.

2.Investigate the impact of climate change scenarios on rainfall and evapotranspiration and estimate the resulting changes in groundwater recharge quantities.

3.Conduct water balance within the shared aquifer with quantified recharge, outflows (base flow) and groundwater abstraction for different management scenarios.

4.Develop suitability maps to enhance conjunctive use of surface and groundwater, namely a suitability maps for potential sites of water harvesting and management of aquifer recharge.

5.Give recommendations for sustainable management and utilization of the shared aquifer.

2. Model Application

The Groundwater model developed in Report A has been applied to investigate the following four scenarios for the management of the aquifer up to year 2050.

1.Scenario 1 (SC1): Baseline scenario with the current pumping and recharge rates.

2.Scenario 2 (SC2): Current pumping rates plus recharge rates impacted by climate.

3.Scenario 3 (SC3): Increase in pumping rates due to population growth and

4.Scenario 4 (SC4): Impact of climate change on recharge plus increase in pumping (worst case scenario)

3. Recharge Estimation under Climate Change

General circulation models have been applied to forecast the future impact of climate change on rainfall and evapotranspiration. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory. The following two Representative Concentration Pathways (RCP) were considered:

RCP 8.5: This assumes emissions to continue to rise throughout the 21st century. RCP8.5 is generally taken as the basis for worst-case climate change scenarios.

RCP 4.5: This is considered as an intermediate scenario in which emissions peak around 2040, then decline taking into account the exhaustible character of non-renewable fuels.

Recharge was estimated using the method described in Report A. The result of analysis shows that the recharge will be decreased by about 10% up to year 2050 as a result of climate change. It was also found that the decrease in recharge for RCP8.5 is very close to that for RCP 4.5. Table 1 shows the monthly and annual recharge estimates before and after considering climate change. The decrease in groundwater recharge is highly correlated to the increase in temperature that is interrelated to the high evapotranspiration rate. National consultants in Sudan (Mohamed Omer, Report B, 2022) and Ethiopia (Sintayehu, Report B, 2022) both agree that the groundwater recharge is going to decrease in the future due to the impacts of climate change.

Table 1: Estimated Groundwater Recharge Considering Climate Change

Month	Recharge (MCM/month)			Recharge (MCM/month) under climate change		
	Gedaref	Adigrat	Total Aquifer	Gedarif	Adegrat	Total Aquifer
June	0.78	14.87	15.65	0.70	13.38	14.09
July	13.93	59.70	73.63	12.54	53.73	66.27
August	18.42	53.94	72.36	16.58	48.55	65.12
September	0.78	6.82	7.6	0.70	6.14	6.84
Total (MCM/year)	33.91	135.33	169.24	30.52	121.80	152.32

4. Population and Water Demand Projections for Gedarif

Population and water demand projections from year 2020 to 2050 for Gedarif and Adegrat have been carried out by the National consultants using the appropriate growth rates. Table 2 and Figure 1 show the projected population and water demand for Gedarif. Population and water demand projections have also been carried out for Adegrat aquifer The results are shown in Table 3 and Figure 2

Table 2: Population and Water Demand Projection for Gedarif up To Year 2050

Year	Population (Million)	water Demand (MCM/y)
2020	1.54	13.00
2030	2.84	23.89
2040	3.22	27.09
2050	3.71	31.23

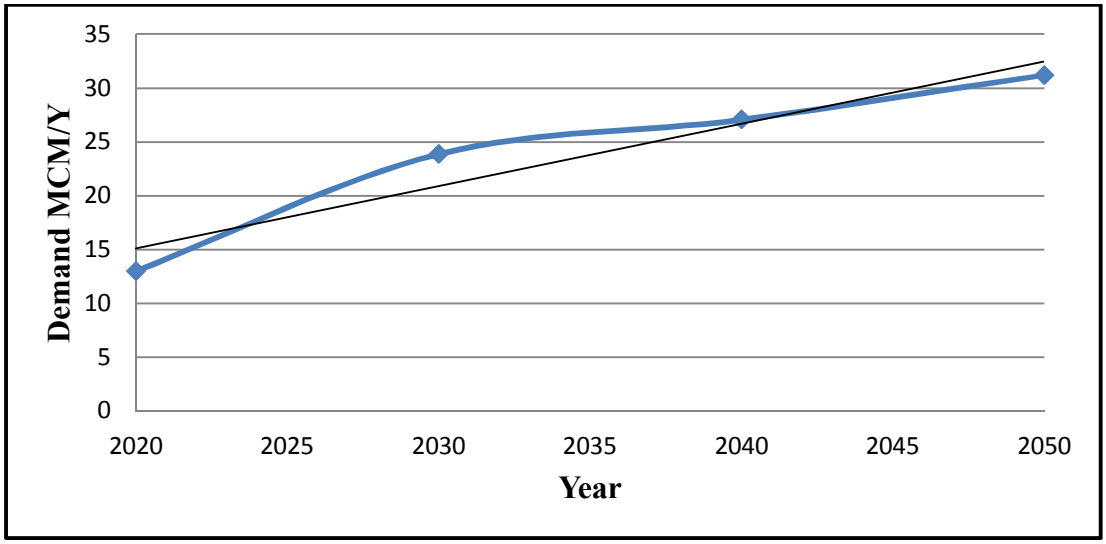


Figure 1: Water Demand Projection for Gedarif Up to Year 2050

Table 3:Population and Water Demand Projections up to Year 2050for Adegrat

Year	Population (Million)	Water demand (MCM/Year)
2020	2.92	11.15
2022	3.04	11.60
2030	4.50	16.42
2040	5.62	21.43
2050	6.85	26.12

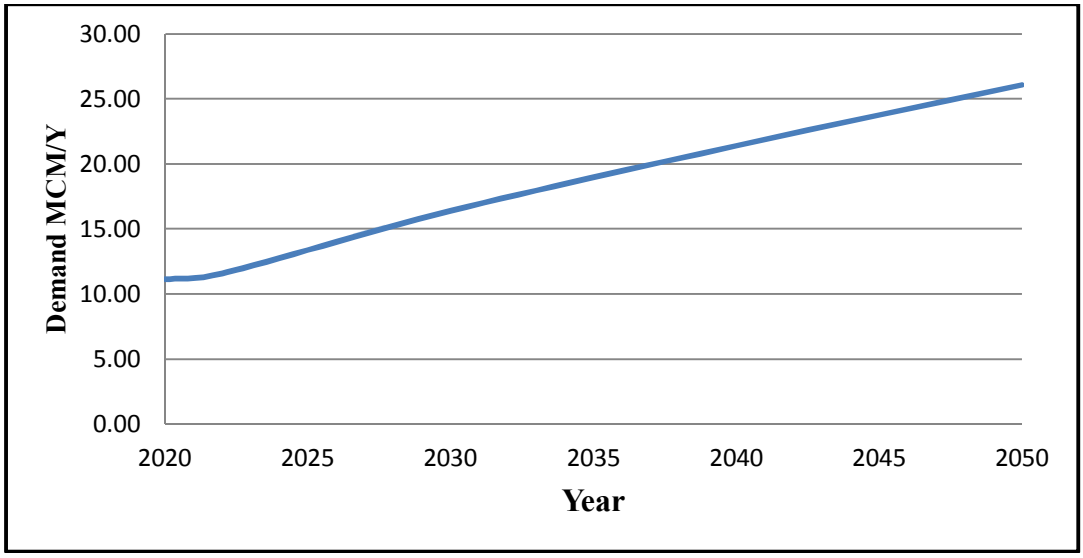


Figure 2: Water Demand Projection for Adegrat up to Year 2050

5. Modelling Results

The model was run under transient state condition up to year 2050 for the four considered management scenarios. The results are discussed below.

