XVIII World Water Congress

Climate Change versus Human Activities: On the Causes of the Shrinkage of Lake Chad

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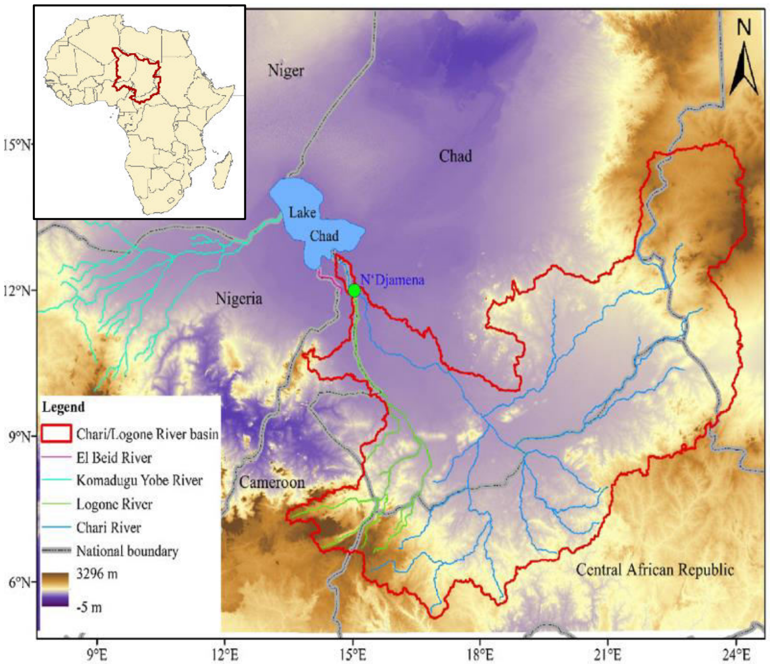
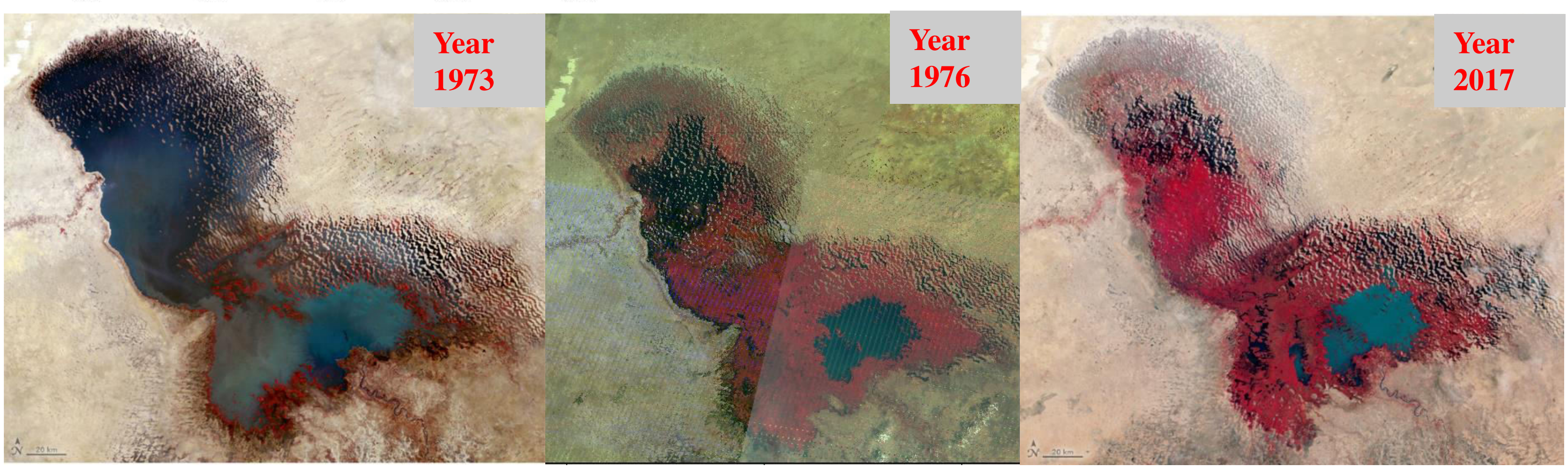
Outline

1. Background
2. Data & Methodology
3. Results & Discussion
4. Conclusions

Background



- Lake Chad is a freshwater lake in North Africa
- Serious shrinkage in the past 60 years (1/20)
- Regional conflicts caused by water scarcity
- Attention from international and local organizations
- Causes: Climate Change VS. Human Activities
- Research difficulty: Lack of ground observations



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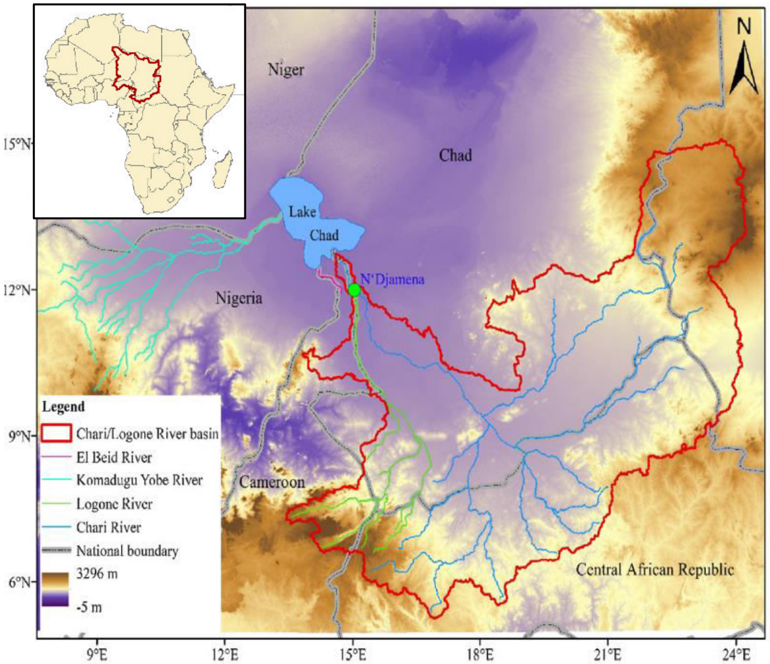

