RICCAR

Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR)

Impact of Climate Change on Groundwater Resources in the Dibdibba Aquifer System

جمهورية العراق
وزارة الموارد المائية
Ministry of Water Resources

ACSAD

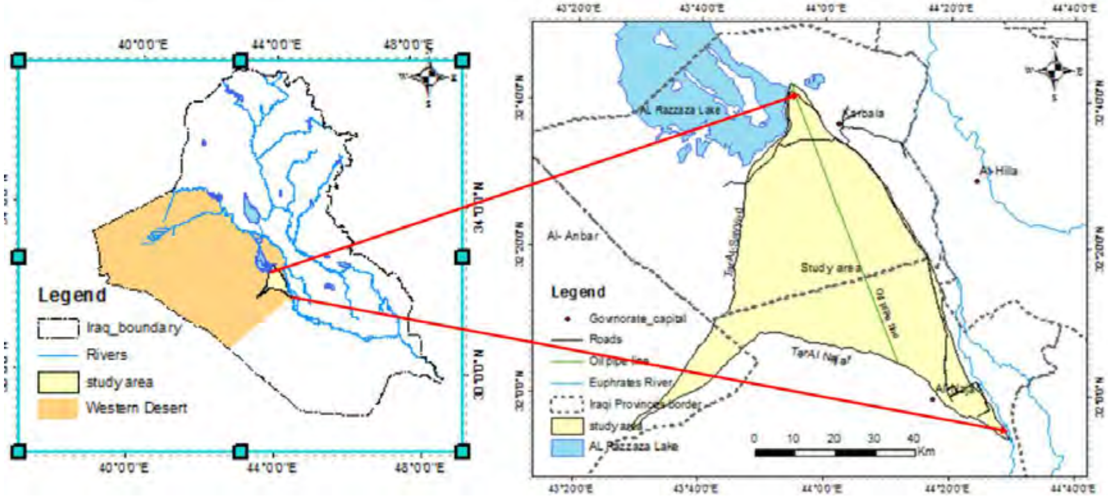
UNITED NATIONS
الاسكوا
ESCWA

Shared Prosperity **Dignified Life**

Impact of Climate Change on Groundwater Resources in the Dibdibba Aquifer System

Location of the study Area

- The Dibdibba Aquifer is located in central Iraq, between Karbala and Najaf cities – between (31 55’–32 45’) latitude and (43 30’–44 30’) longitude.
- The main area covers about 2700 km^2 , and the Dibdibba area (study area) is about 1100 km^2 .



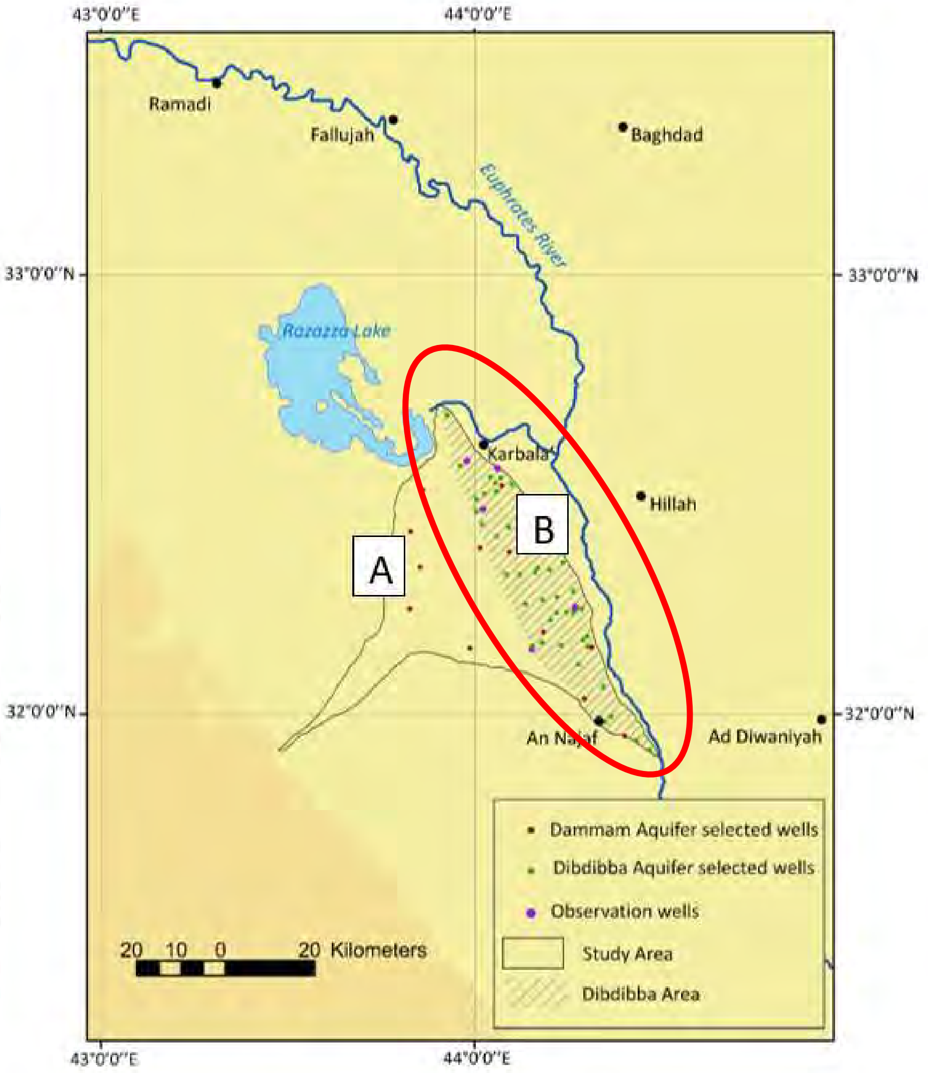
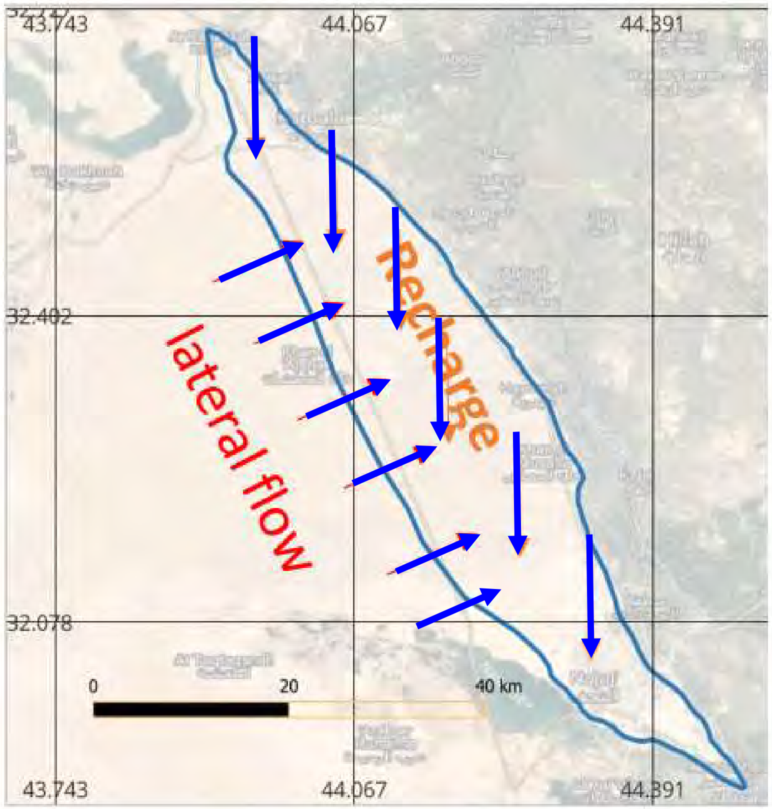


Figure 1- Location of the study area (A – Main area, B- Dibdibba Aquifer)

Inflow

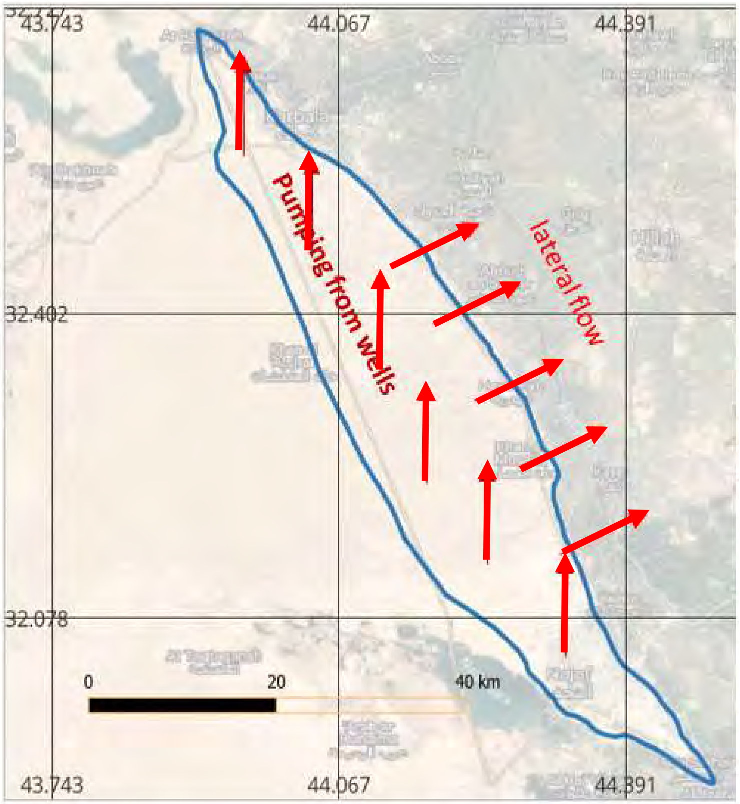
- Recharge from rainfall and irrigation water,
- Lateral flow from the western boundaries.



Inflows to Dibdibba aquifer

Outflow

- Pumping from wells for various purposes,
- Lateral outflow from the eastern boundaries.



Outflows from Dibdibba aquifer

Economic Activities

- The main activity in the study area is agriculture and the main crops are vegetables like cucumber, tomatoes, pepper and beans.
- Crops are irrigated from the top unconfined aquifer(Dibdiba aquifer) , by more than 1,000 pumping wells, distributed along the study area.

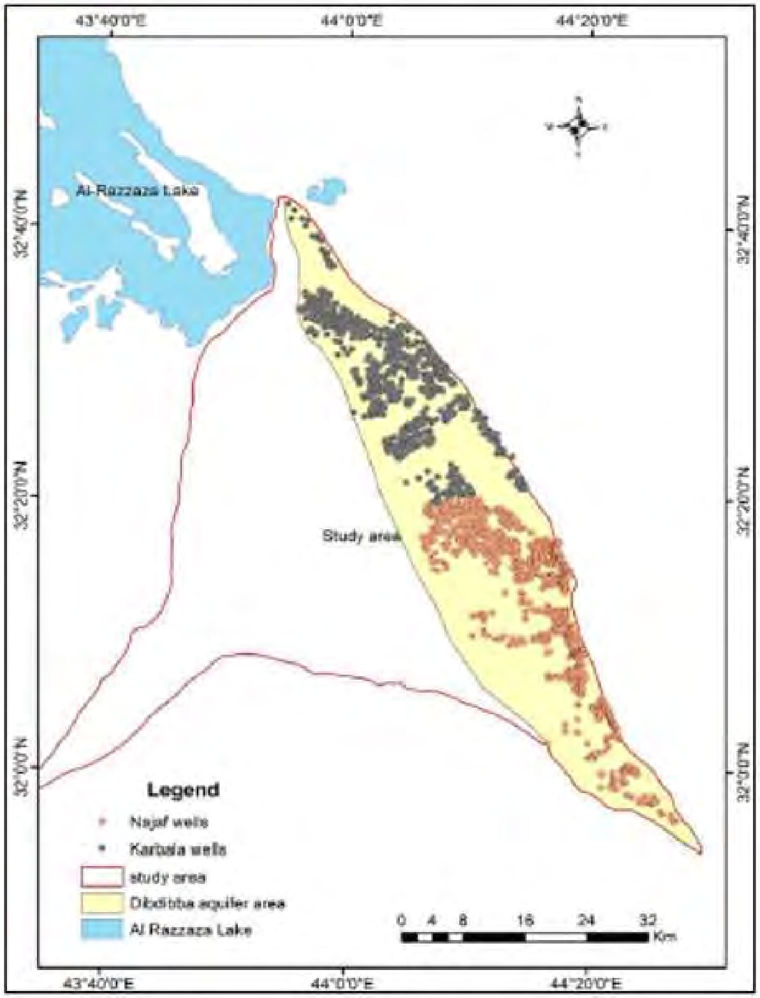
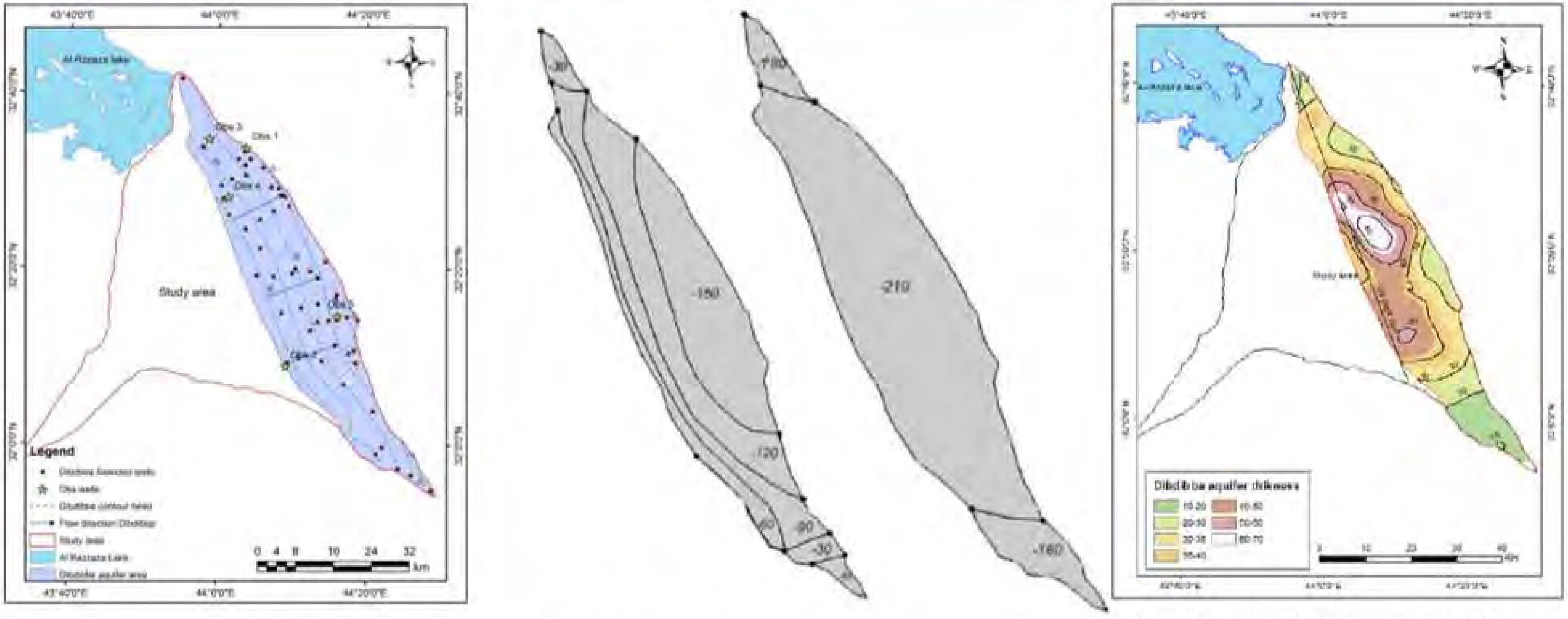