5.1. Water Level Variation for Various Scenarios

The water level variations up to year 2050 at a general point in Gadarif aquifer are shown in Figure 3 for all scenarios. The results show that for the first scenario S1 (existing pumping and recharge), the aquifer remains at a steady state condition after the year 2030. For scenario S2 (existing pumping and decreased recharge due to climate change) the water levels follow the same trend as for S1with very small decrease in water levels. This indicates that the impact of decreased recharge is not that significant. For scenario S3 (increased pumping and existing recharge), the water level starts to decline after 2024 resulting to a drawdown of about 3 m at 2025. For Scenario S4 (increased pumping and decreased recharge), the water level variation is more or less that same as that for Scenario S3. This again indicates that the impact of decreased recharge is not that significant compared to the impact of increased pumping.

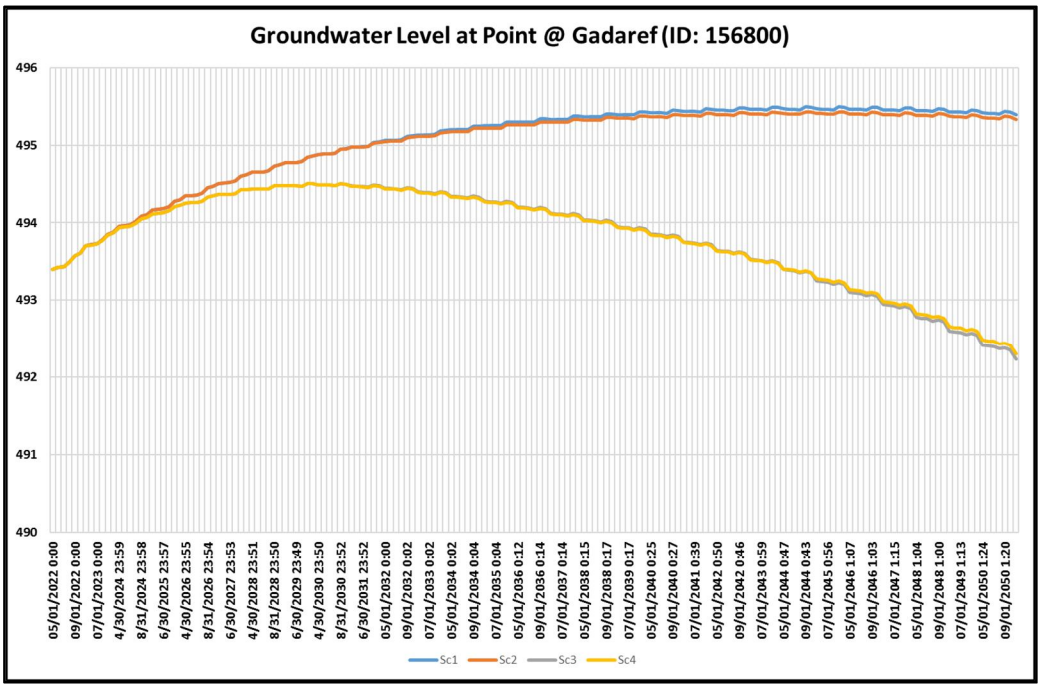


Figure 3: Water level Variation for management Scenarios for Gedarif

The water level variations up to year 2050 at a general point in Adegrat aquifer are shown in Figure 4 for all scenarios. As can be seen, the water level trends are similar to those of Gadarif aquifer. However, the drawdowns in Adegrat for S3 and S4 are greater reaching about 10m. The results again show that the impact of decreased recharge is not significant compared to increase in pumping.

Figure 5 is a drawdown map for S4, the worst case scenario, at year 2050. The map shows that even with increased pumping and decreased recharge, there are large areas of the aquifer with little or no drawdown in 2050. Therefore there is still large potential for groundwater development of the aquifer either through increased pumping from existing wells or introduction of new additional wells. It can also be seen that there will be areas of large drawdown exceeding 30 m due to concentration of pumping wells such as in Gadarif and South Western area of Adegrat aquifer.