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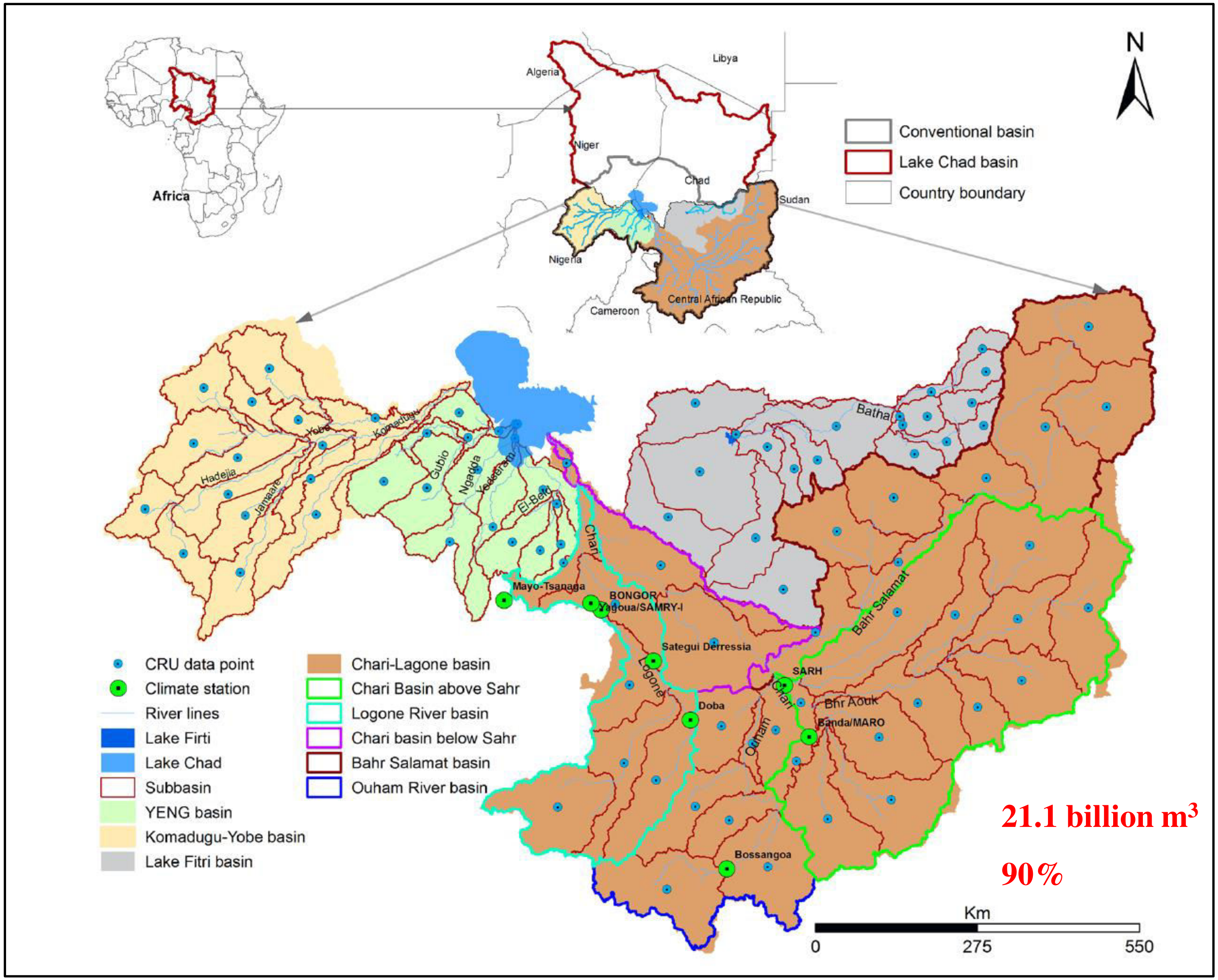


21.1 billion m^3

90%

Data & Methodology

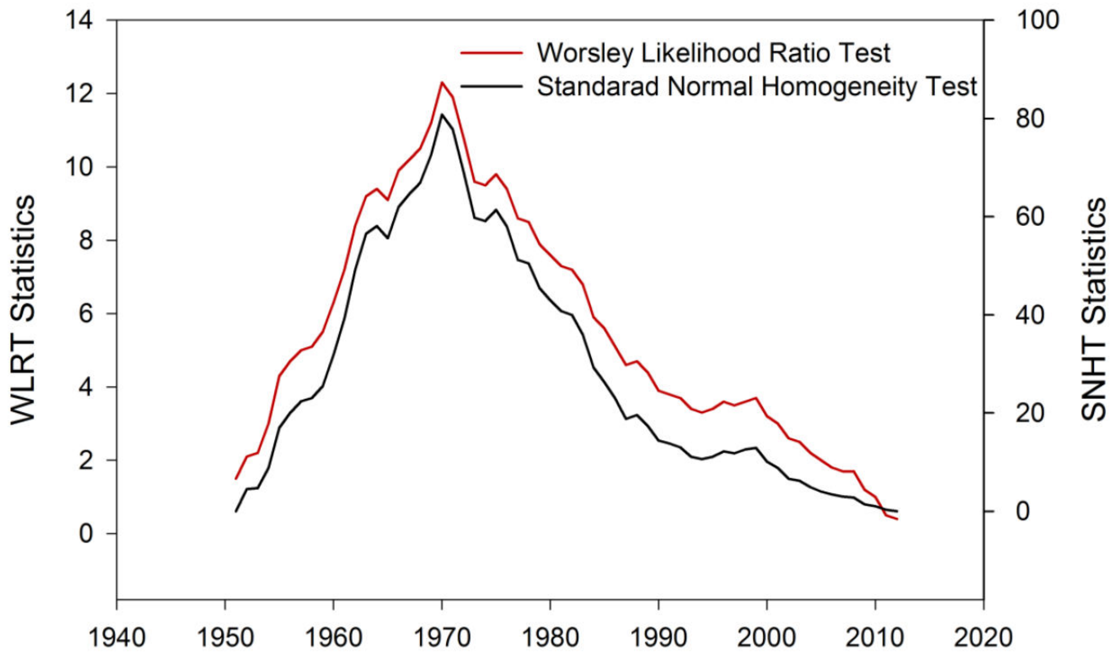
➢ Data Sources

- Monthly discharge of Chari River into Lake Chad from 1950 to 2013
- Monthly precipitation observed at N'Djamena station from 1950 to 2013
- Gridded climatic forcing data from Climatic Research Unit (CRU)
- Land use and land cover data from U.S. Geological Survey (USGS)
- Soil parameters from Harmonized World Soil Database (HWSD)
- Digital Elevation Model (DEM) from SRTM
- Future climate scenarios from CMIP5