Figure 6 - Pumping wells from groundwater[ix]

Impacts of climate change on groundwater

Dibdibba Groundwater Conceptual model was developed (depending on the basin characteristics and hydraulic parameters (**Aquifer thickness, Heads, Hydraulic conductivity, Recharge, …….),** *Al-Kubaisi, Q.Y., Al-Abadi, A.M., and Al-Ghanimy, M.A. (2018*)



Distribution water head in the study area

Hydraulic conductivity zones

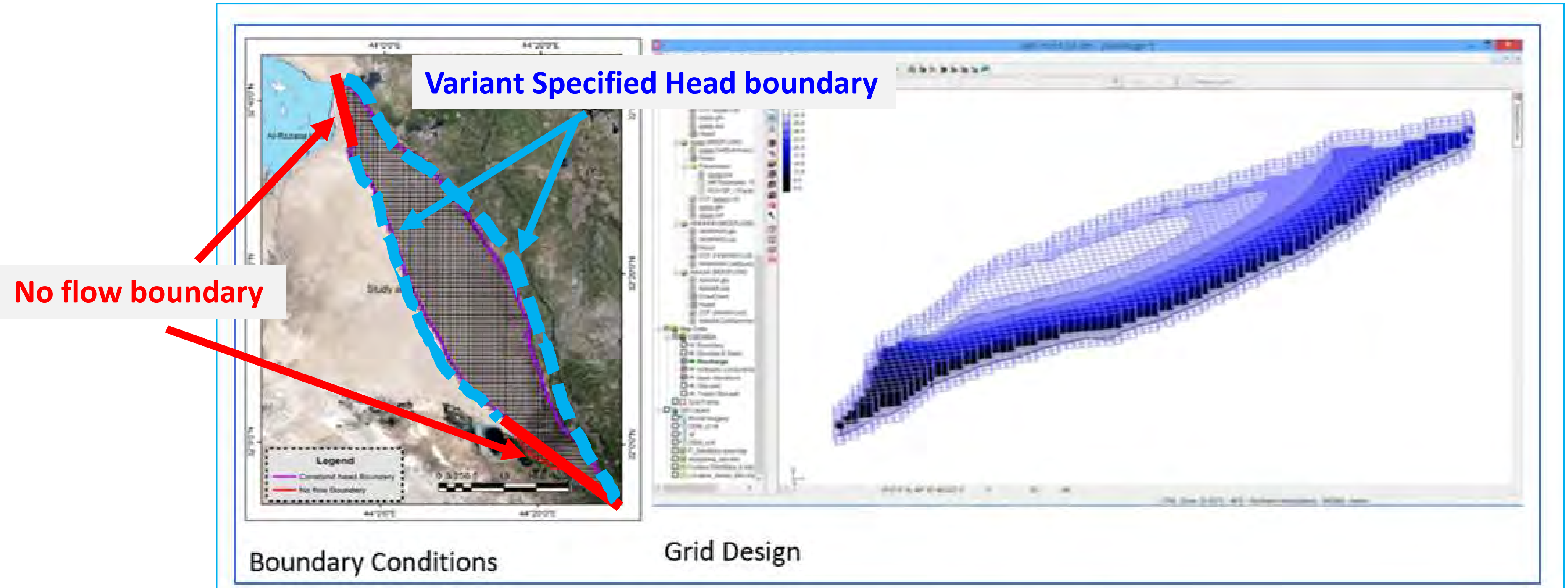
Recharge Zones

Spatial distribution of Dibdibba aquifer thickness in the study area

Figure 21- Conceptual components of the WTF groundwater model

Boundary Conditions & Model Grid

- No flow boundary condition at the north-west and south-east border to represent Tar Alsaid and Tar Alnajaf.
- Variant Specified Head boundary condition was assigned to the eastern and western boundaries.
- The model grid contains 1307 active square cells, with cell dimensions (1000×1000 m)
- The Dibdibba aquifer is the uppermost unconfined aquifer.



Variant Specified Head boundary

No flow boundary

Boundary Conditions

Grid Design

Figure 22 - Groundwater model – Boundary condition and Grid design.

Calibration result for steady state

The mathematical model was run and calibrated for steady state and transient state for the period from 2015 to 2017 using groundwater level measurements.

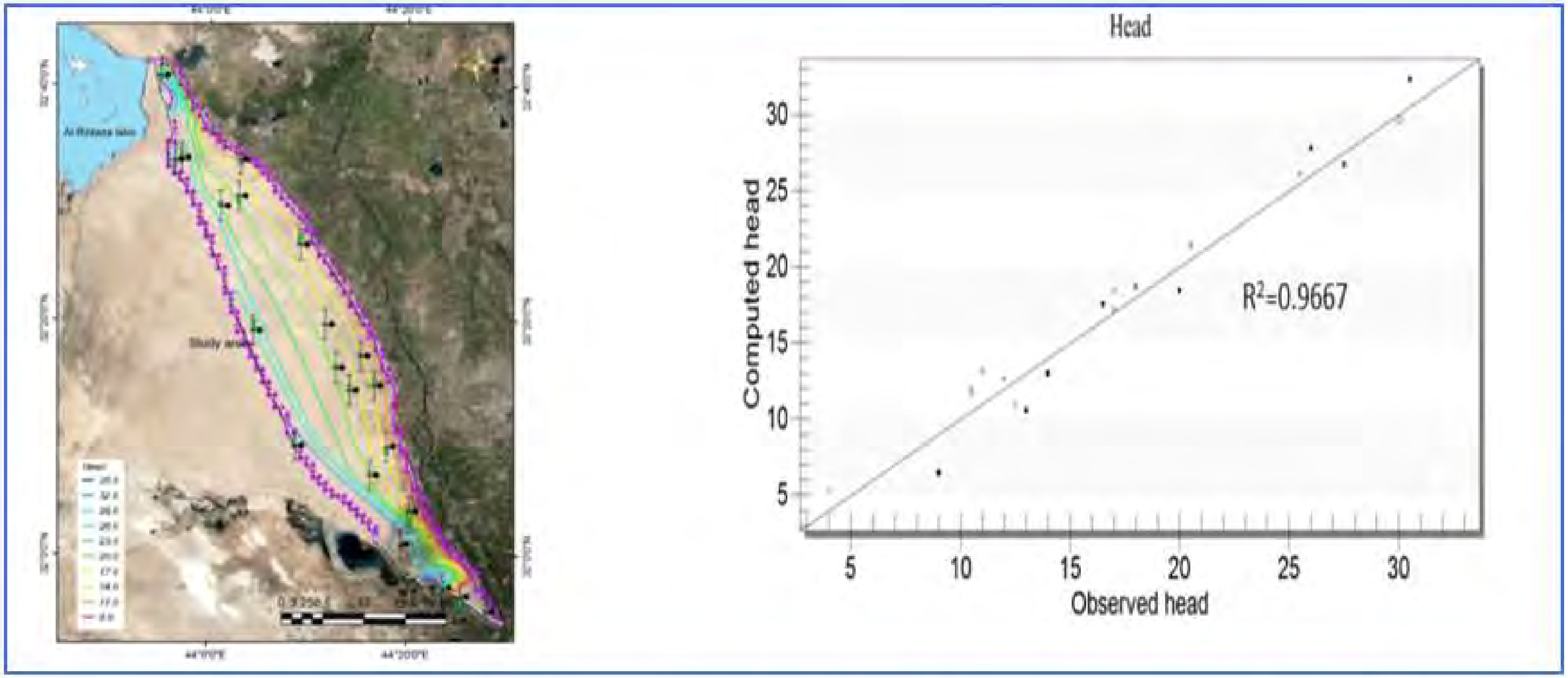


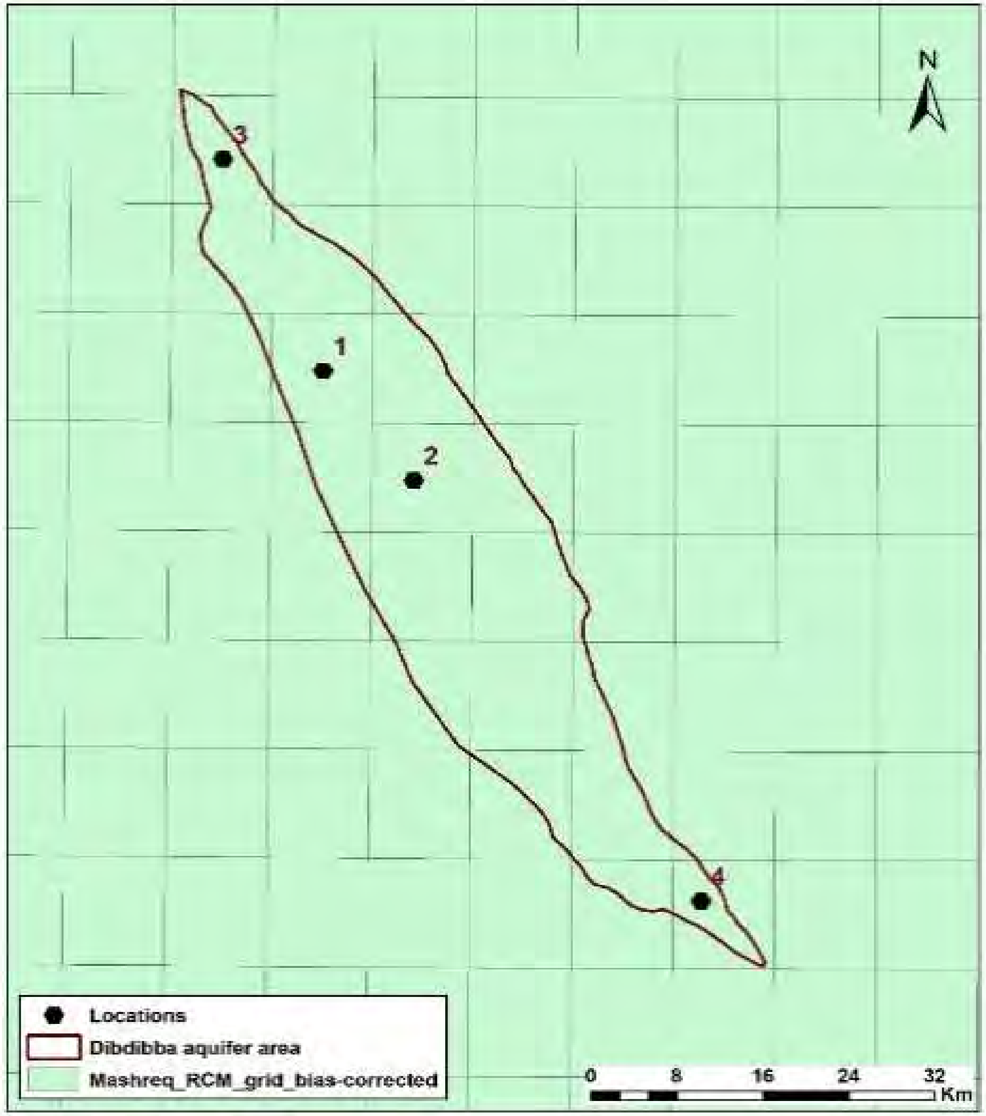
Figure 23 - Groundwater model – Calibration result for steady state.