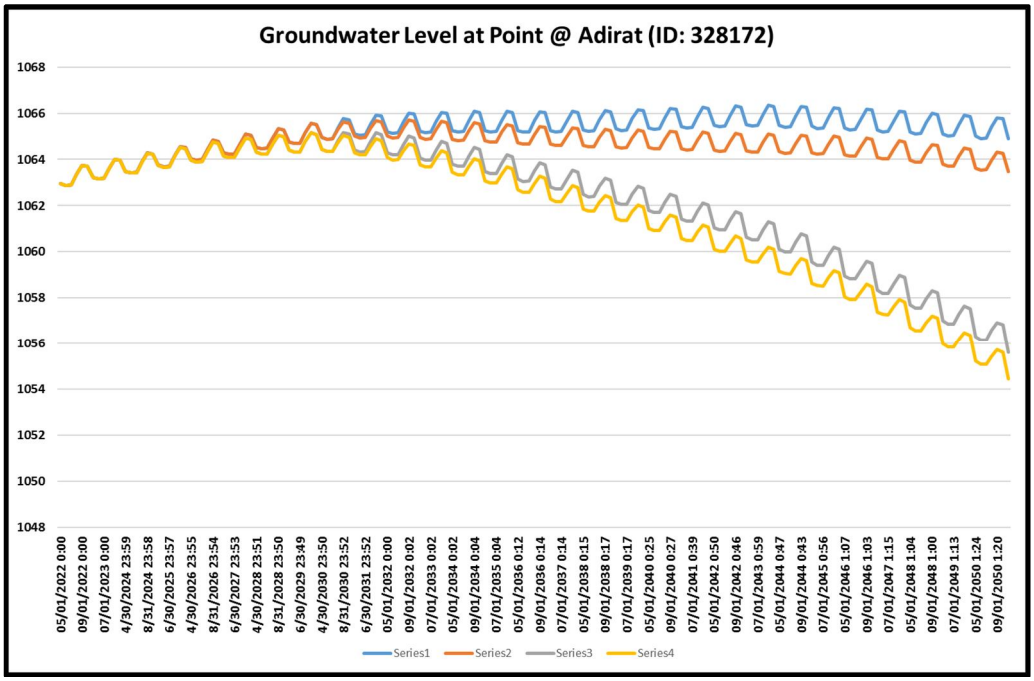


Figure 4: Water level Variation for Management Scenarios for Adegrat

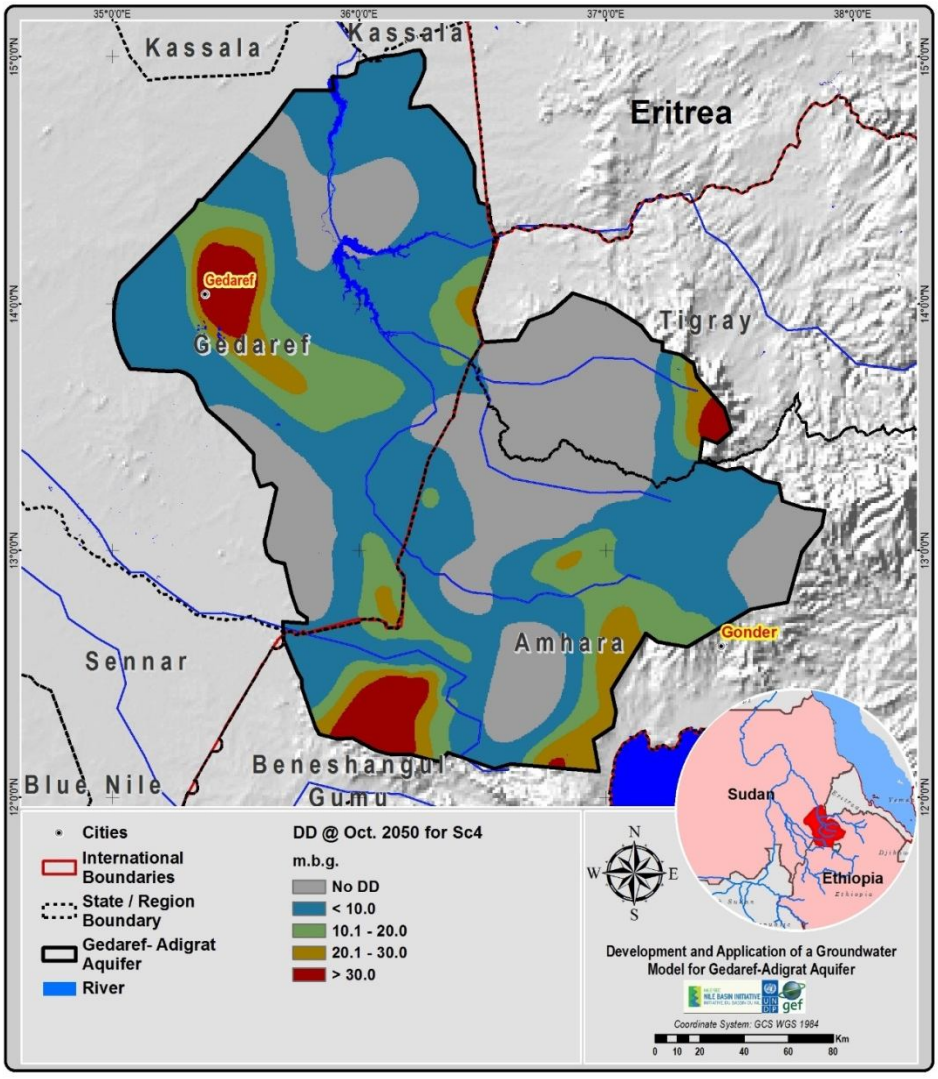


Figure 5: Drawdown for Scenario 4 at 2050

5.2. Water Balance Analysis

The annual water balance and zone budgets for scenarios SC1 and SC4 for Gadarif and Adegrat at the year 2050 are shown in Table 4 Table 5 Table 6 and Table 7. The results for the SC1 scenario show that for the year 2050, there is a total outflow from the aquifer as base flow contribution to rivers of about 138.1 MCM/year distributed as 49.3 MCM/year and 88.8 MCM/year from Gadarif and Adegrat sides respectively. It is also shown that for the year 2050 there is a total of about 5.7 MCM/year of removed from aquifer storage of which 4.7 MCM/year from Gadarif and 1.0 MCM/year from Adegrat.

For the SC4 scenario the results show that for the year 2050, there is a total outflow from the aquifer as base flow contribution to rivers of about 132.2 MCM/year distributed as 46.1 MCM/year and 86.2 MCM/year from Gadarif and Adegrat sides respectively. It is also shown that for the year 2050 there is a total of about 32.6 MCM/year of water removed from aquifer storage of which 24.9 MCM/year from Gadarif and 7.7 MCM/year from Adegrat resulting in larger drawdowns compared to other scenarios. Therefore, for both scenarios, there are large volumes of outflow from the aquifer as base flow contribution to rivers which can be harvested and utilized through water harvesting techniques.

Table 4: Water Balance for Gadarif for SC1 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	1.1	4.2	1.0	-3.4
June	0.9	2.8	1.0	4.0	1.0	-2.4
July	14.5	2.9	1.1	4.3	1.0	11.0
August	18.9	2.9	1.1	4.4	1.0	15.4
September	0.8	2.8	1.0	4.1	1.0	-2.5
October - April	0.0	19.8	7.4	28.4	6.9	-22.9
Total	35.1	34.1	12.7	49.3	11.9	-4.7

Table 5: Water Balance for Adegrat for SC1 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	0.9	7.1	2.9	-9.9
June	14.8	0.9	0.9	7.0	2.8	3.6
July	59.1	1.0	0.9	8.8	2.9	41.6
August	53.4	1.0	0.9	9.1	2.9	36.1
September	6.8	1.0	0.9	7.6	2.8	-4.2
October - April	0.0	6.7	6.1	49.1	19.7	-68.2
Total	134.1	11.5	10.6	88.8	33.9	-1.0

Table 6: Water Balance for Gadarif for SC4 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	2.8	3.9	1.0	-4.8
June	0.8	2.8	2.7	3.8	0.9	-3.8
July	13.0	2.9	2.8	4.0	1.0	8.2
August	17.0	2.9	2.8	4.1	1.0	12.1
September	0.8	2.8	2.7	3.8	0.9	-3.9
October - April	0.0	19.6	19.1	26.5	6.6	-32.6
Total	31.6	33.7	32.9	46.1	11.3	-24.9

Table 7: Water Balance for Adegrat for SC4 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	2.3	6.9	2.9	-11.2
June	13.3	0.9	2.3	6.8	2.8	2.4
July	53.2	1.0	2.3	8.5	2.9	40.5
August	48.1	1.0	2.3	8.8	2.9	35.0
September	6.1	0.9	2.3	7.4	2.8	-5.4
October - April	0.0	6.6	15.9	47.7	19.6	-76.6
Total	120.7	11.3	27.4	86.1	33.7	-15.2

Water balance results as well as drawdown maps for year 2050 for all scenarios are given in Annex (1).

6. Conjunctive Use of Surface and Groundwater

6.1.Existing Surface Water Sources in Gedarif

At present Gadarif town is experiencing shortage of water to satisfy the basic needs for domestic water requirements. The main source of water at present is the seasonal Atbara River where a treatment plant was constructed at El Showak town at Atbara River in 1970 .A steel pipeline of length 70km and diameter 0.5m was erected to convey 10,000 m3 /day of treated water to Gadarif town. Other minor surface water sources for Gadarif town are groundwater from boreholes at Aboelnaga and Azaza besides water harvesting systems from small dams constructed at Dalassa ,Wad Eldmak , Sharif El Agib , Saraf and Abayo.

6.2.Planned Surface Water Supply Projects in Gedarif

In 2010 when construction of Dam Complex of Upper Atbara Project started, the government took into consideration water supply to the Gedarif town from the dam. A provision was made to pump about 75,000 m3/day of water to Gedarif via high lift pump. The off-take is located at Rumula Dam left embankment on Atbara river. A treatment plant located about 1.1km from the off-take to treat 150,000 m3 /day was constructed in phase I which will be followed by 75,000m3 /day in phase II. This makes the total capacity of the plant 150,000m3 /day by year 2040.