Data & Methodology

➢ **Basic framework to quantify the contribution of climate change and human activities**

- **Selection of baseline period (the impact of human activities can be ignored)**
  - ✓ **From 1950 to 1960 (Literature review)**
  - ✓ **From 1950 to 1971 (Statistical analysis)**



Data & Methodology

- **Basic framework to quantify the contribution of climate change and human activities**

  - **Selection of baseline period（the impact of human activities can be ignored）**
    - ✓ **From 1950 to 1960（Literature review）**
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  - **Quantify the role of climate change and human activities in evaluation period**

$$\Delta Q_{total} = \Delta Q_{climate} + \Delta Q_{human} = Q_o - \overline{Q_{baseline}}$$

$$C_{climate} = \frac{\Delta Q_{climate}}{\Delta Q_{climate} + \Delta Q_{human}} \times 100\%$$

$$C_{human} = \frac{\Delta Q_{human}}{\Delta Q_{climate} + \Delta Q_{human}} \times 100\%$$

Data & Methodology

➢ Methodology I：Budyko analysis

$$\frac{E}{P} = \frac{1 + \omega x}{1 + \omega x + x^{-1}}$$

$$x = E_o/P$$

$$P = E + Q + \Delta S$$

$$\Delta Q_{climate} = \varepsilon_P \Delta P + \varepsilon_{E_0} \Delta E_0$$

$$\varepsilon_P = \frac{1 + 2x + 3\omega x}{(1 + x + \omega x^2)^2}$$

$$\varepsilon_{E_0} = \frac{1 + 2\omega x}{(1 + x + \omega x^2)^2}$$

➢ Methodology II：Stepwise multilinear regression analysis

$$\Delta Q_{human} = Q_o - Q_N$$

$$Q_{N,i} = f\left(P_i, P_{i-1}, P_{i-2}, P_{i-3}, E_{0,i}, E_{0,i-1}, E_{0,i-2}, E_{0,i-3}\right)$$

$$Q_{N,i} = 0.014P_{i-1} + 0.030P_{i-2} + 0.024P_{i-3} + 0.032E_{0,i} - 0.026E_{0,i-3} - 0.429$$