Projected rainfall data from the six climate models

Time series monthly rainfall data were extracted for the climate models:

- **CMCC-CM2-SR5,**
- **CNRM-ESM2-1,**
- **EC-Earth3-Veg,**
- **MPI-ESM1-2-LR,**
- **MRI-ESM2-0,**
- **NorESM2-MM,**

at four points in the Dibdibba aquifer area.



The projected rainfall data at the four points obtained from the six models, which are used to estimate water level & recharge values in the projection period (2018-2070), to be used as input to the groundwater mathematical model.

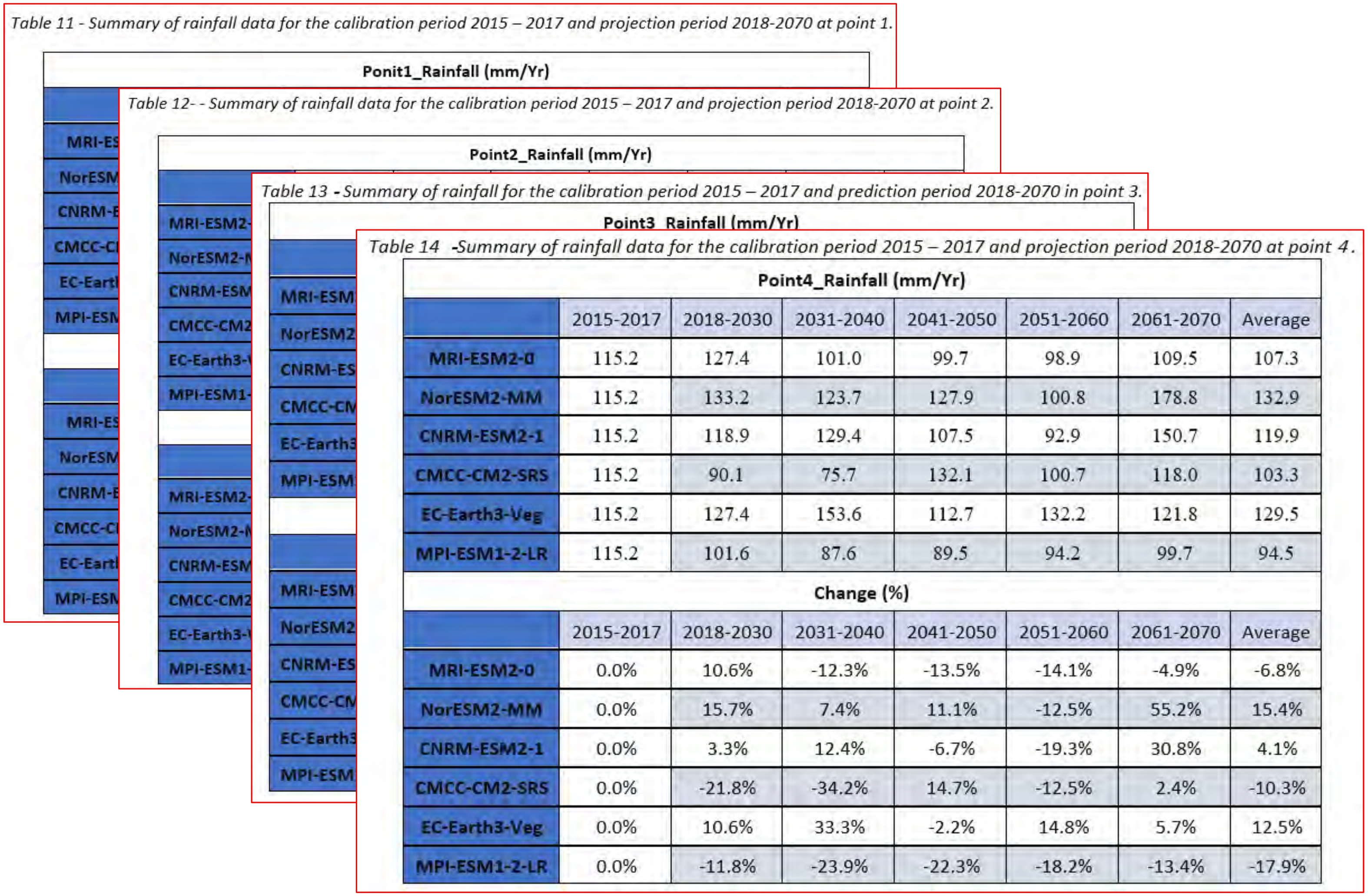


Table 11 - Summary of rainfall data for the calibration period 2015 – 2017 and projection period 2018-2070 at point 1.

Ponit1_Rainfall (mm/Yr)

Table 12- - Summary of rainfall data for the calibration period 2015 – 2017 and projection period 2018-2070 at point 2.

Point2_Rainfall (mm/Yr)

Table 13 - Summary of rainfall for the calibration period 2015 – 2017 and prediction period 2018-2070 in point 3.

Point3_Rainfall (mm/Yr)

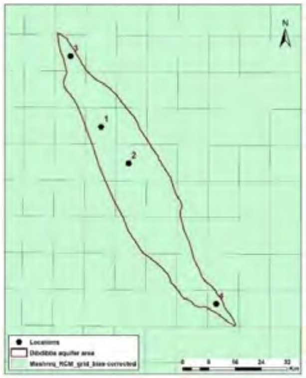
Table 14 -Summary of rainfall data for the calibration period 2015 – 2017 and projection period 2018-2070 at point 4 .

Point4_Rainfall (mm/Yr)

	2015-2017	2018-2030	2031-2040	2041-2050	2051-2060	2061-2070	Average
MRI-ESM2-0	115.2	127.4	101.0	99.7	98.9	109.5	107.3
NorESM2-MM	115.2	133.2	123.7	127.9	100.8	178.8	132.9
CNRM-ESM2-1	115.2	118.9	129.4	107.5	92.9	150.7	119.9
CMCC-CM2-SRS	115.2	90.1	75.7	132.1	100.7	118.0	103.3
EC-Earth3-Veg	115.2	127.4	153.6	112.7	132.2	121.8	129.5
MPI-ESM1-2-LR	115.2	101.6	87.6	89.5	94.2	99.7	94.5

Change (%)

	2015-2017	2018-2030	2031-2040	2041-2050	2051-2060	2061-2070	Average
MRI-ESM2-0	0.0%	10.6%	-12.3%	-13.5%	-14.1%	-4.9%	-6.8%
NorESM2-MM	0.0%	15.7%	7.4%	11.1%	-12.5%	55.2%	15.4%
CNRM-ESM2-1	0.0%	3.3%	12.4%	-6.7%	-19.3%	30.8%	4.1%
CMCC-CM2-SRS	0.0%	-21.8%	-34.2%	14.7%	-12.5%	2.4%	-10.3%
EC-Earth3-Veg	0.0%	10.6%	33.3%	-2.2%	14.8%	5.7%	12.5%
MPI-ESM1-2-LR	0.0%	-11.8%	-23.9%	-22.3%	-18.2%	-13.4%	-17.9%



Estimation of water level changes for prediction period during rainy months

A regression relationship was derived between rainfall and groundwater level change during rainy months using the monthly rainfall (*available data*) and groundwater level change during the period 2010 – 2017.

Table 9 -Values of rainfall and corresponding groundwater level changes during the period 2010 – 2017.

Year	month	Rainfall (mm)	Δh*(m)	year	month	Rainfall (mm)	Δh*(m)
2010	FEB.	26.1	0.03	2014	FEB.	2.7	0.05
2010	MAR.	25.9	0.03	2014	MAR.	27.1	0.05
2010	APR.	13	0.04	2014	APR.	14	0.15
2010	DEC.	4.9	0.1	2014	OCT.	11.5	0.3
2011	JAN.	31.3	0.1	2014	NOV.	9.6	0.3
2011	FEB.	27.5	0.1	2014	DEC.	3	0.5
2011	APR.	18.1	0.1	2015	FEB.	3.2	0.05
2011	MAY.	1.7	0.1	2015	MAR.	28.3	0.05
2011	OCT.	3	0.3	2015	OCT.	19.5	0.2
2011	DEC.	3.2	0.25	2015	NOV.	32	0.1
2012	FEB.	8.406	0.22	2015	DEC.	32.4	0.1
2012	MAR.	0.903	0.1	2016	JAN.	3.8	0.4
2012	APR.	-	-	2016	FEB.	30.3	0.4
2012	MAY.	2.5	0.1	2016	DEC.	28.4	0.3
2012	OCT.	0.001	0.04	2017	FEB.	4.6	0.2
2012	NOV.	19.5	0.02	2017	MAR.	16.8	0.2
2012	DEC.	44.9	0.02	2017	APR.	11.2	0.1
2013	JAN.	48.9	0.13				
2013	FEB.	2.3	0.1				
2013	MAR.	0.001	0.05				
2013	NOV.	119.3	0.4				
2013	DEC.	2.7	0.15				

- All values are positive because they were taken in rainy season to reflect the recharge process.

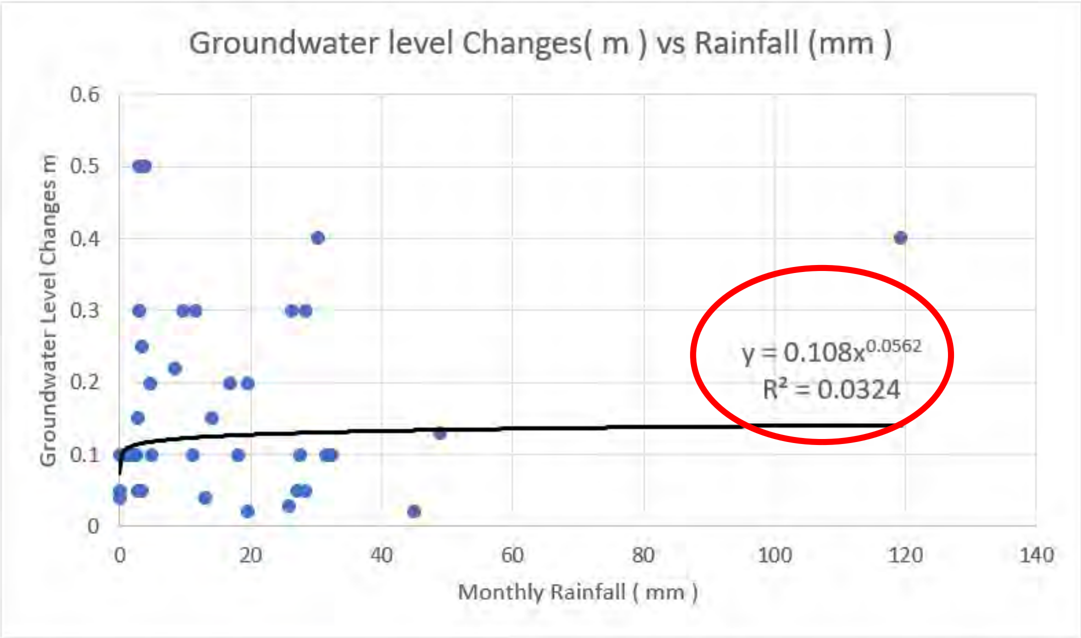
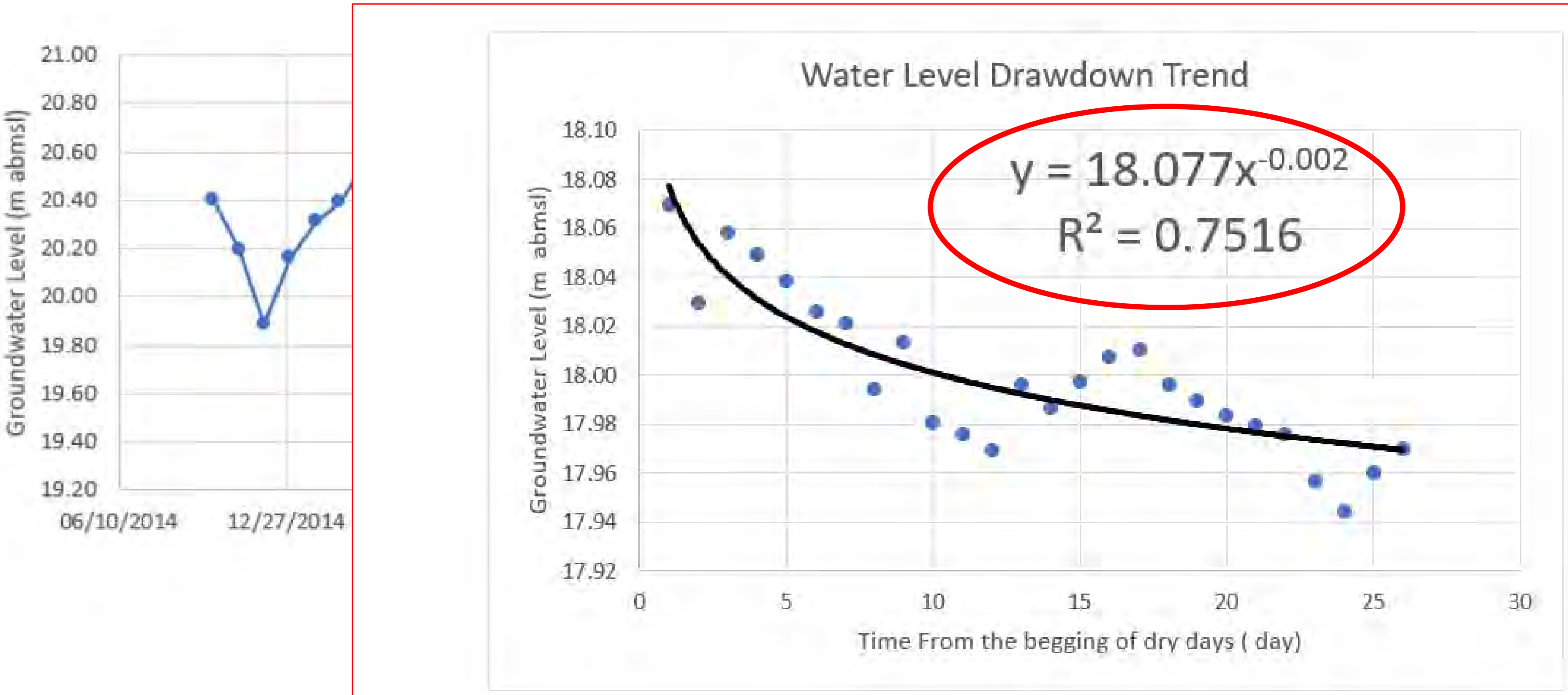