Currently work is going on in the construction of the pipeline from the dam to Gedarif. For such large amount of water to be delivered to the city, the existing water distribution network of the city is now being redesigned and rehabilitated in order to accommodate the present and future water demands for Gedarif town up to year 2040.

7. Development of Potentiality Map for Rain Water Harvesting Structures (Small Dams)

7.1. Background

Identification of potential sites for rainwater harvesting (RWH) is an important step towards maximizing water availability. However, selection of appropriate sites for these technologies on a large scale presents a great challenge. Geospatial technologies have become an important tool in water studies due to their capability in developing spatial-temporal information and effectiveness in spatial data analysis and prediction.

Different approaches have been adopted to identify potential rainwater harvesting sites in remote and data scare area; in most of these methods, thematic maps are derived from Remote Sensing (RS) data and integrated in GIS database. In this study, six thematic maps were used for the identification of rainwater harvesting potential areas for both artificial recharge and water supply structures (dams), which are rainfall map, catchment slope, flow accumulation, drainage density, land use / land cover and soil texture.

7.2. GIS Process

Thematic layers have been considered for site suitability analysis. Based on the available knowledge on the role of each of these parameters in controlling the occurrence, storage and distribution of water, 'weight' is assigned to the data layers to reflect their relative importance. In addition, ratings are assigned to reflect the importance of a class within a category; RWH Index have been calculated as the product of the weightage and rate.

All the processing in finding RWH suitability map has been implemented in a suitability model developed in the ArcGIS program. The suitability model generates suitability maps for RWH by integrating different input criteria maps using Weighted Overlay Process (WOP) also known as Multi-Criteria Evaluation (MCE). MCE can be achieved by a weighted linear combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. With a weighted linear combination, criteria are combined by

applying a weight to each followed by a summation of the results to yield a suitability map using the following equation:

$$I = \sum w_i x_i$$

Where:

I = Suitability RWH and GWP Index

wi = weight of layer i

xi = criterion rating of layer i

Assigned weight to the layers and assigned rates to each category within the layers for study area shown in Table 8.

Table 8: Thematic maps and Assigned Weights for Potential Water Harvesting Sites (Small Dams)

No.	Criterion (layers)	Weight	Category	Rating
1	Flow Accumulations	30	0 - 14000	0
			14000 - 56000	3
			56000 - 237500	4
			237500- 1500000	5
			>1500000	5
2	Drain density (in km/ sq. km.)	15	0 – 0.1	0
			0.1 – 0.23	1
			0.23 – 0.5	3
			0.5 – 0.6	4
			0.6 – 0.72	5
3	Slope (%)	20	< 2 (Flat)	2
			2-8 (Undulating)	5
			8-15 (Rolling)	4
			15-30 (Hilly)	2
			>30 (Mountainous)	1
4	Land Use/Cover	10	Urban and Built-Up Land	1
			Dryland Cropland and pasture	2
			Cropland/Woodland Mosaic	5
			Grassland	4
			Shrubland	3
			Savanna	3
			Water Bodies	0
5	Soil	25	Water Bodies	0
			Cambisols	2
			Fluvisols	1
			Luvisols	0
			Regosols	5
			Lixisols	5
			Vertisols	5
			Leptoslos	0

Figure 6 shows 12 potential sites for water harvesting structures such as small dams . The proposed sites coincide with areas of high flow accumulation, high drainage density and low to moderate slope. Table 9 gives the coordinates of the proposed sites.

Table 9: Coordinates of Proposed Water Harvesting Sites.

Aquifer	Site Number	Coordinate	
		E	N
Gadarif	SD_1	144913	1636279
	SD_2	81595	1558309
	SD_3	78075	1536197
	SD_4	159402	1579763
	SD_5	164374	1547391
	SD_6	171366	1530226
	SD_7	156287	1408125
Adegrat	ET_1	262241	1490312
	ET_2	258472	1460259
	ET_3	234054	1394372
	ET_4	246642	1383651
	ET_5	230202	1369965

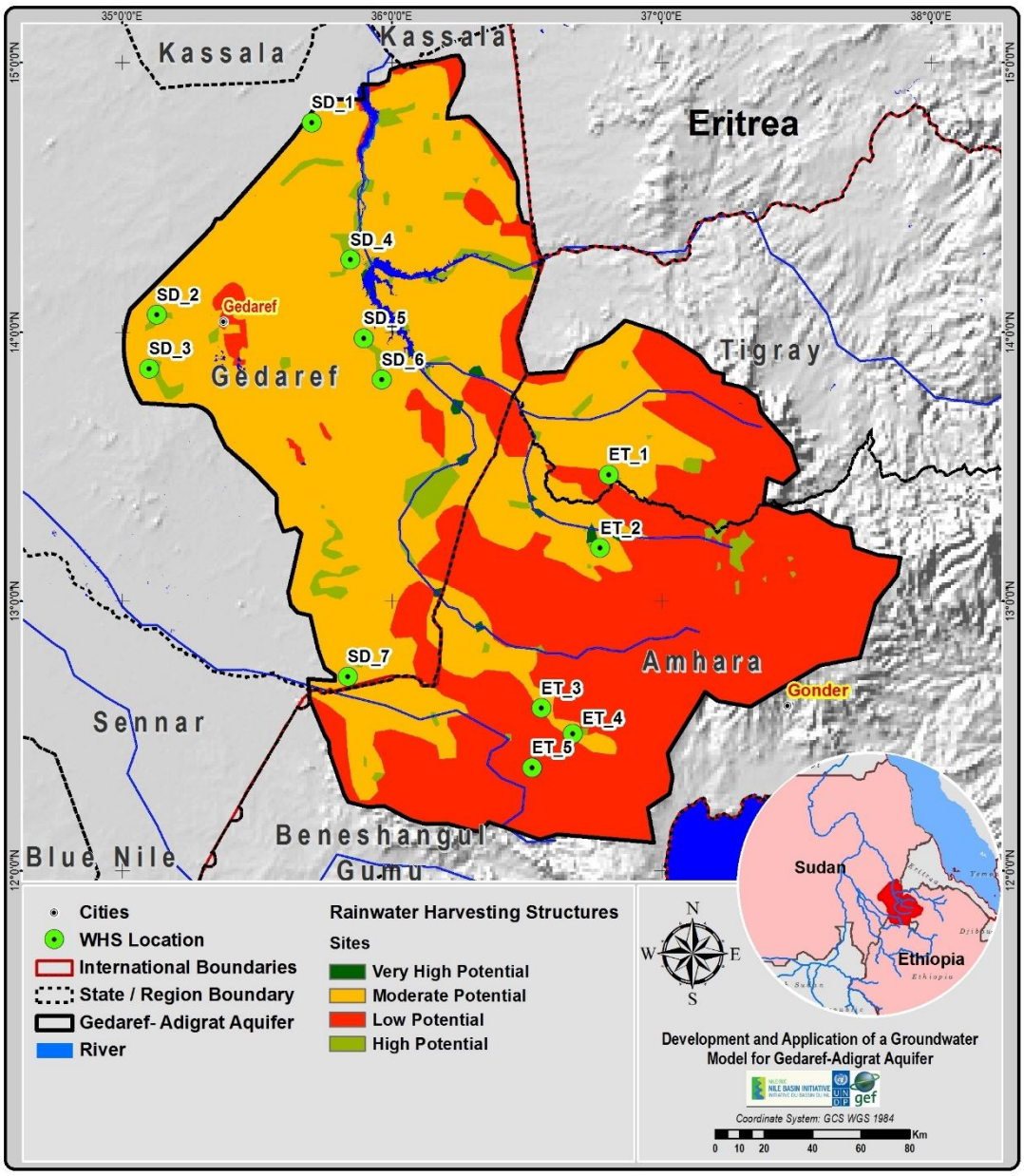


Figure 6: Potential sites for Water Harvesting Structures (Small Dams)

8. Development of Potentiality Map for Managed Aquifer Recharge (MAR)

Using the same GIS approach described above, a potentiality map for identification of potential areas for managed aquifer recharge has been developed. The thematic maps utilized are geology, rainfall, lineament density, slope, LU/LC, soil (Table 10).