Data & Methodology

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Data & Methodology

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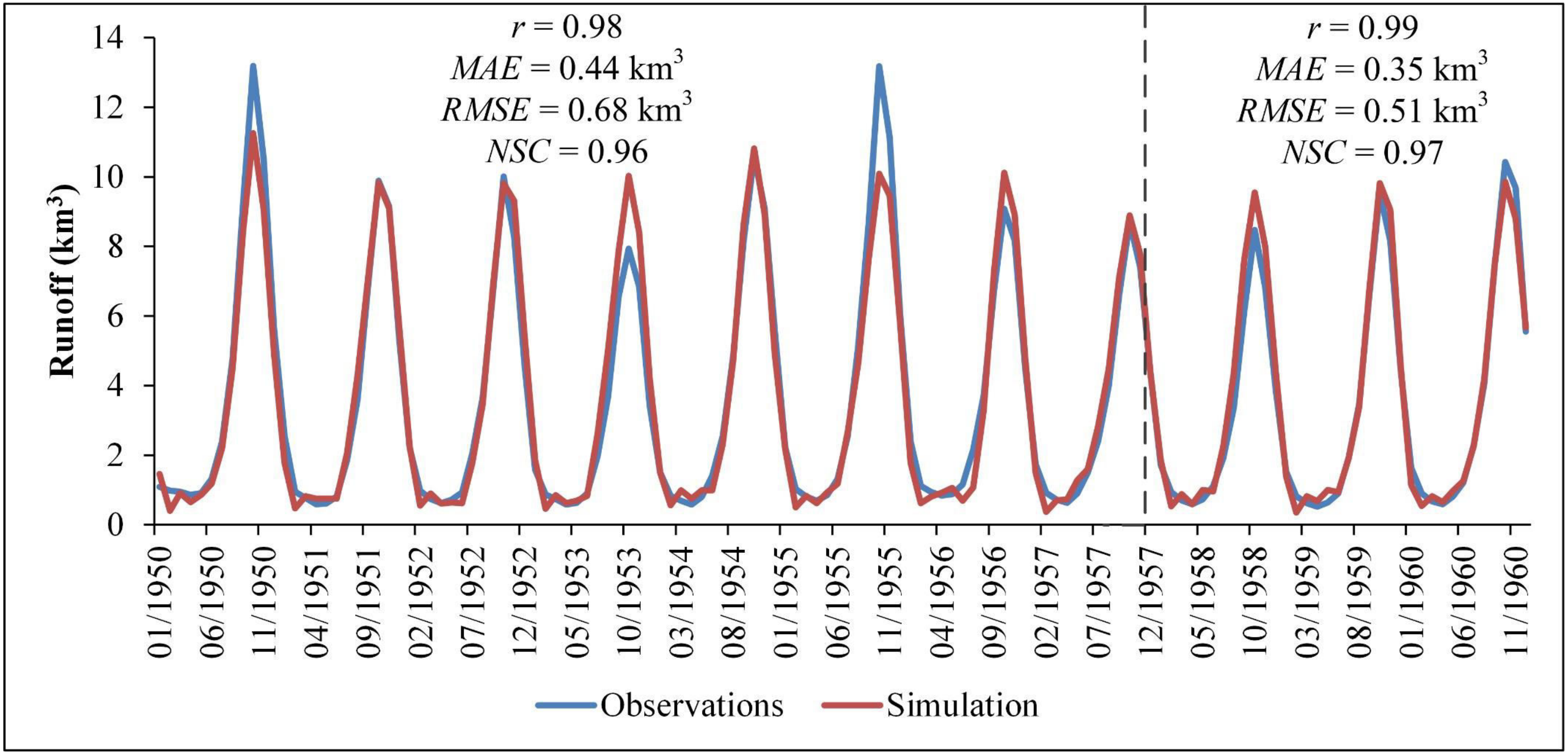
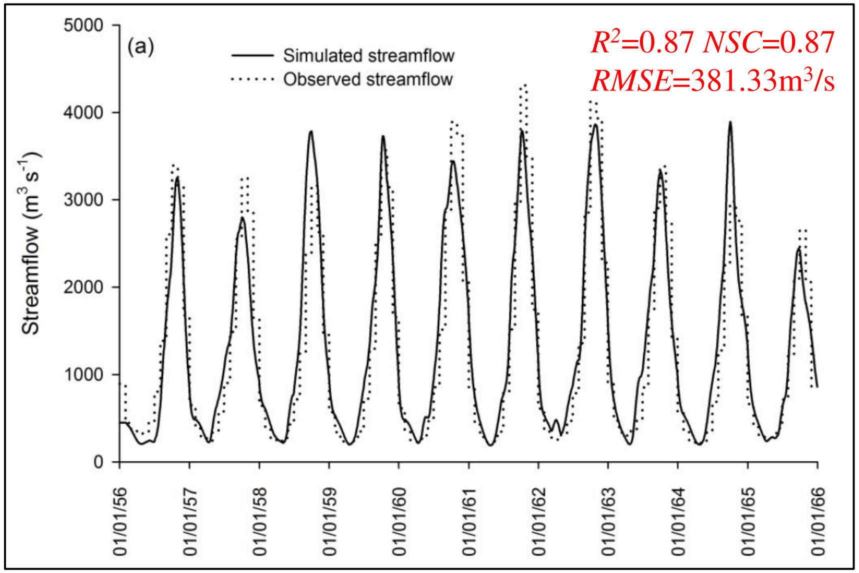
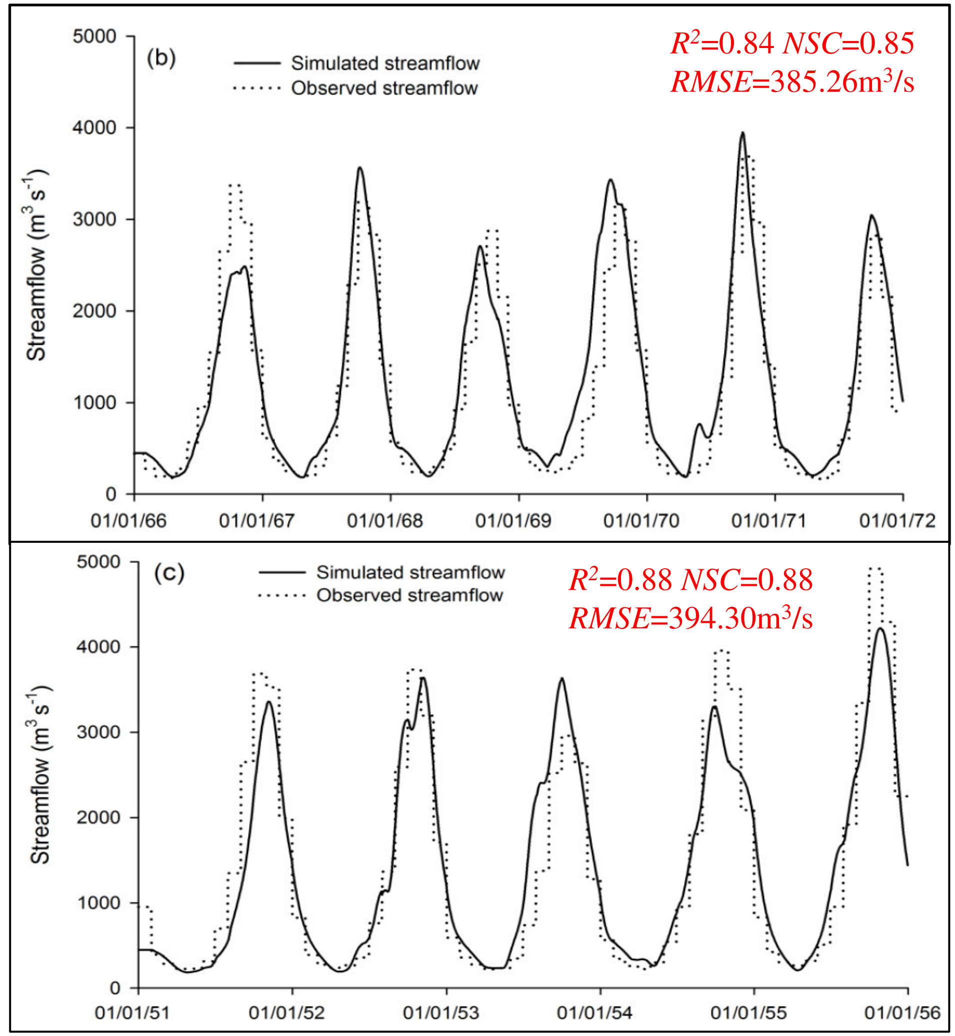