Figure 24 Empirical equation for the change in the groundwater level in relation to monthly rainfall

Estimation of water level changes for prediction period during dry months

An equation was derived using the groundwater level change in a monitoring well



B

Figure 25 - Finding an empirical equation for the drawdown in the groundwater level during dry months – A) groundwater level fluctuation during the entire measurement period, B) groundwater level fluctuation during dry period only

Calculated Water level values

for time variant head at the boundary condition for the projection period (2018 - 2070) according to the mentioned climate models.

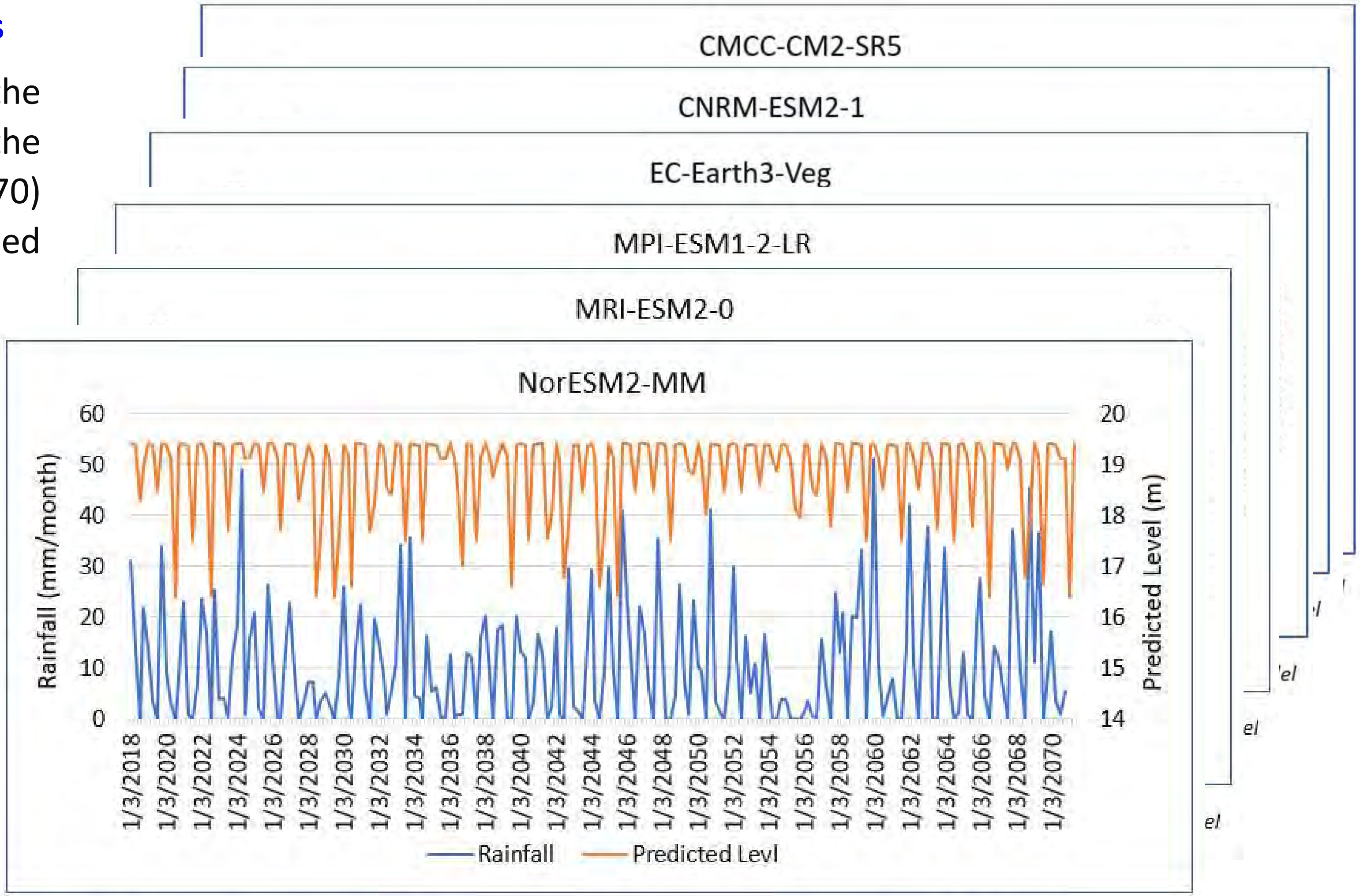


Figure 31 - Projected Time-Variant Specified-Head boundary condition using projected rainfall values from the climate model (NorESM2-MM)

Estimation of groundwater recharge for the projection period (2018-2070)

An empirical equation was derived between recharge and rainfall, by using the calculated value of recharge from measured rainfall value during the period 2014 – 2017.

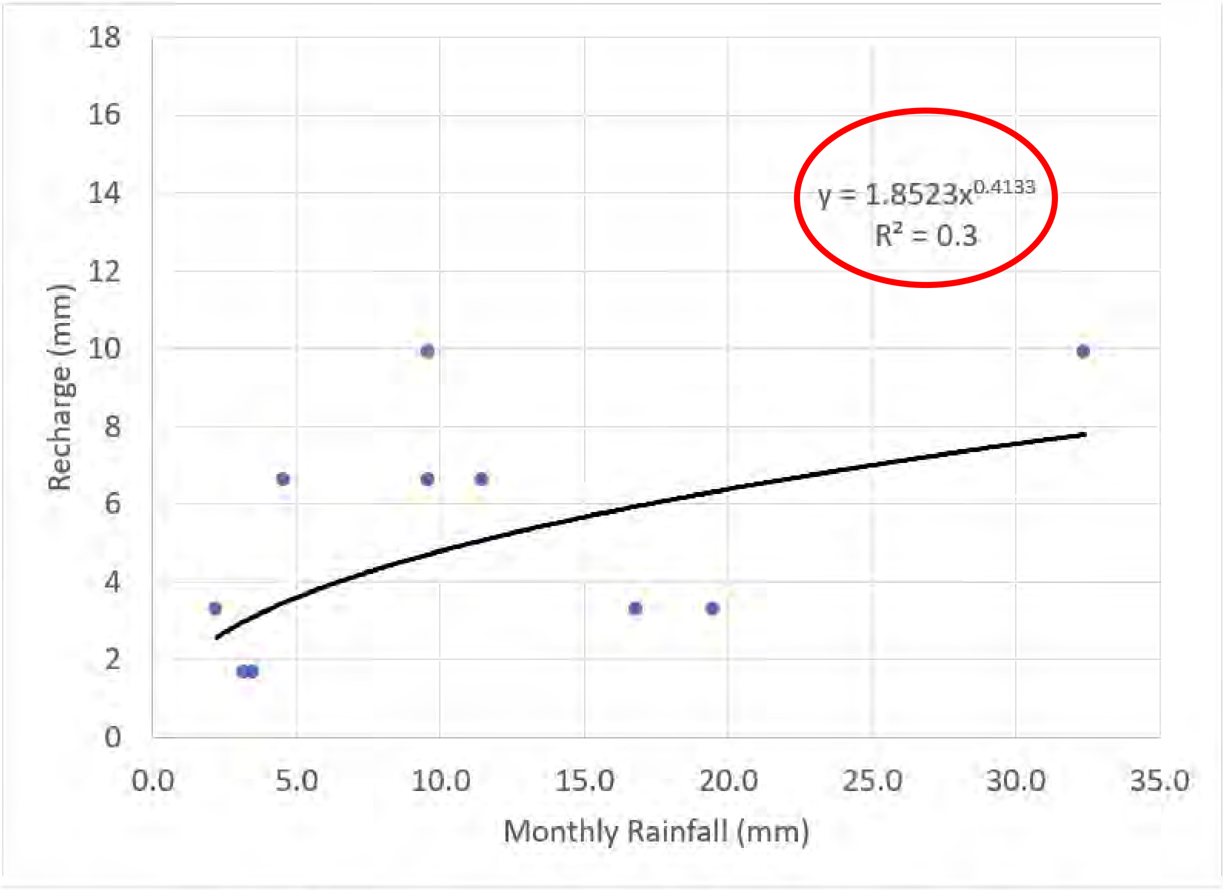


Figure 32- Relation between groundwater recharge and monthly rainfall.

Table 10 -Value *ical equation after*

YEAR
2014
2014
2015
2015
2015
2015
2016
2017
2017
2017

Estimated groundwater recharge associated with the projected rainfall data from the climate models. The calculated recharge values were used as inputs to the groundwater model. Figures (33 -38) show an average recharge for middle zone as example.

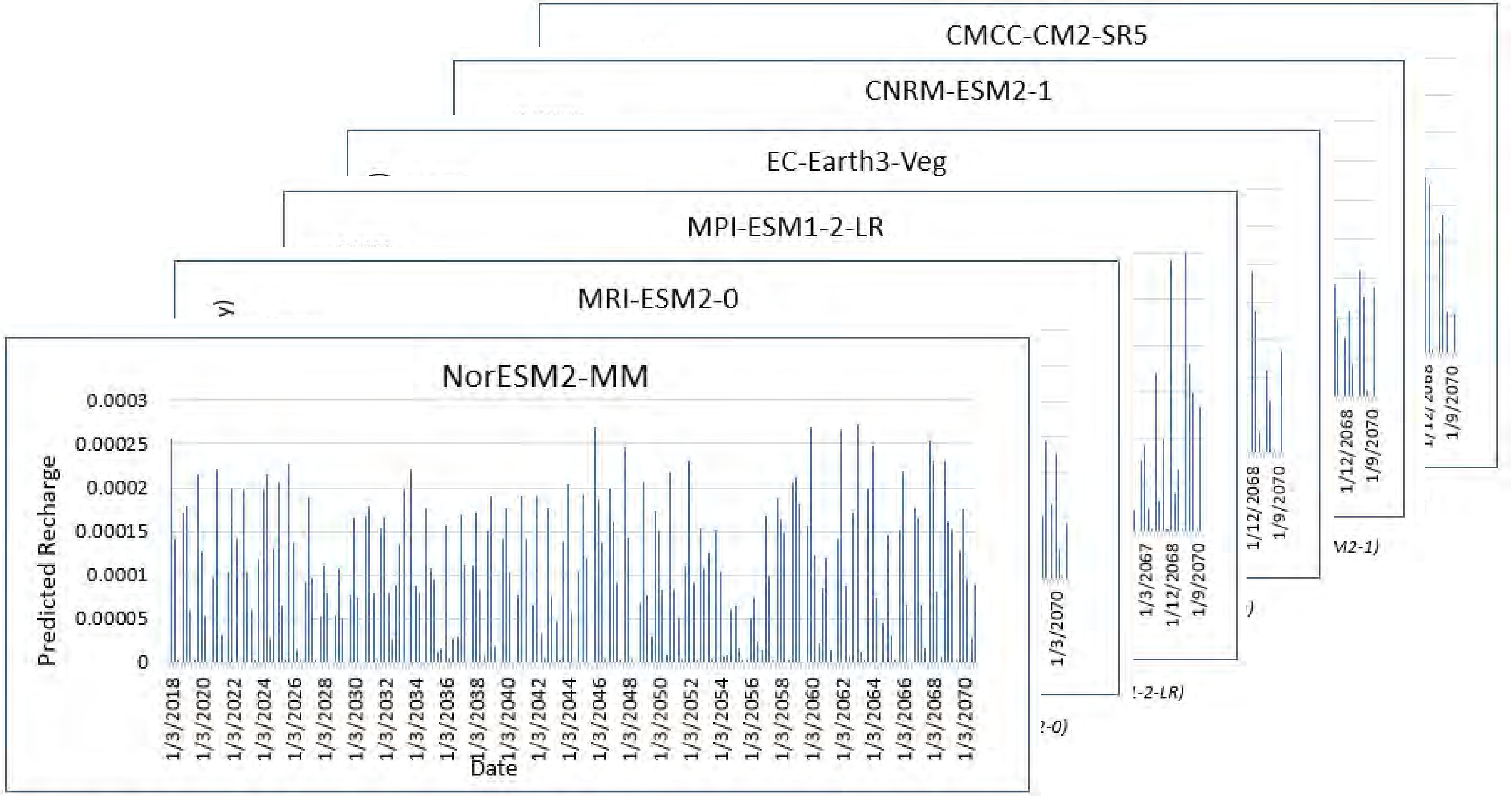


Figure 38 - Groundwater recharge values using projected rainfall data from climate model (NorESM2-MM)

Results of groundwater mathematical model running under the different mentioned climate models

The results of the groundwater model will be presented as following:

1. **Groundwater level changes** at four points distributed over the model area to reflect changes in various parts of the area. *As an example, a detailed output will be presented for climate model CMCC-CM2-SR5 and only summaries will be presented for the other five climate models.*
2. **Groundwater level maps** at the beginning(2019), middle(2044) and end (2070) of the simulation period,
3. **Summary of the groundwater budget** including: changes in groundwater recharge, groundwater storage and lateral groundwater flow.
4. **Summary of groundwater level drawdown** **(**2018 – 2070).