Table 10: Thematic Maps and Assigned Weights for Managed Aquifer Recharge Potential (MAR)

Themes	Weight	Category	Rate
Geology	30	Water	5
		Alluvium	5
		Nubian Sand Stone	4
		Basement Complex	0
		Basalt	0
Lineaments	8	0 to 0.05 (low density)	0
		0.05 to 0.3 (moderate density)	3
		0.3 to 0.45 (high density)	4
		> 0.45 (very high density)	5
Drainage density (in km/ sq. km.)	9	0 to 0.1 (low density)	1
		0.1 to 0.23 (moderate density)	2
		0.23 to 0.45 (high density)	3
		> 0.45 (very high density)	5
Rainfall (mm/year)	10	390 - 500	3
		500 - 600	3
		600 - 700	4
		> 700	5
Land use/cover	5	Urban and Built-Up Land	1
		Dryland Cropland and Pasture	2
		Cropland/Grassland Mosaic	5
		Grassland	4
		Shrubland	3
		Savanna	3
		Water Bodies	5
		Barren or Sparsely Vegetated	1
Soil	18	Water Bodies	5
		Cambisols	1
		Fluvisols	3
		Luvisols	2
		Regosols	5
		Lixisols	3
		Nitisols	3
		Vertisols	4
		Leptoslos	0
Slope %	20	< 2 (Flat)	5
		2-8 (Undulating)	3
		8-15 (Rolling)	1
		15-30 (Hilly)	1
		>30 (Mountainous)	0

The developed potentiality map is shown in Figure 7. As can be seen, most of the very high potential area for MAR falls in the Gedarif part of the aquifer, whereas the Adegrat part is generally of low potential for MAR.

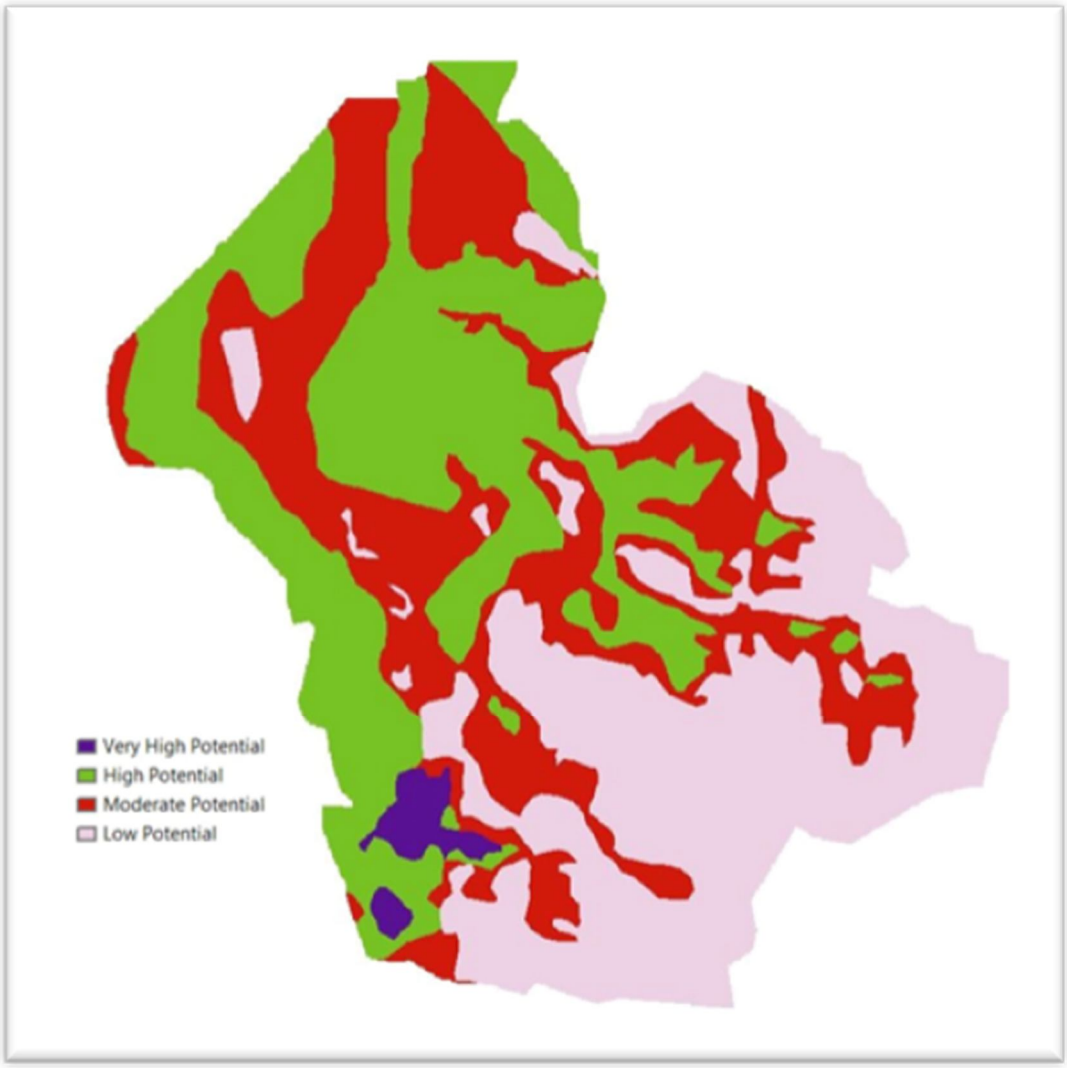


Figure 7: Potentiality Map for Managed Aquifer Recharge (MAR)

9. Conclusions and Recommendations

1. Based on the available data, a groundwater model has been developed for the Gedarif-Adegrat aquifer. There is a serious problem of data availability that does not allow the development of an adequately calibrated model. Therefore the developed model should be considered as indicative model at this stage. Efforts should be made for more data collection through the establishment of a monitoring system. As data become available, the model can be adequately re-calibrated in

order to have confidence in the model results and the recommended management scenarios.

2. Climate change analysis shows that groundwater recharge will decrease by about 10% up to year 2050. It was found from the modelling results that this reduction in recharge has little or no impact on the groundwater levels in the aquifer. It can therefore be concluded that the impact of climate change on the aquifer levels up to 2050 is not significant. However, climate change may have a significant impact on the aquifer after 2050 particularly for the worst case climate change scenario (RCP 8.5). It is therefore recommended to study the impact of climate change on aquifer recharge from 2050 up to the end of the Century.