Data & Methodology

➢ Methodology III：Hydrological model（HEC-HMS）



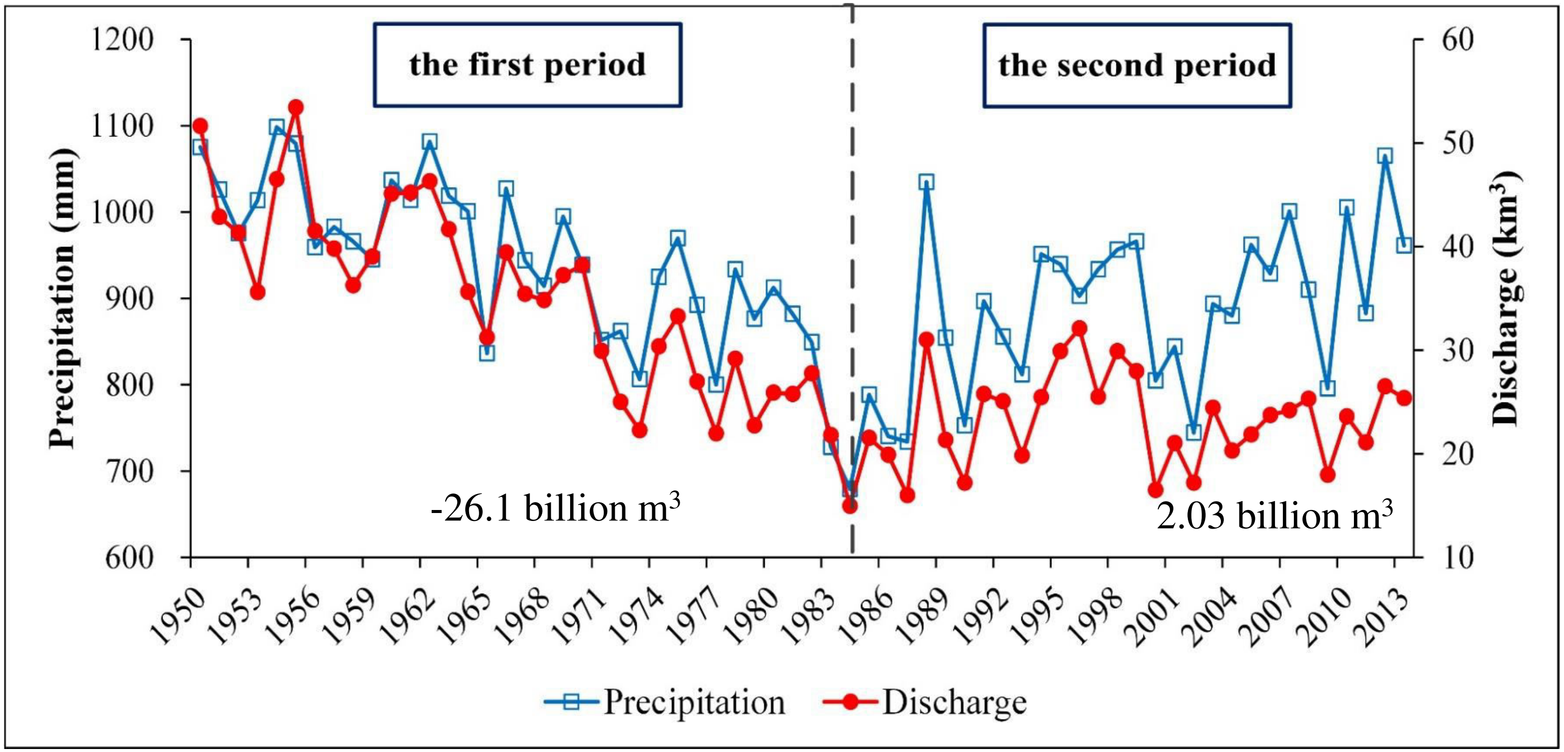


$$\Delta Q_{human} = Q_O - Q_N$$

$$\Delta Q_{climate} = Q_N - Q_{baseline}$$

Results & Discussion

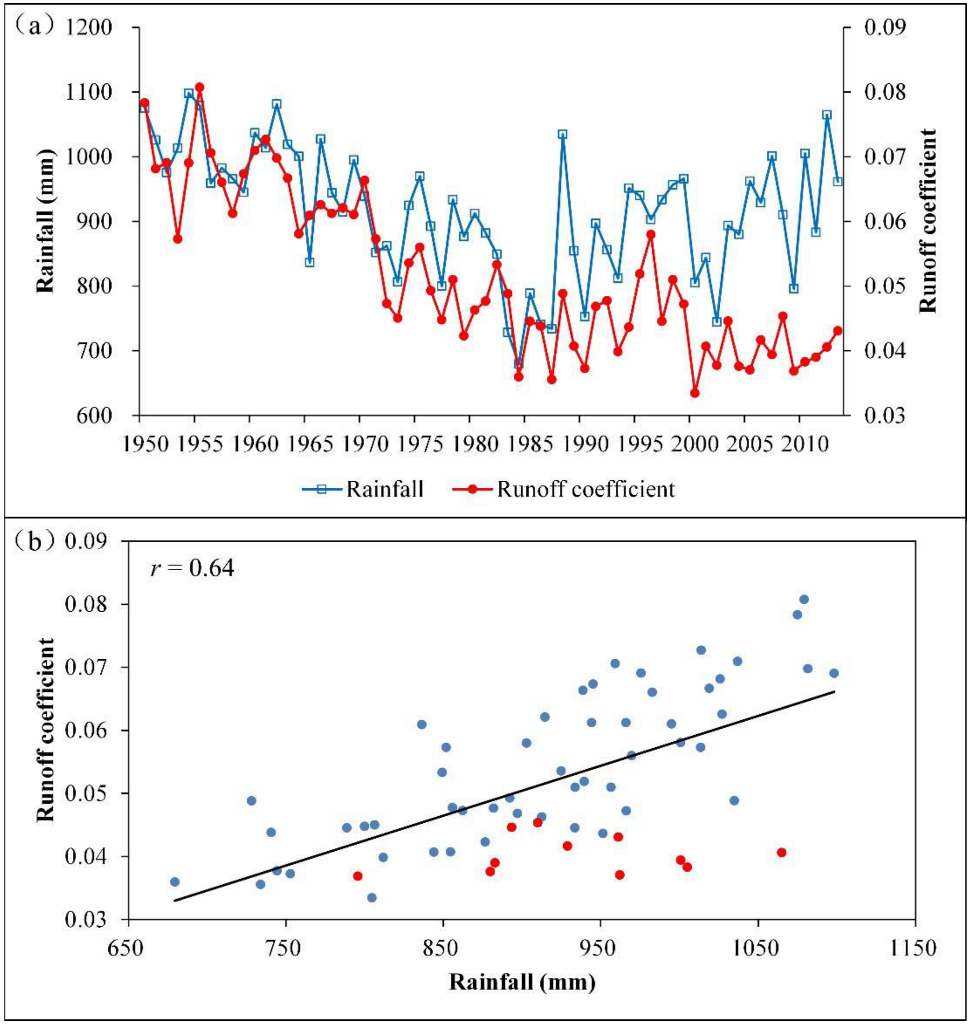
➢ **Time series of observed precipitation and runoff from 1950 to 2013**



- **First period: significant decrease in both rainfall and runoff, 7.40mm/yr vs. 0.77 billion m³/yr;**
- **Second period: significant increase in rainfall but slight increase in runoff, 5.72mm/yr vs. 0.07 billion m³/yr.**