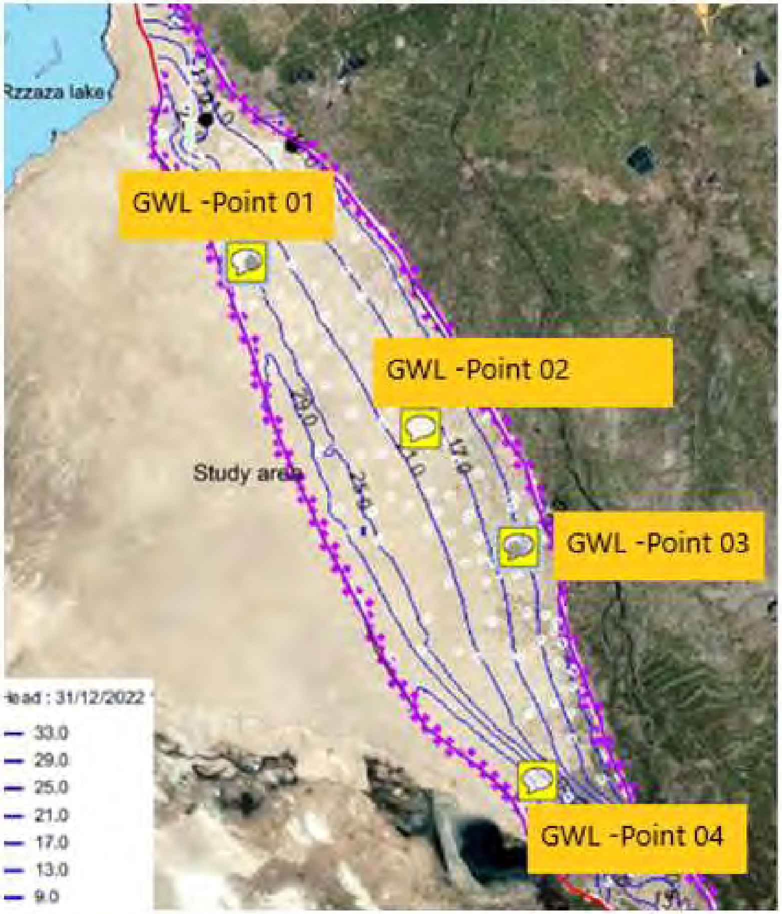


Figure 40- Location of the four points of which results of groundwater model will be presented.

Results based on climate Model CMCC-CM2-SR5

The **groundwater level** at point 1 -4 during the period 2018 to 2070.

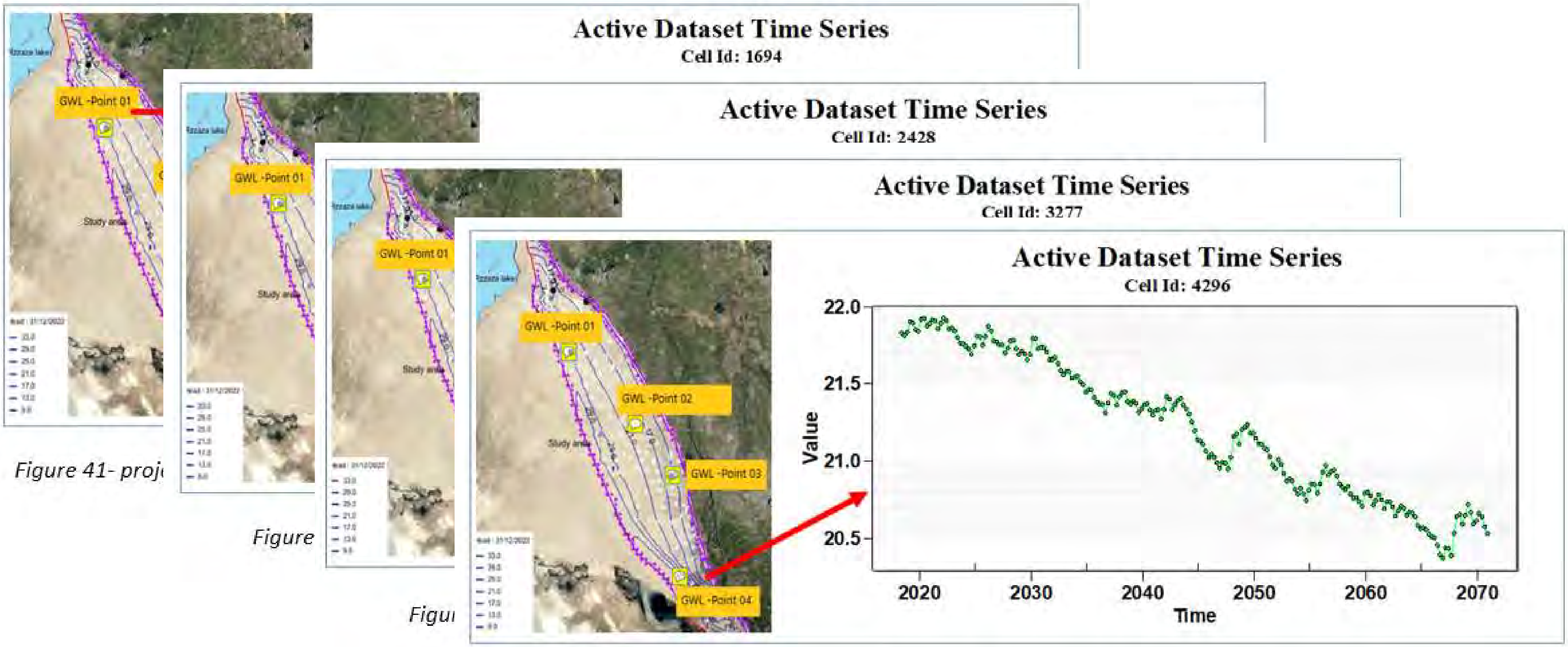


Figure 44- projected groundwater level (m) at point 4 during the period 2018 to 2070 based on the output from climate model CMCC-CM2-SR5

Groundwater level maps at years 2019, 2044 and 2070 based on the output of climatic **model CMCC-CM2-SR5**. These maps indicate apparent dry cells at the northern and southern boundaries of the study area. This is due to the small thickness of the aquifer at these areas and the effect of nearby no flow boundaries. The groundwater level maps show a drop in the groundwater level in the eastern part of the region as time proceed.

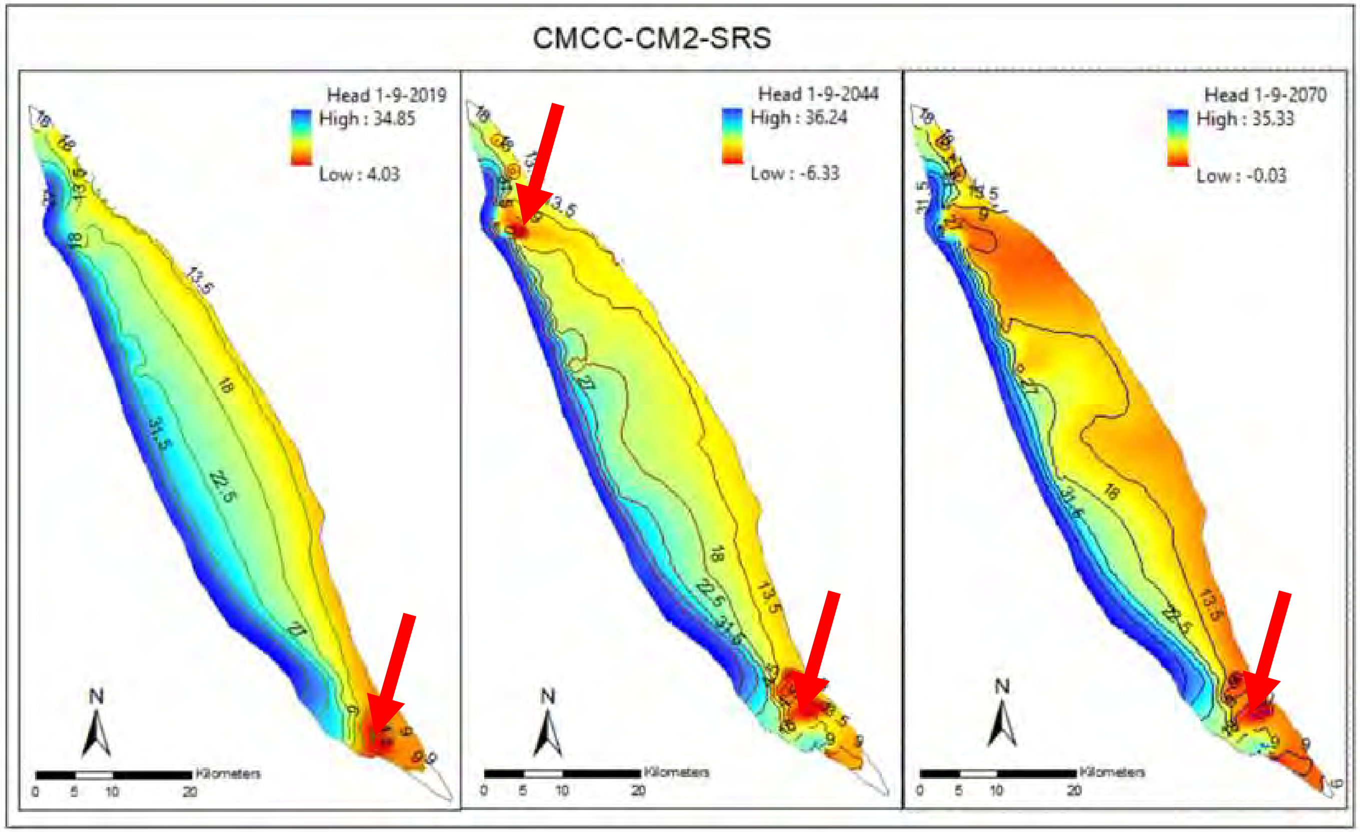
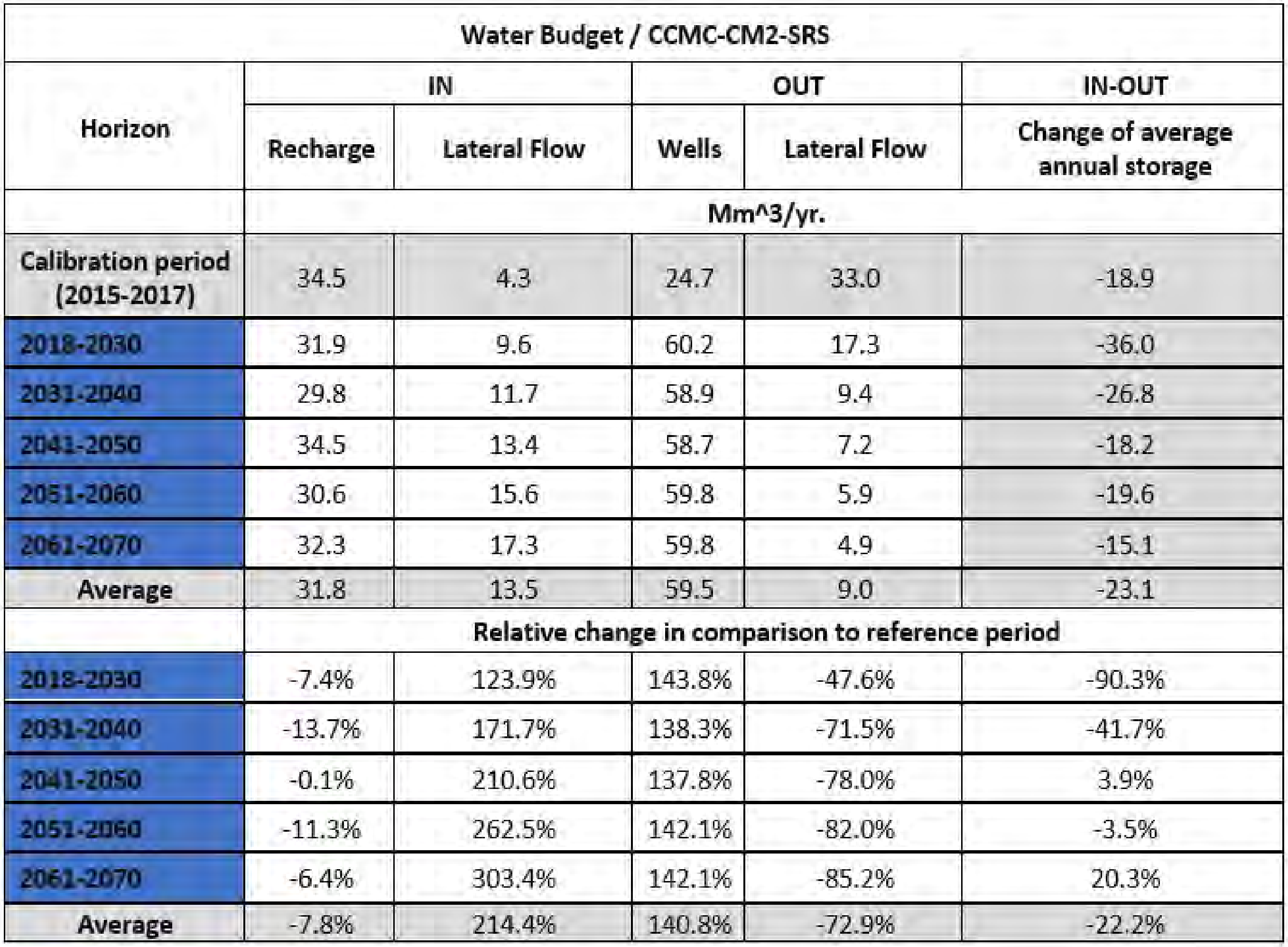