3. The current and future pumping rates in the aquifer are much smaller than the groundwater recharge. Therefore there is a big potential for the aquifer development to satisfy the increased demands in the future.

4. There is also a very high outflow from the aquifer as base flow to rivers and streams running in the aquifer area. This outflow could be intercepted through water harvesting structures to contribute to meeting the demand both in Gedarif and Adegrat.

5. Drawdown maps at 2050 for all scenarios showed that there are still large areas within the aquifer with little or no drawdown that can be developed either through increasing pumping from existing wells or introduction of additional wells.

6. It is also noted that up to 2050, there will be no significant drawdown at the trans-boundary area even with the worst case scenario SC4 of increased pumping and recharge reduction due to climate change. However, care should be taken after 2050 since climate change may have a significant impact on recharge.

7. The developed suitability map for water harvesting projects reveal that there is a high potential of using excess surface water in conjunction with groundwater through construction of small dams. 12 potential sites for small dams have been proposed in Gedarif and Adegrat areas.

8. Also the potentiality map for managed aquifer recharge (MAR) showed that there is high potential for increasing groundwater recharge. Various artificial recharge techniques are available that could be utilized for this purpose.

9. In summary, the Gedarif Adegrat aquifer still has great potentials for development. In view of the high population growth and frequent occurrence of droughts, conjunctive use of surface and groundwater is expected to play greater role in meeting the future demand for water.

10. One of the great challenges that are facing proper management of the aquifer is lack of information due to absence of monitoring. Therefore there is a need for the eestablishment of a monitoring system with focus on trans-boundary monitoring as well as groundwater data and information exchange platform between Sudan and Ethiopia at national and local levels. There is also a need for introducing adequate administrative institutions for data collection and information dissemination.

10. Annex

Table 11: Water Balance for Adegrat for SC1 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	0.9	7.3	2.9	-10.1
June	14.8	1.0	0.9	7.2	2.8	4.9
July	59.1	1.0	0.9	9.5	2.9	46.9
August	53.4	1.0	0.9	9.8	2.9	40.8
September	6.8	1.0	0.9	7.9	2.8	-3.8
October - April	0.0	6.9	6.1	50.5	19.8	-69.5
Total	134.1	11.9	10.6	92.2	34.1	9.1

Table 12: Water Balance for Adegrat for SC2 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	0.9	7.1	2.9	-9.9
June	13.3	0.9	0.9	7.0	2.8	3.6
July	53.2	1.0	0.9	8.8	2.9	41.6
August	48.1	1.0	0.9	9.1	2.9	36.1
September	6.1	1.0	0.9	7.6	2.8	-4.2
October - April	0.0	6.7	6.1	49.1	19.7	-68.2
Total	120.7	11.5	10.6	88.8	33.9	-1.0

Table 13: Water Balance for Adegrat for SC3 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	2.3	7.1	2.9	-11.3
June	14.8	1.0	2.3	7.0	2.8	3.7
July	59.1	1.0	2.3	9.1	2.9	45.8
August	53.4	1.0	2.3	9.5	2.9	39.7
September	6.8	1.0	2.3	7.6	2.8	-5.0
October – April	0.0	6.8	15.9	49.0	19.7	-77.8
Total	134.1	11.7	27.4	89.3	33.9	-4.9

Table 14: Water Balance for Adegrat for SC4 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Gadarif	Wells	Drains	To Gadarif	
May	0.0	1.0	2.3	6.9	2.9	-11.2
June	13.3	0.9	2.3	6.8	2.8	2.4
July	53.2	1.0	2.3	8.5	2.9	40.5
August	48.1	1.0	2.3	8.8	2.9	35.0
September	6.1	0.9	2.3	7.4	2.8	-5.4
October – April	0.0	6.6	15.9	47.7	19.6	-76.6
Total	120.7	11.3	27.4	86.1	33.7	-15.2

Table 15: Water Balance for Gadarif for SC1 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	1.1	4.2	1.0	-3.4
June	0.9	2.8	1.0	4.0	1.0	-2.4
July	14.5	2.9	1.1	4.3	1.0	11.0
August	18.9	2.9	1.1	4.4	1.0	15.4
September	0.8	2.8	1.0	4.1	1.0	-2.5
October – April	0.0	19.8	7.4	28.4	6.9	-22.9
Total	35.1	34.1	12.7	49.3	11.9	-4.7

Table 16: Water Balance for Gadarif for SC2 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	1.1	4.1	1.0	-3.3
June	0.8	2.8	1.0	4.0	0.9	-2.4
July	13.0	2.9	1.1	4.2	1.0	9.6
August	17.0	2.9	1.1	4.3	1.0	13.5
September	0.8	2.8	1.0	4.1	1.0	-2.5
October – April	0.0	19.7	7.4	28.2	6.7	-22.6
Total	31.6	33.9	12.7	49.0	11.5	-7.7

Table 17: Water Balance for Gadarif for SC3 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	2.7	3.9	1.0	-4.7
June	0.9	2.8	2.6	3.8	1.0	-3.6
July	14.5	2.9	2.7	4.0	1.0	9.7
August	18.9	2.9	2.7	4.1	1.0	14.1
September	0.8	2.8	2.6	3.9	1.0	-3.7
October – April	0.0	19.7	18.2	26.5	6.8	-31.8
Total	35.1	33.9	31.3	46.2	11.7	-20.0

Table 18: Water Balance for Gadarif for SC3 at 2050

Months	IN (MCM)		OUT (MCM)			Net (MCM)
	Recharge	From Adigrat	Wells	Drains	To Adigrat	
May	0.0	2.9	2.8	3.9	1.0	-4.8
June	0.8	2.8	2.7	3.8	0.9	-3.8
July	13.0	2.9	2.8	4.0	1.0	8.2
August	17.0	2.9	2.8	4.1	1.0	12.1
September	0.8	2.8	2.7	3.8	0.9	-3.9
October – April	0.0	19.6	19.1	26.5	6.6	-32.6
Total	31.6	33.7	32.9	46.1	11.3	-24.9