Results & Discussion

➢ **Relationship between rainfall and runoff coefficient from 1950 to 2013**

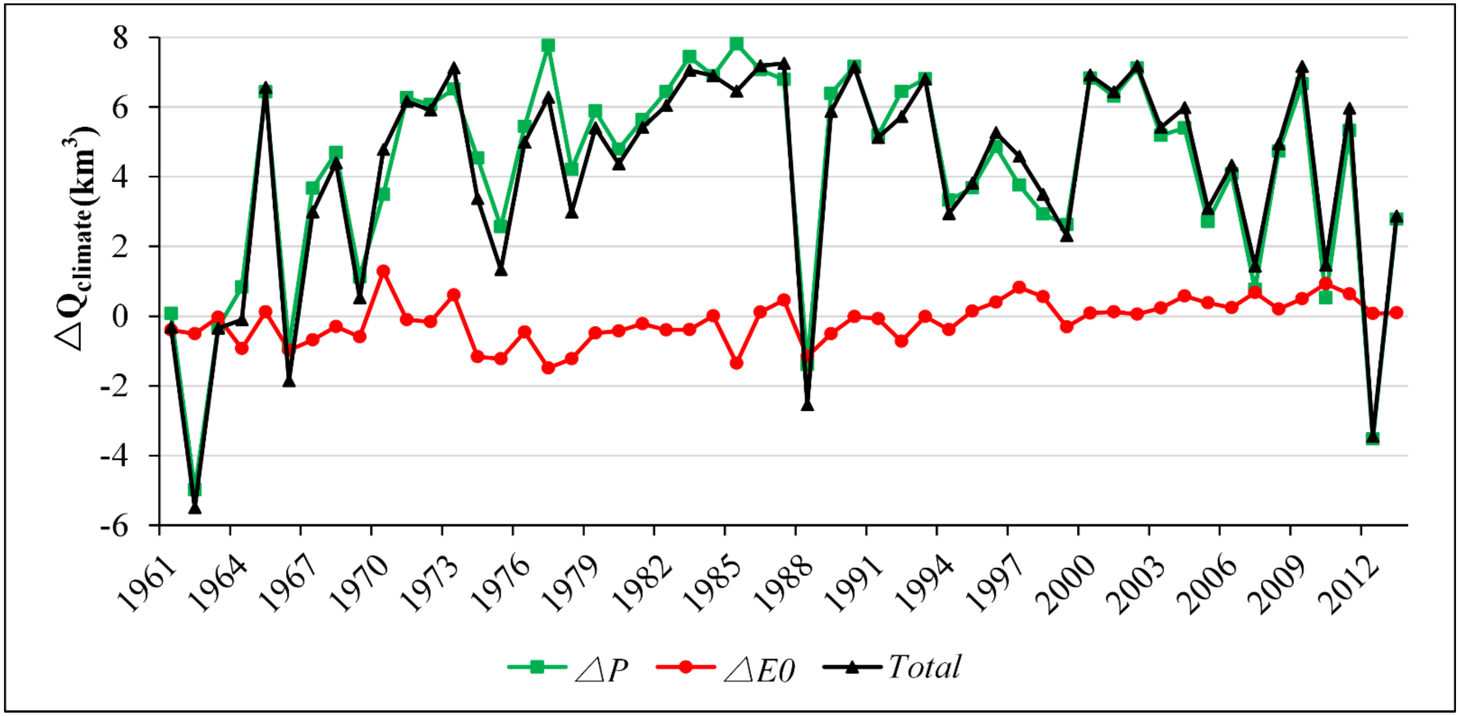


- ☐ **They correlated well with each other in the first period, but the runoff coefficient in the second period did not increase accordingly with the increase of rainfall;**

- ☐ **The Chari River discharge into Lake Chad did not keep level with precipitation increase. The only plausible explanation is the increase of water withdrawal upstream.**

Results & Discussion

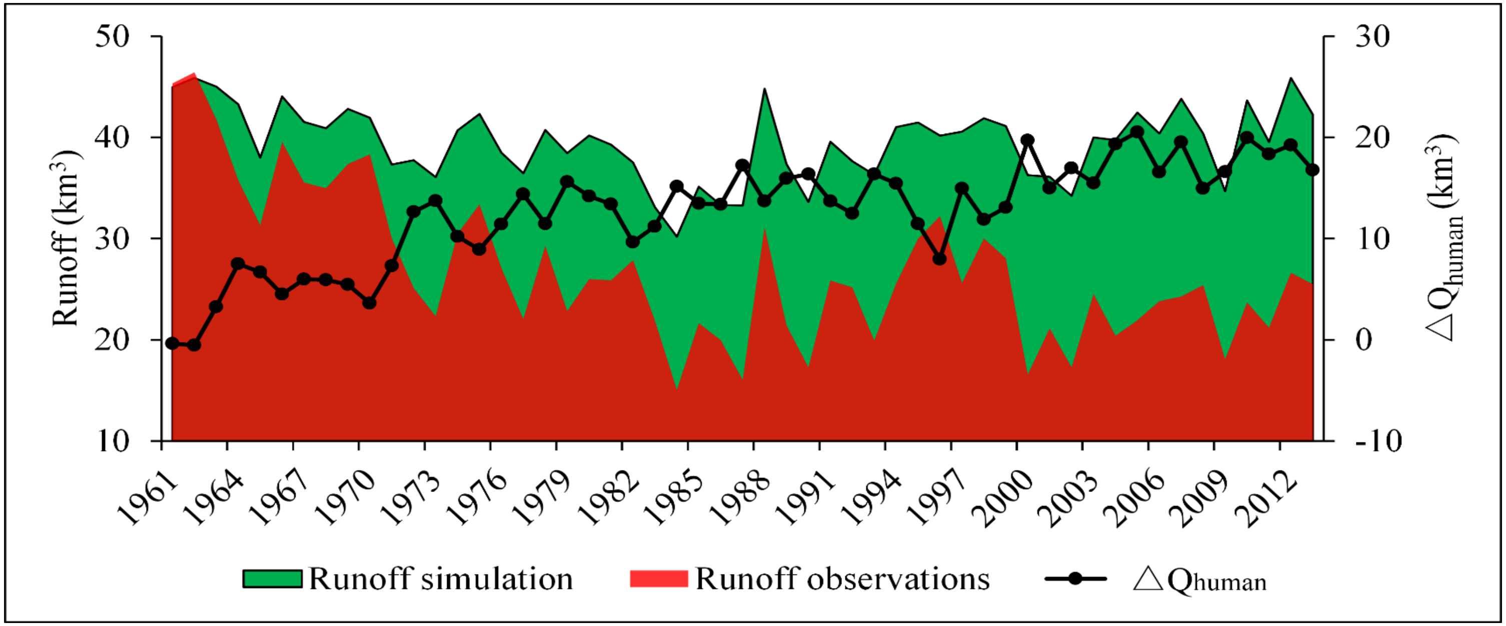
➢ Impact of climate change on river discharge (Budyko analysis)