Figure 45- Groundwater level map at years 2019,2044 and 2070 based on the output of climatic model CMCC-CM2-SR5

Summary of the groundwater budget for CMCC-CM2-SR5 climate model.

Table 15- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model CMCC-CM2-SR5



Water Budget / CCMC-CM2-SRS					
Horizon	IN		OUT		IN-OUT
	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33.0	-18.9
2018-2030	31.9	9.6	60.2	17.3	-36.0
2031-2040	29.8	11.7	58.9	9.4	-26.8
2041-2050	34.5	13.4	58.7	7.2	-18.2
2051-2060	30.6	15.6	59.8	5.9	-19.6
2061-2070	32.3	17.3	59.8	4.9	-15.1
Average	31.8	13.5	59.5	9.0	-23.1
	Relative change in comparison to reference period				
2018-2030	-7.4%	123.9%	143.8%	-47.6%	-90.3%
2031-2040	-13.7%	171.7%	138.3%	-71.5%	-41.7%
2041-2050	-0.1%	210.6%	137.8%	-78.0%	3.9%
2051-2060	-11.3%	262.5%	142.1%	-82.0%	-3.5%
2061-2070	-6.4%	303.4%	142.1%	-85.2%	20.3%
Average	-7.8%	214.4%	140.8%	-72.9%	-22.2%

Results for CNRM-ESM2-1 climate Model :

- Groundwater level at distributed points,
- groundwater level Maps,
- Water Budget.

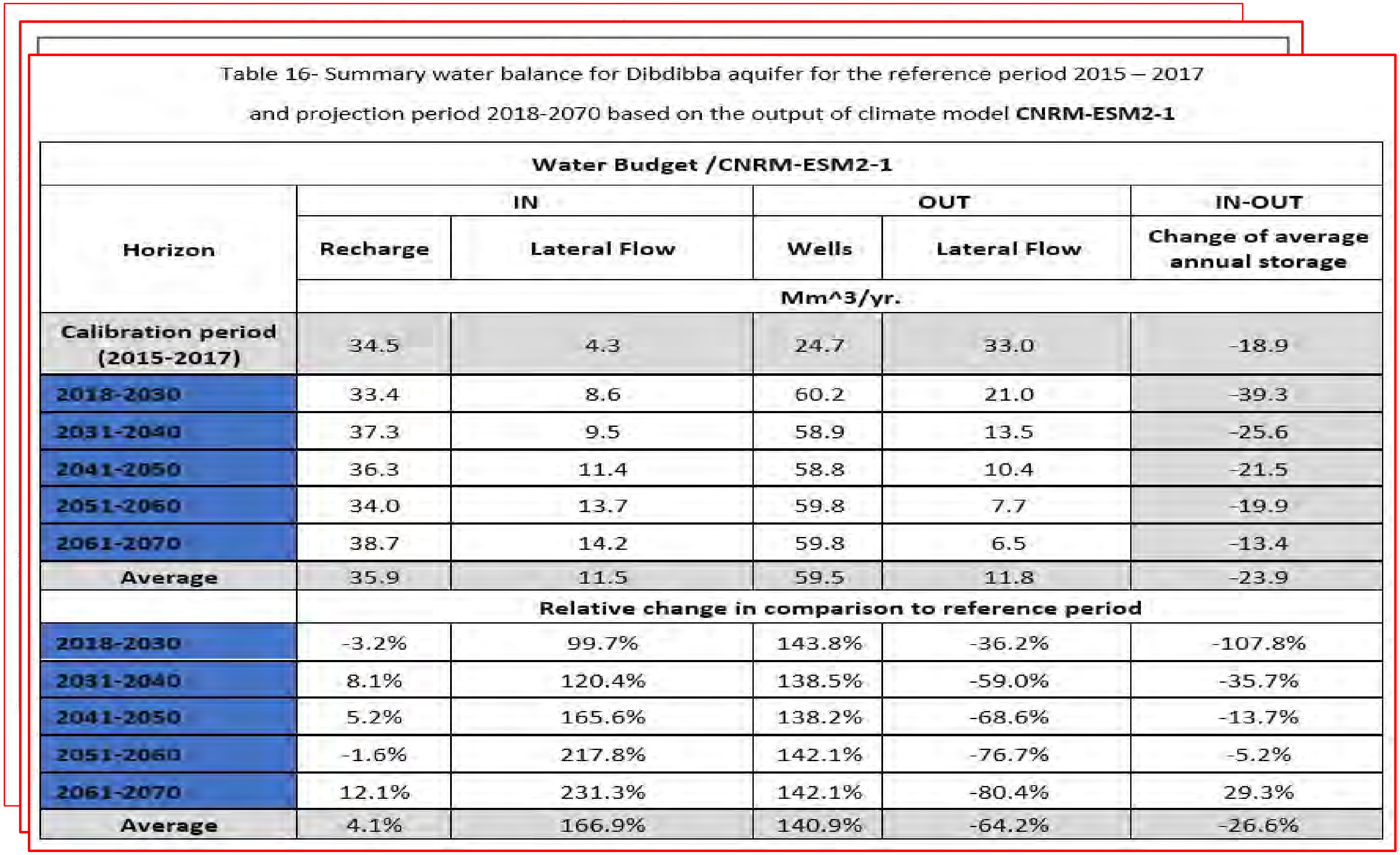


Table 16- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model **CNRM-ESM2-1**

Water Budget /CNRM-ESM2-1					
Horizon	IN		OUT		IN-OUT
	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33.0	-18.9
2018-2030	33.4	8.6	60.2	21.0	-39.3
2031-2040	37.3	9.5	58.9	13.5	-25.6
2041-2050	36.3	11.4	58.8	10.4	-21.5
2051-2060	34.0	13.7	59.8	7.7	-19.9
2061-2070	38.7	14.2	59.8	6.5	-13.4
Average	35.9	11.5	59.5	11.8	-23.9
	Relative change in comparison to reference period				
2018-2030	-3.2%	99.7%	143.8%	-36.2%	-107.8%
2031-2040	8.1%	120.4%	138.5%	-59.0%	-35.7%
2041-2050	5.2%	165.6%	138.2%	-68.6%	-13.7%
2051-2060	-1.6%	217.8%	142.1%	-76.7%	-5.2%
2061-2070	12.1%	231.3%	142.1%	-80.4%	29.3%
Average	4.1%	166.9%	140.9%	-64.2%	-26.6%

- **Results based on EC-Earth3-Veg climate Model**,
- Groundwater level at distributed points,
- groundwater level Maps,
- Water Budget.

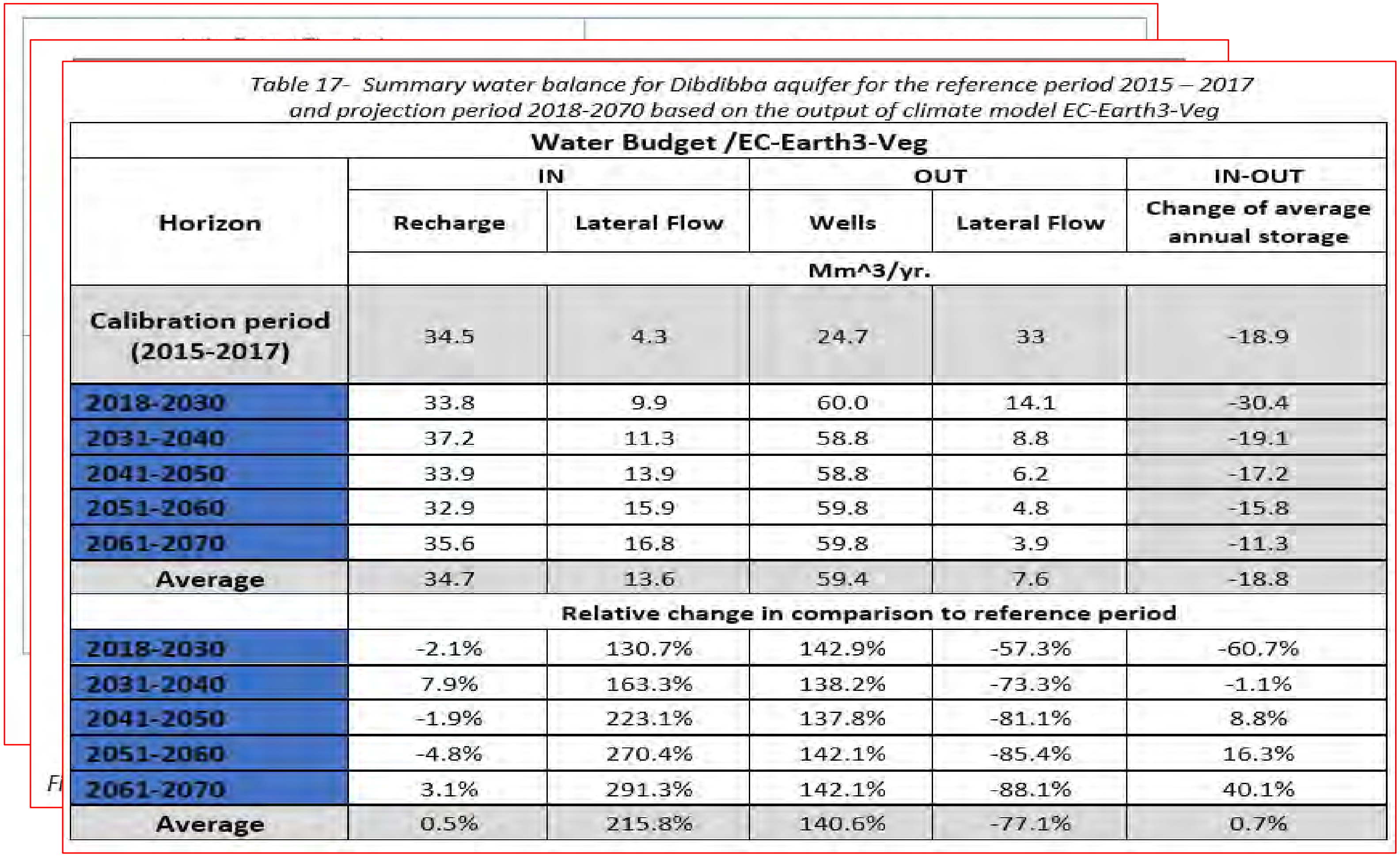


Table 17- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model EC-Earth3-Veg

Water Budget /EC-Earth3-Veg					
	IN		OUT		IN-OUT
Horizon	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33	-18.9
2018-2030	33.8	9.9	60.0	14.1	-30.4
2031-2040	37.2	11.3	58.8	8.8	-19.1
2041-2050	33.9	13.9	58.8	6.2	-17.2
2051-2060	32.9	15.9	59.8	4.8	-15.8
2061-2070	35.6	16.8	59.8	3.9	-11.3
Average	34.7	13.6	59.4	7.6	-18.8
	Relative change in comparison to reference period				
2018-2030	-2.1%	130.7%	142.9%	-57.3%	-60.7%
2031-2040	7.9%	163.3%	138.2%	-73.3%	-1.1%
2041-2050	-1.9%	223.1%	137.8%	-81.1%	8.8%
2051-2060	-4.8%	270.4%	142.1%	-85.4%	16.3%
2061-2070	3.1%	291.3%	142.1%	-88.1%	40.1%
Average	0.5%	215.8%	140.6%	-77.1%	0.7%