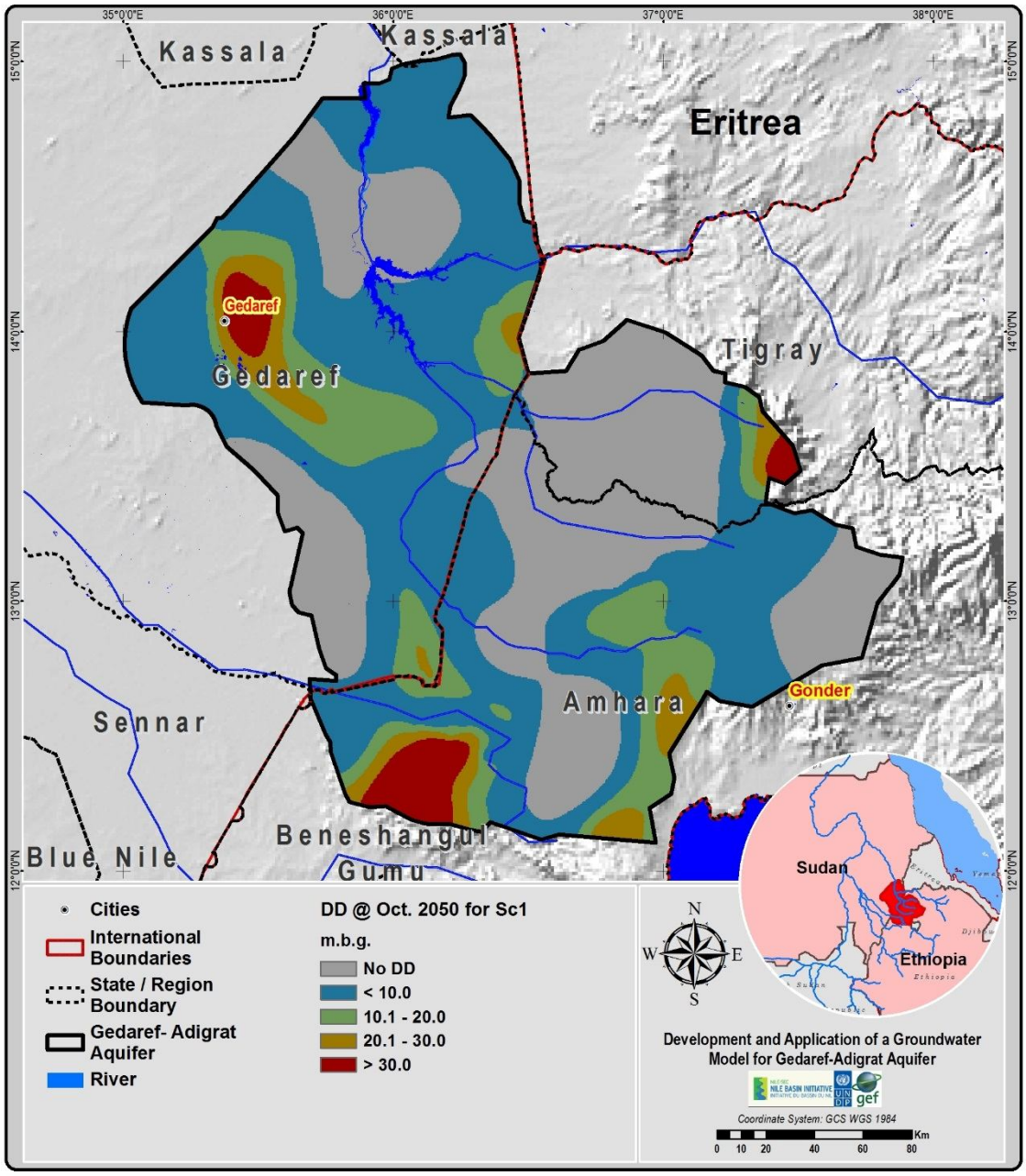


Figure 8: Drawdown for Scenario 1 at 2050

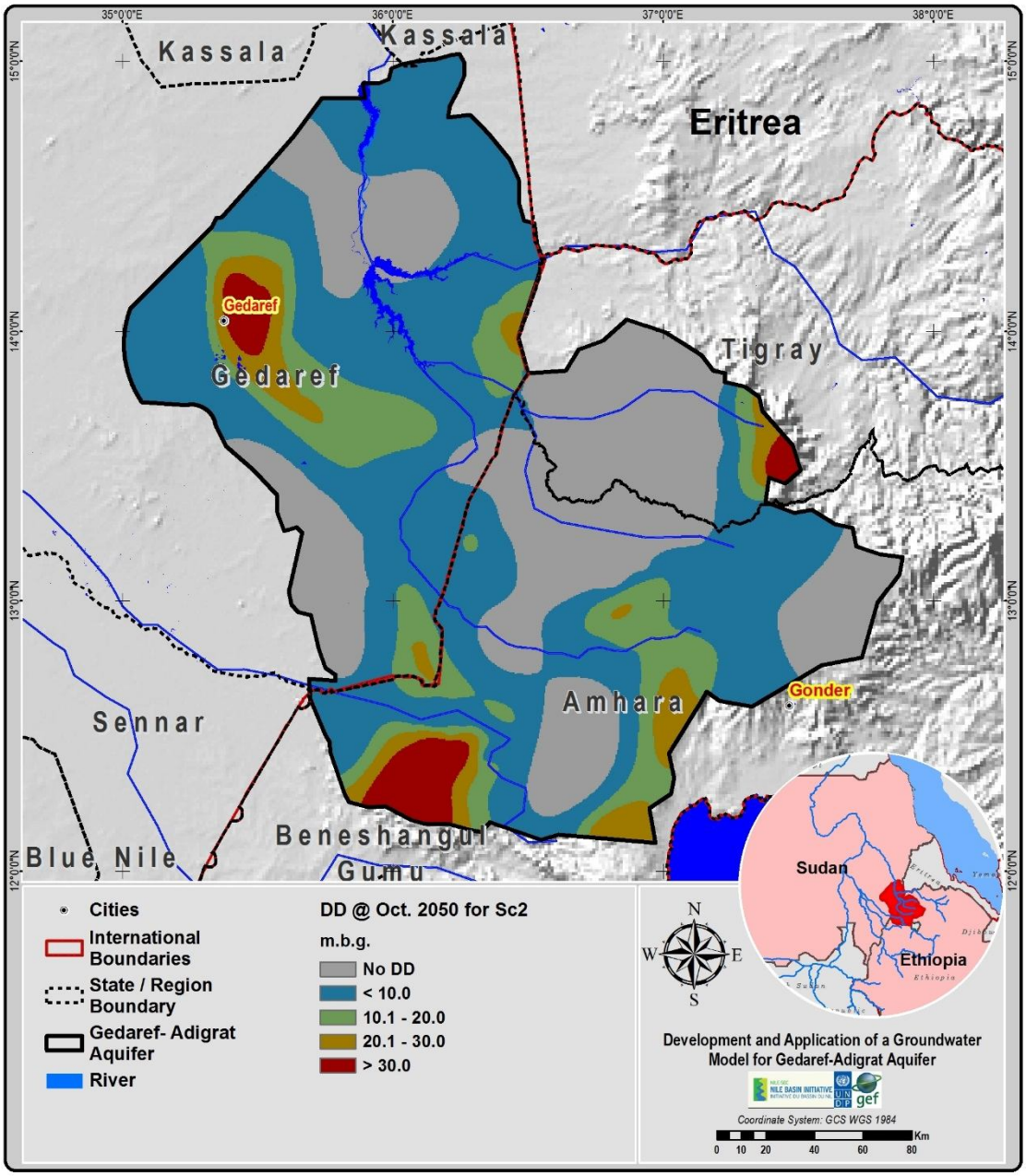


Figure 9: Drawdown for Scenario 2 at 2050