- ☐ **Compared with the baseline period, the runoff change caused by rainfall and potential evapotranspiration is 4.20 billion m^3 and -0.14 billion m^3 respectively on annual average scale;**
- ☐ **They influence runoff in the opposite direction. The variability of rainfall leads to a decrease of river discharge (85.60%) while the variability of PET is beneficial to runoff generation (14.40%).**

Results & Discussion

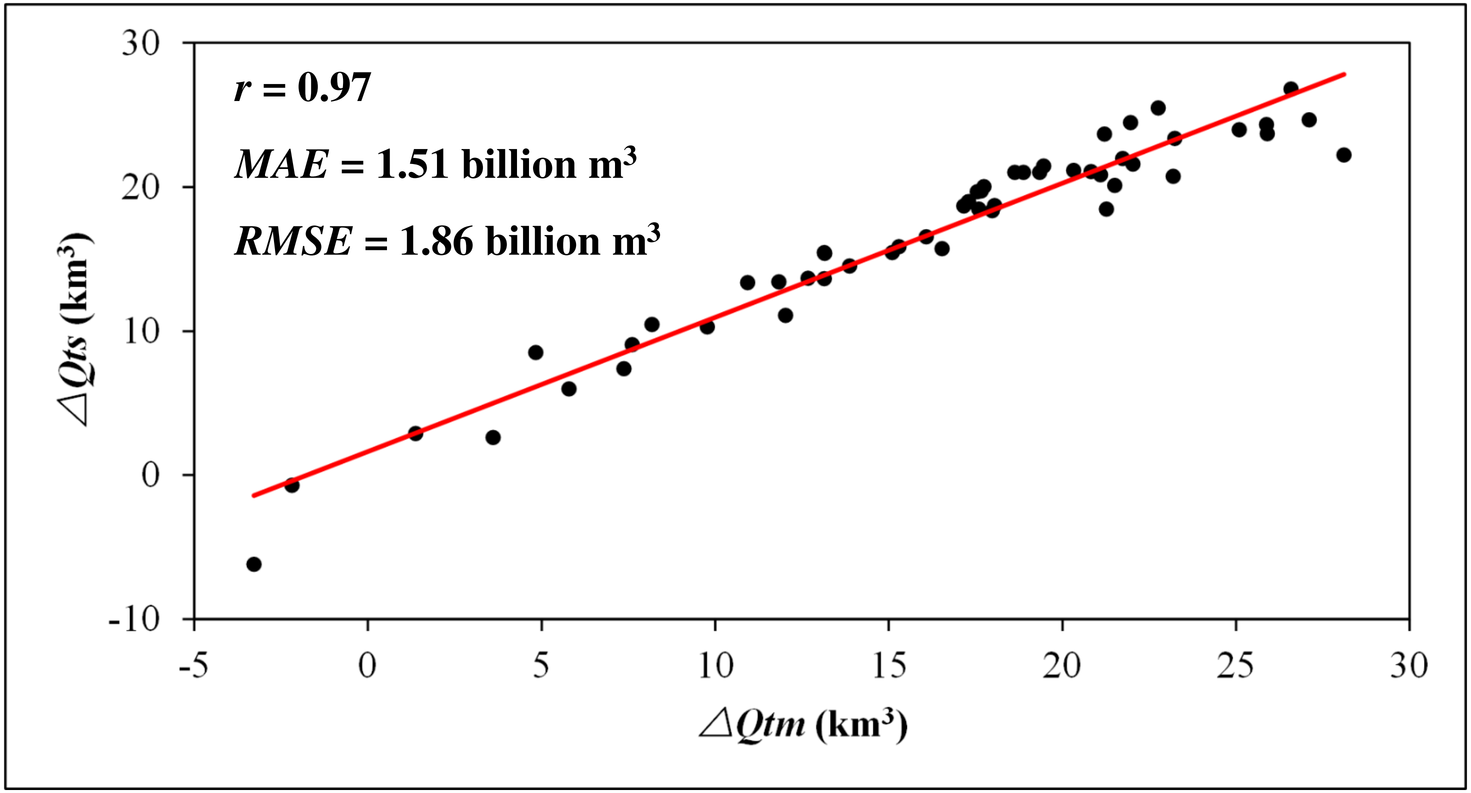
➢ **Impact of human activities on river discharge (stepwise multilinear regression analysis)**



- **The difference between natural and observed runoff is becoming larger and larger, indicating a growing impact of human activities. The annual average water withdrawal is 12.60 billion m³/yr.**
- **From 1961 to 1970 the water loss caused by water withdrawal was relatively small (4.19); from 1971 to 1982 a significant increase was observed in irrigation withdrawal (11.92); from 1983 to 1996 there was a slight increase (13.9); and from 1997 to 2013 the annual average was as high as 17.99.**