- **Results based on MPI-ESM1-2-LR climate Model**,
- Groundwater level at distributed points
- grou
- Wate

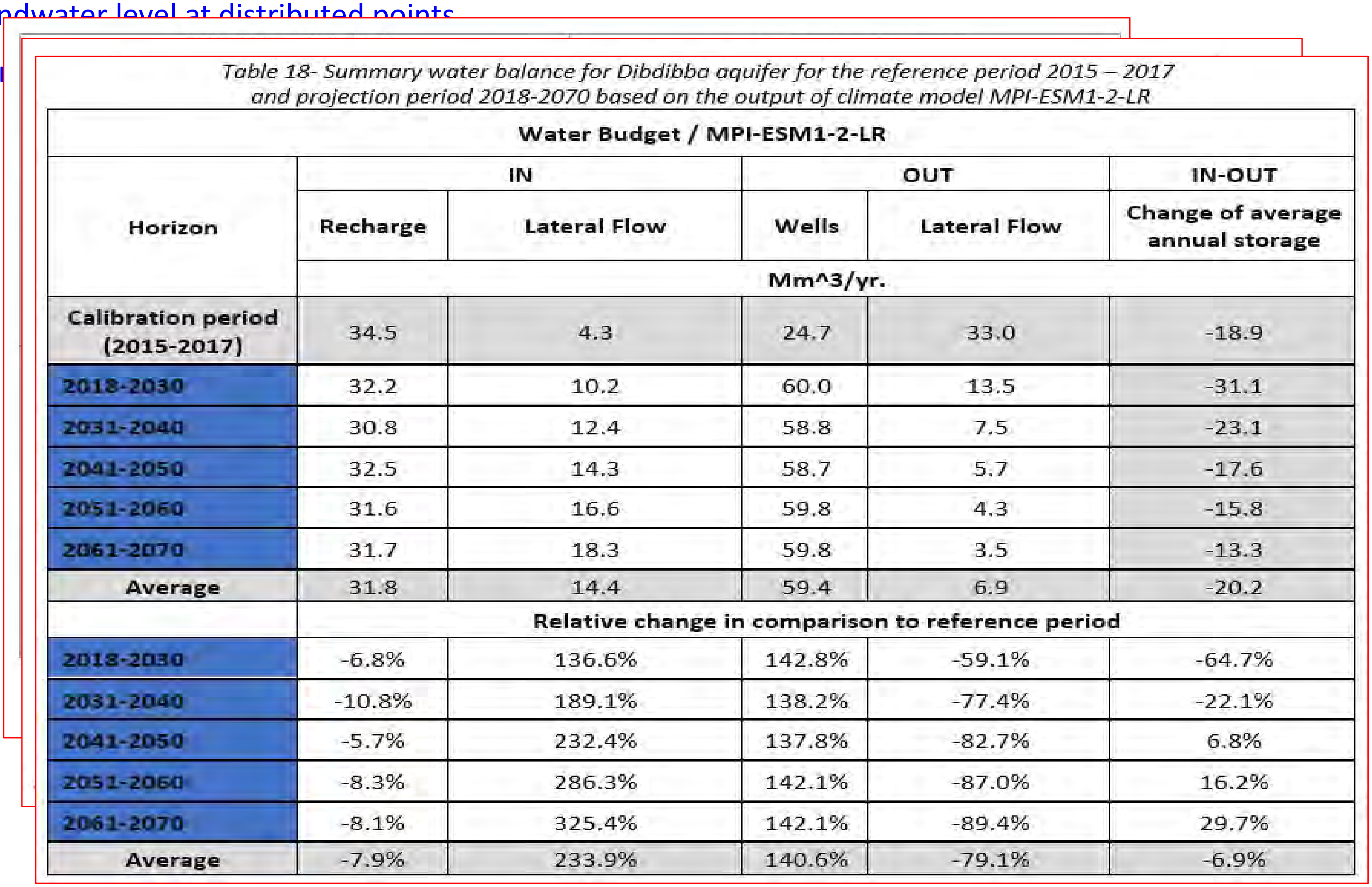


Table 18- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model MPI-ESM1-2-LR

Water Budget / MPI-ESM1-2-LR					
	IN		OUT		IN-OUT
Horizon	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33.0	-18.9
2018-2030	32.2	10.2	60.0	13.5	-31.1
2031-2040	30.8	12.4	58.8	7.5	-23.1
2041-2050	32.5	14.3	58.7	5.7	-17.6
2051-2060	31.6	16.6	59.8	4.3	-15.8
2061-2070	31.7	18.3	59.8	3.5	-13.3
Average	31.8	14.4	59.4	6.9	-20.2
	Relative change in comparison to reference period				
2018-2030	-6.8%	136.6%	142.8%	-59.1%	-64.7%
2031-2040	-10.8%	189.1%	138.2%	-77.4%	-22.1%
2041-2050	-5.7%	232.4%	137.8%	-82.7%	6.8%
2051-2060	-8.3%	286.3%	142.1%	-87.0%	16.2%
2061-2070	-8.1%	325.4%	142.1%	-89.4%	29.7%
Average	-7.9%	233.9%	140.6%	-79.1%	-6.9%

- **Results based on MRI-ESM2-0 climate Model,**

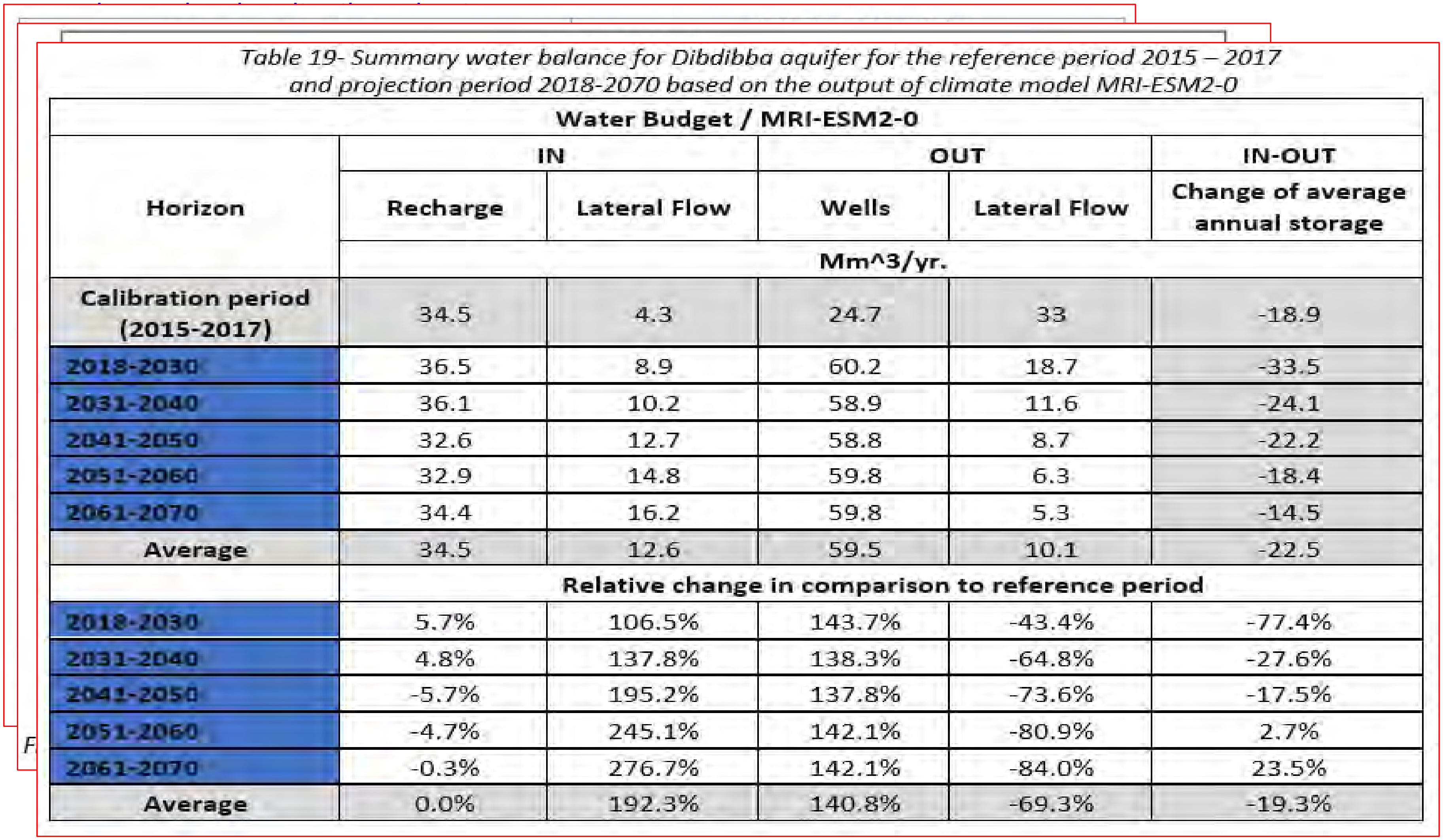


Table 19- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model MRI-ESM2-0

Water Budget / MRI-ESM2-0					
Horizon	IN		OUT		IN-OUT
	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33	-18.9
2018-2030	36.5	8.9	60.2	18.7	-33.5
2031-2040	36.1	10.2	58.9	11.6	-24.1
2041-2050	32.6	12.7	58.8	8.7	-22.2
2051-2060	32.9	14.8	59.8	6.3	-18.4
2061-2070	34.4	16.2	59.8	5.3	-14.5
Average	34.5	12.6	59.5	10.1	-22.5
	Relative change in comparison to reference period				
2018-2030	5.7%	106.5%	143.7%	-43.4%	-77.4%
2031-2040	4.8%	137.8%	138.3%	-64.8%	-27.6%
2041-2050	-5.7%	195.2%	137.8%	-73.6%	-17.5%
2051-2060	-4.7%	245.1%	142.1%	-80.9%	2.7%
2061-2070	-0.3%	276.7%	142.1%	-84.0%	23.5%
Average	0.0%	192.3%	140.8%	-69.3%	-19.3%