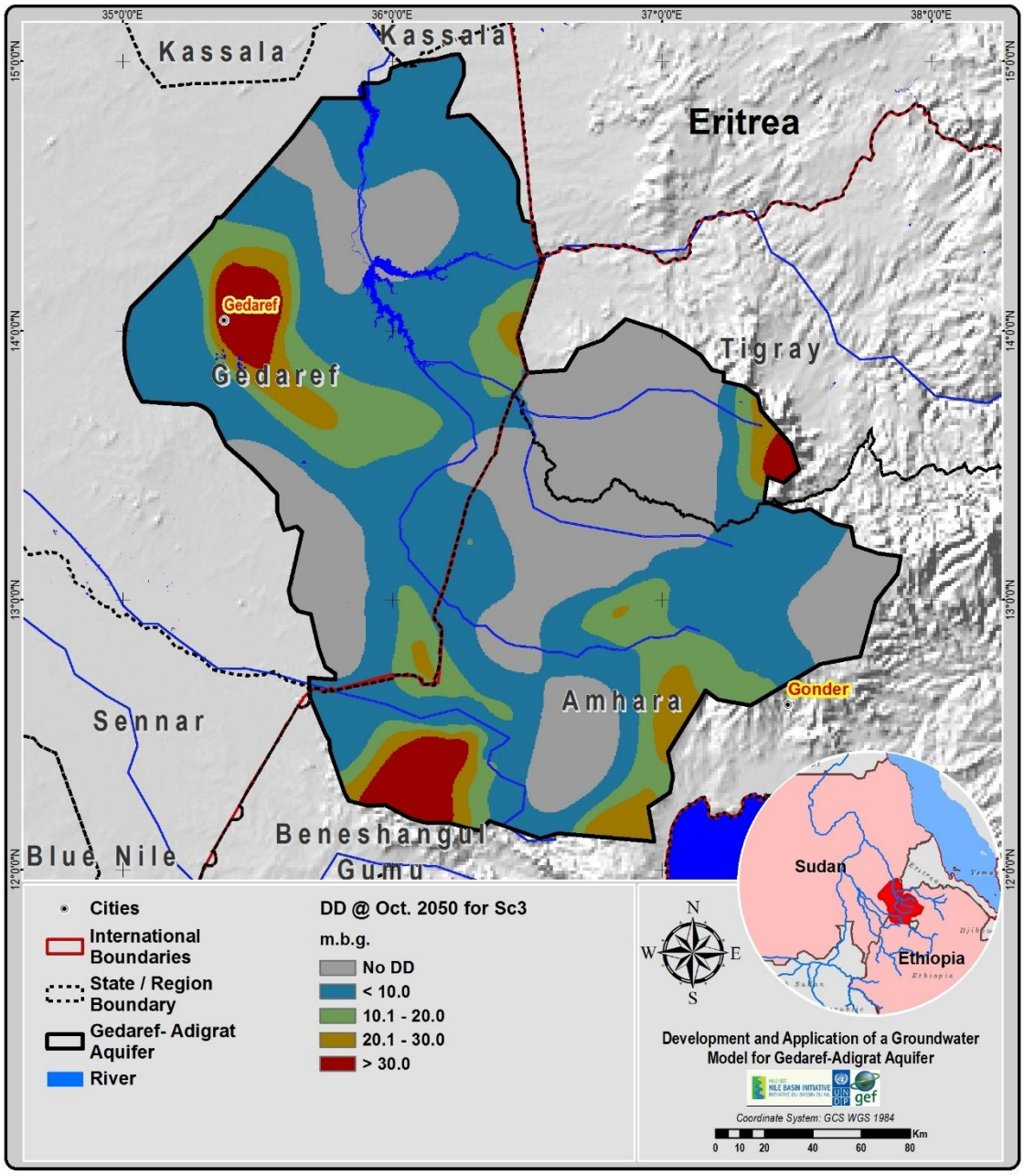


Figure 10: Drawdown for Scenario 3 at 2050

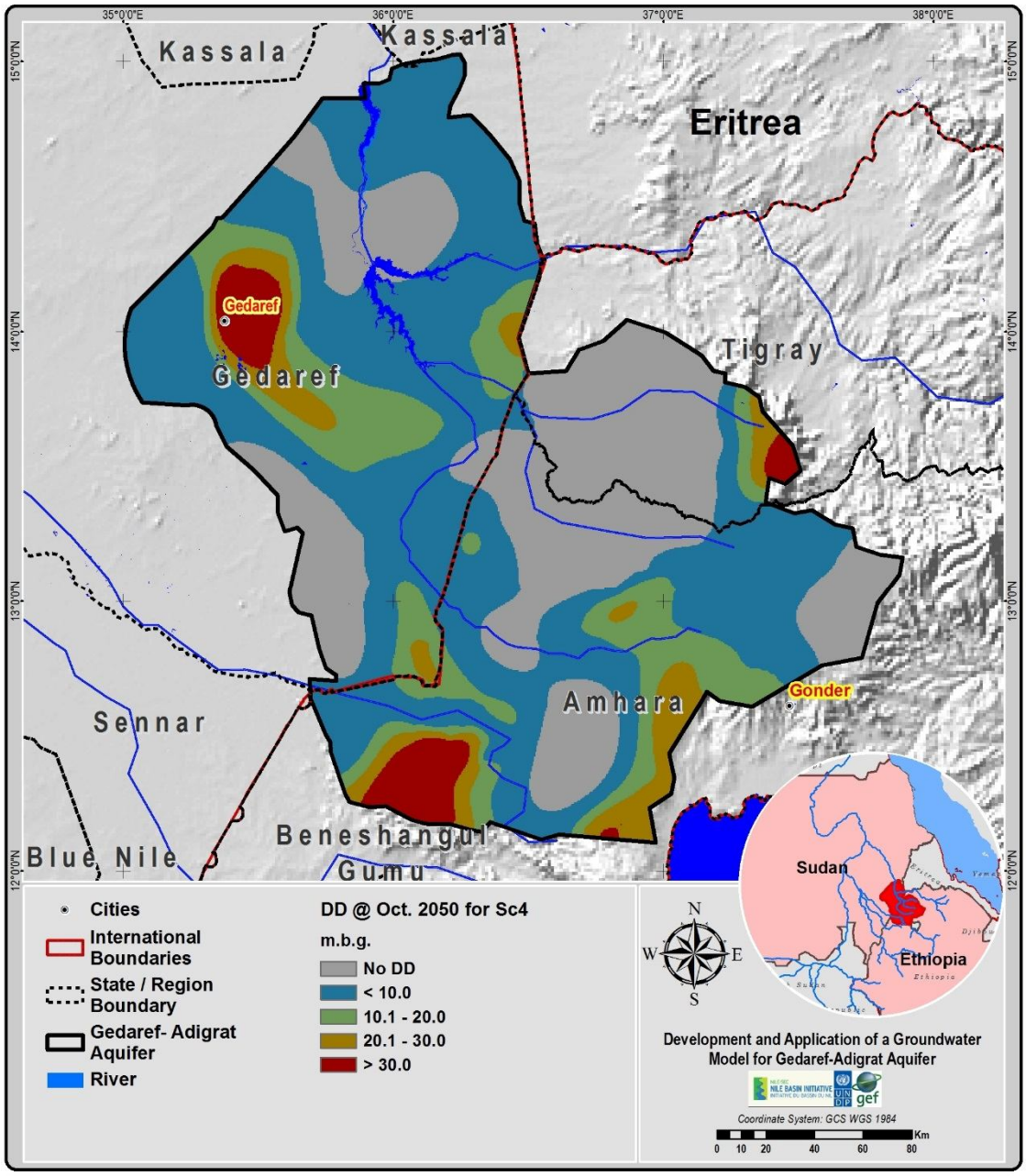


Figure 11: Drawdown for Scenario 4 at 2050