- **Results based on NorESM2-MM climate Model,**
- Gr
- gr
- Wa

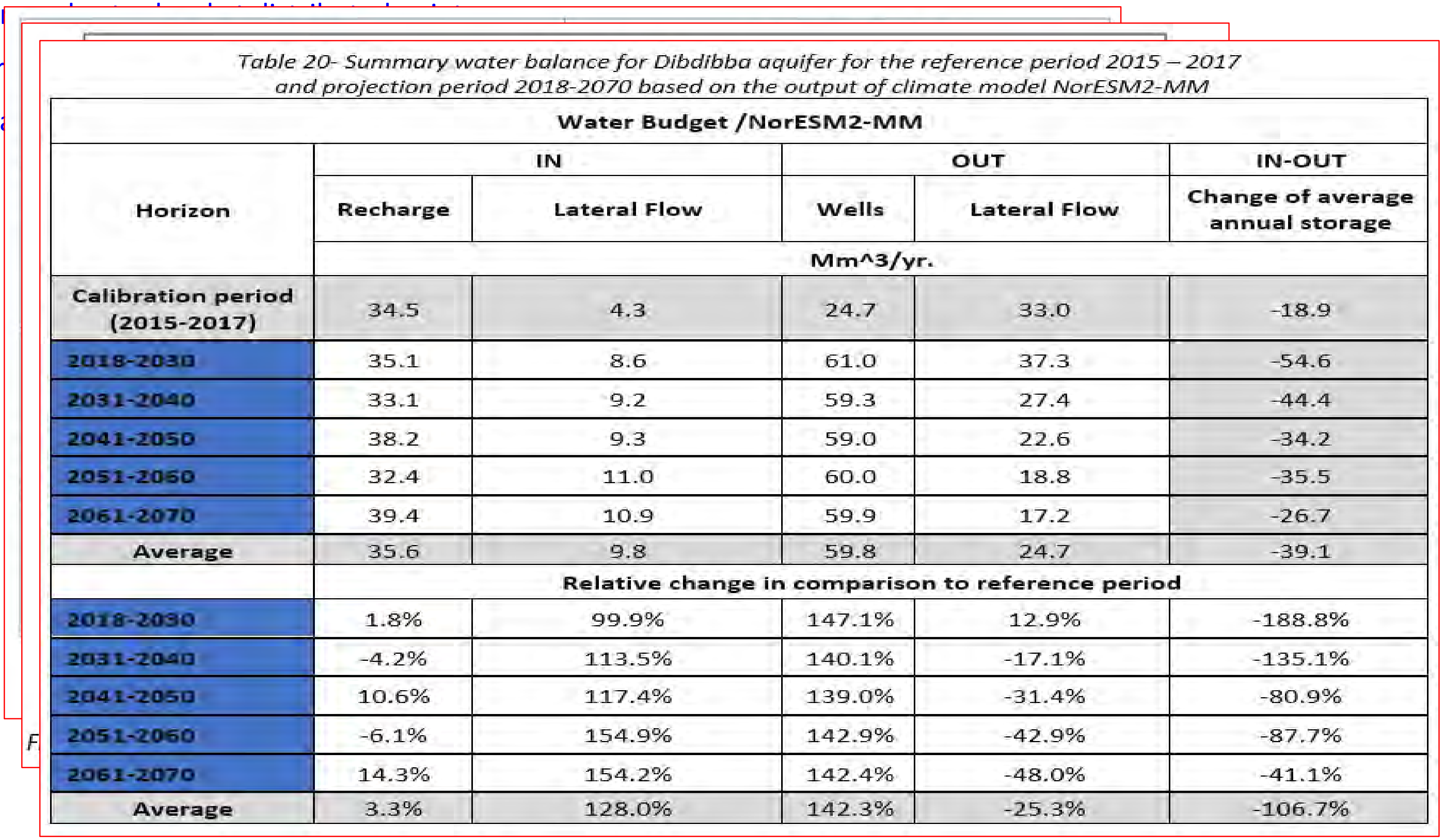
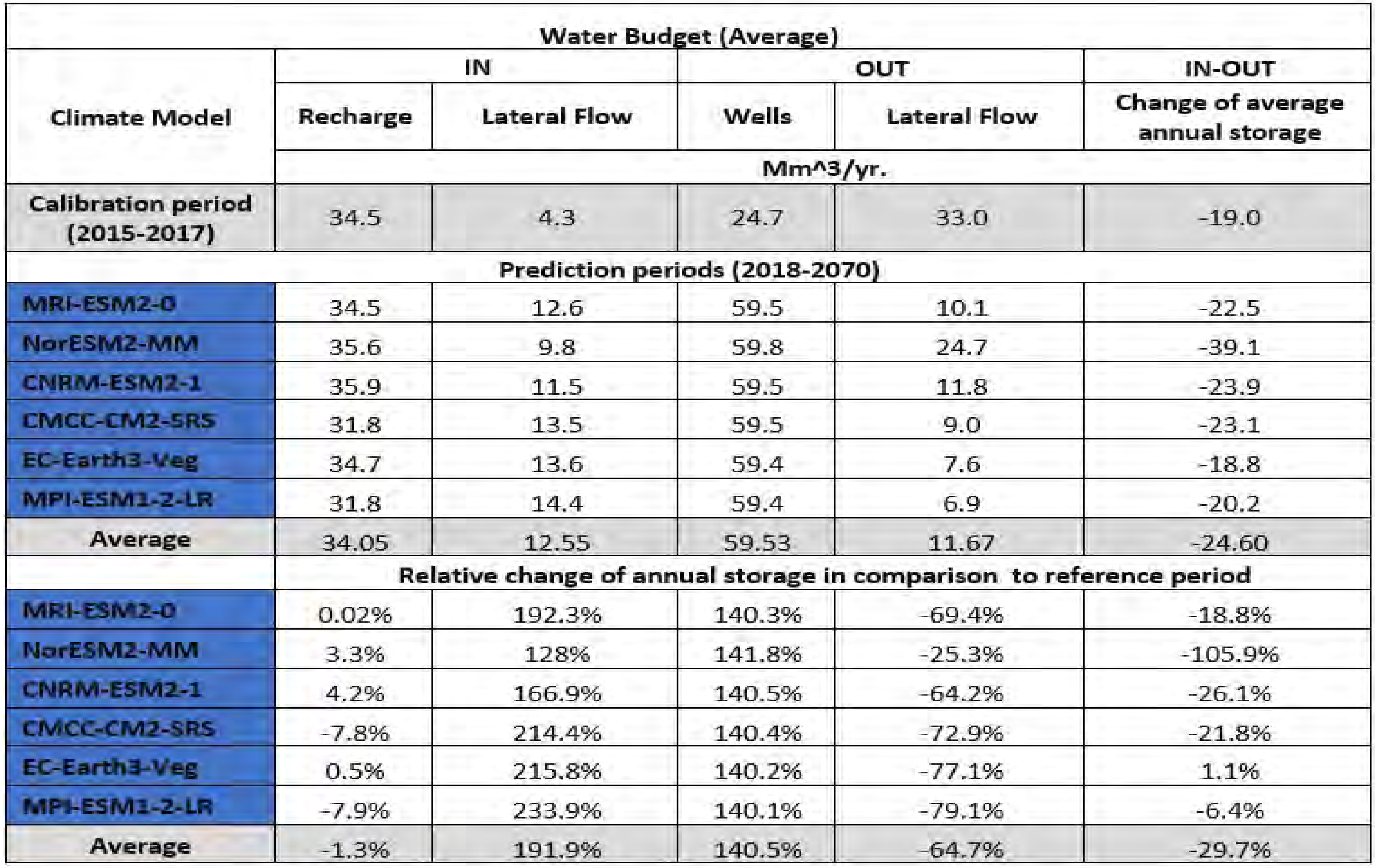


Table 20- Summary water balance for Dibdibba aquifer for the reference period 2015 – 2017 and projection period 2018-2070 based on the output of climate model NorESM2-MM

Water Budget /NorESM2-MM					
	IN		OUT		IN-OUT
Horizon	Recharge	Lateral Flow	Wells	Lateral Flow	Change of average annual storage
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33.0	-18.9
2018-2030	35.1	8.6	61.0	37.3	-54.6
2031-2040	33.1	9.2	59.3	27.4	-44.4
2041-2050	38.2	9.3	59.0	22.6	-34.2
2051-2060	32.4	11.0	60.0	18.8	-35.5
2061-2070	39.4	10.9	59.9	17.2	-26.7
Average	35.6	9.8	59.8	24.7	-39.1
	Relative change in comparison to reference period				
2018-2030	1.8%	99.9%	147.1%	12.9%	-188.8%
2031-2040	-4.2%	113.5%	140.1%	-17.1%	-135.1%
2041-2050	10.6%	117.4%	139.0%	-31.4%	-80.9%
2051-2060	-6.1%	154.9%	142.9%	-42.9%	-87.7%
2061-2070	14.3%	154.2%	142.4%	-48.0%	-41.1%
Average	3.3%	128.0%	142.3%	-25.3%	-106.7%

Summary of water budgets for all climate models

Table 21- Summary of water budget for the reference period 2015 – 2017 and prediction period 2018 - 2070 for all climatic models



Water Budget (Average)					
Climate Model	**IN**		**OUT**		**IN-OUT**
	Recharge	**Lateral Flow**	**Wells**	**Lateral Flow**	**Change of average annual storage**
	Mm^3/yr.				
Calibration period (2015-2017)	34.5	4.3	24.7	33.0	-19.0
	Prediction periods (2018-2070)				
MRI-ESM2-0	34.5	12.6	59.5	10.1	-22.5
NorESM2-MM	35.6	9.8	59.8	24.7	-39.1
CNRM-ESM2-1	35.9	11.5	59.5	11.8	-23.9
CMCC-CM2-SR5	31.8	13.5	59.5	9.0	-23.1
EC-Earth3-Veg	34.7	13.6	59.4	7.6	-18.8
MPI-ESM1-2-LR	31.8	14.4	59.4	6.9	-20.2
Average	34.05	12.55	59.53	11.67	-24.60
	Relative change of annual storage in comparison to reference period				
MRI-ESM2-0	0.02%	192.3%	140.3%	-69.4%	-18.8%
NorESM2-MM	3.3%	128%	141.8%	-25.3%	-105.9%
CNRM-ESM2-1	4.2%	166.9%	140.5%	-64.2%	-26.1%
CMCC-CM2-SR5	-7.8%	214.4%	140.4%	-72.9%	-21.8%
EC-Earth3-Veg	0.5%	215.8%	140.2%	-77.1%	1.1%
MPI-ESM1-2-LR	-7.9%	233.9%	140.1%	-79.1%	-6.4%
Average	-1.3%	191.9%	140.5%	-64.7%	-29.7%

Summary of groundwater level drawdown 2018 – 2070, based on climate models.

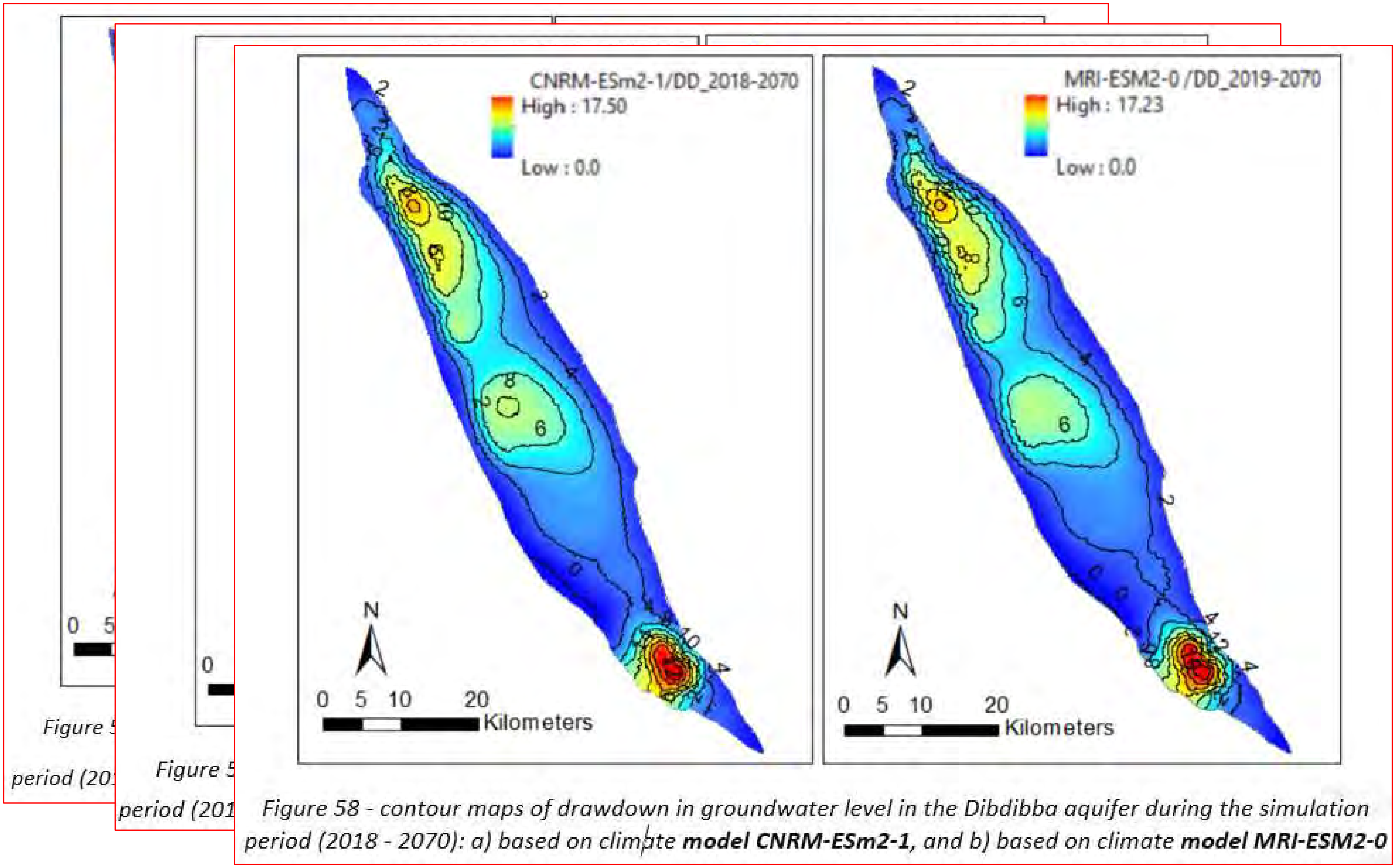


*Figure 58 - contour maps of drawdown in groundwater level in the Dibdibba aquifer during the simulation period (2018 - 2070): a) based on climate **model CNRM-ESm2-1**, and b) based on climate **model MRI-ESM2-0***

Summary and Conclusions

- Results based on all climate models showed decline of the groundwater table over the entire aquifer area with values ranging from 14 m in the northern part, 4-10 m in the middle part and up to 18 m in the southern part.
- The climate models **MRI-ESM2-0, CMCC-CM2-SR5,and MPI-ESM1-2-LR** projected a decrease of average annual rainfall toward year 2070 with percentage ranged from 2% to 15% according to scenario RCP8.5, that's reduced the amount of groundwater recharge from rainfall with percentage ranged from 0.03 to 7.93.
- While, the climate models **CNRM-ESM2-1, EC-Earth3-Veg and NorESM2-MM** projected an increase of average annual rainfall towards 2070 by a percentage of 1% to 9% and groundwater recharge increased with the percentage ranged from 0.46 to 4.12.
- The storage volume is decreasing with time towards 2070 (Table 21). The relative change in storage in comparison with reference period ranged from 1.1 % to -105.9 %.
- **The result of the study showed that climate changes will have significant impact on groundwater at Dibdibba aquifer causing reduction in groundwater storage and accordingly a considerable decline in groundwater table.**

Thanks