Results & Discussion

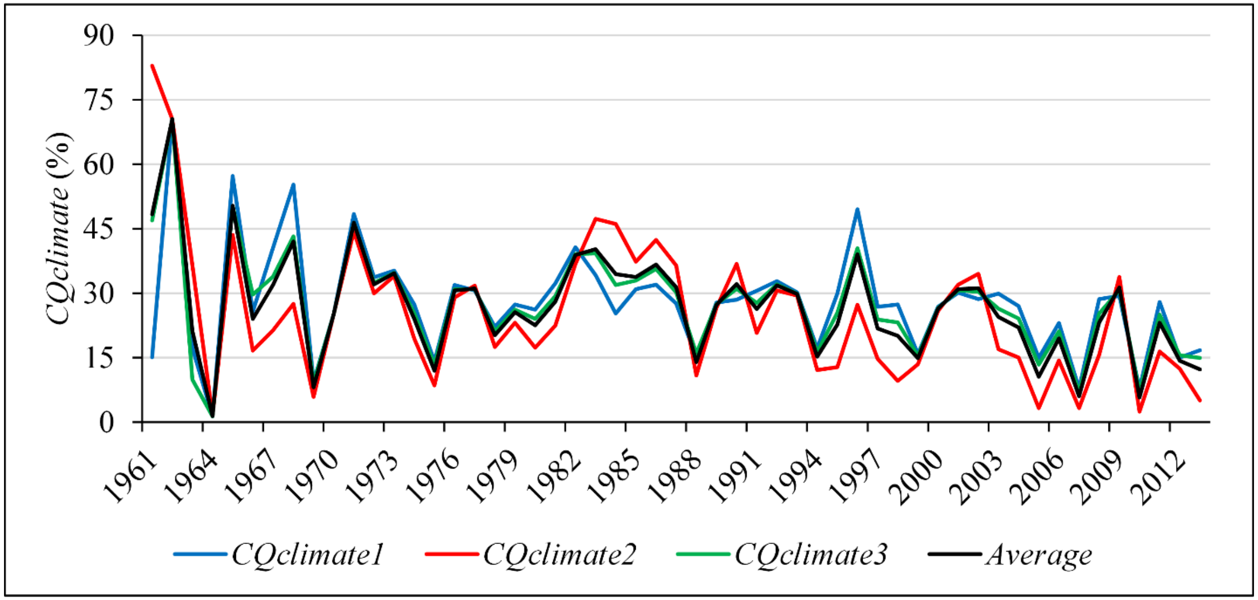
➢ **Cross-validation of total runoff change (Q_{total})**



$$\Delta Q_{total} = \Delta Q_{climate} + \Delta Q_{human} = Q_o - \overline{Q_{baseline}}$$

Results & Discussion

➢ Cross-validation of the contribution of climate change and human activities



$$CQ_{climate1} = \frac{|\Delta Q_{climate}|}{|\Delta Q_{total}|} \times 100(\%)$$

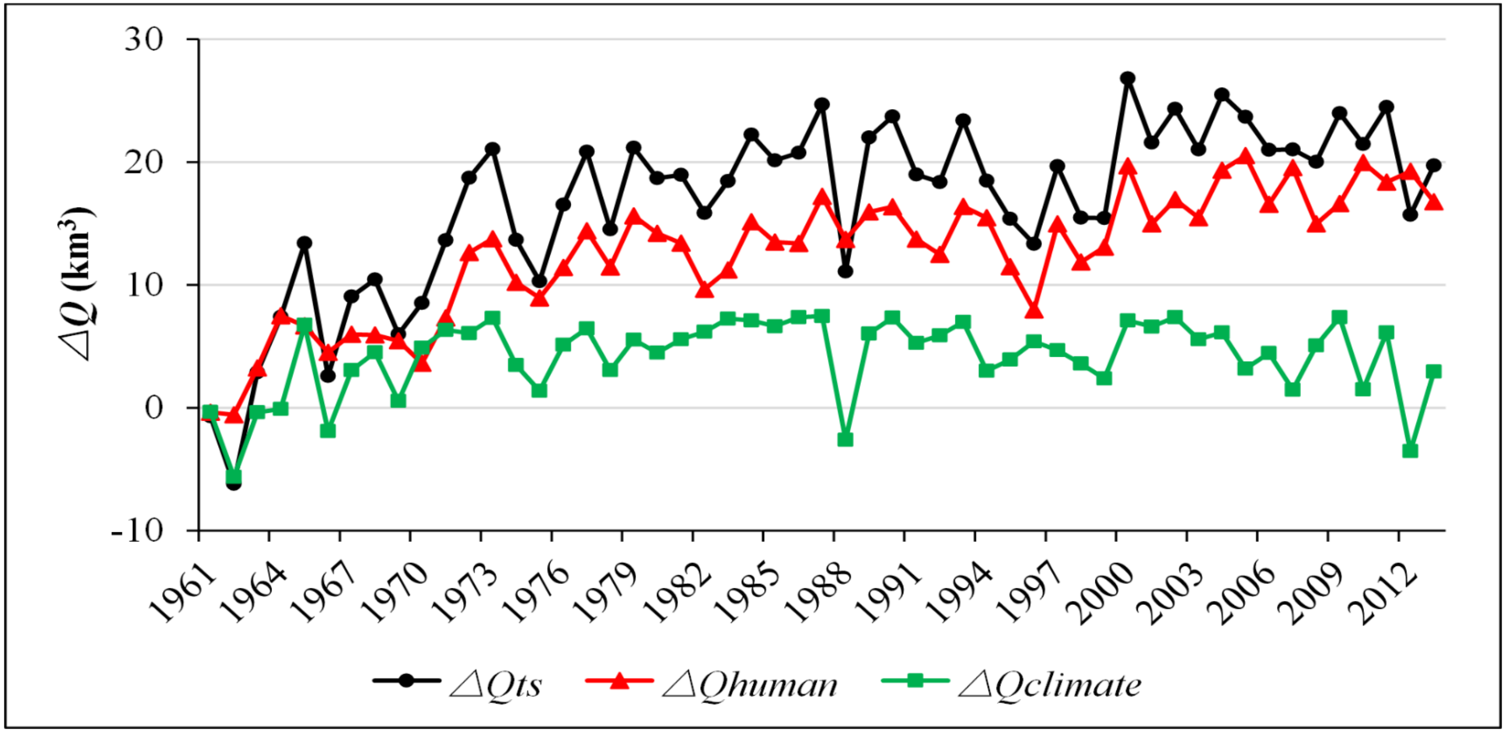
$$CQ_{climate2} = \frac{|\Delta Q_{total}| - |\Delta Q_{human}|}{|\Delta Q_{total}|} \times 100(\%)$$

$$CQ_{climate3} = \frac{|\Delta Q_{climate}|}{|\Delta Q_{climate}| + |\Delta Q_{human}|} \times 100(\%)$$

- **Apart from the year 1961, there is generally good agreement among the $CQ_{climate}$ retrieved from three different equations;**
- **In terms of *r* and *RMSE*, $CQ_{climate3}$ shows the best performance, which is also the closest to the average of $CQ_{climate}$ retrieved from three different equations;**
- **We adopted $CQ_{climate3}$ and CQ_{human3} as the final indictor to quantify the contribution.**

Results & Discussion

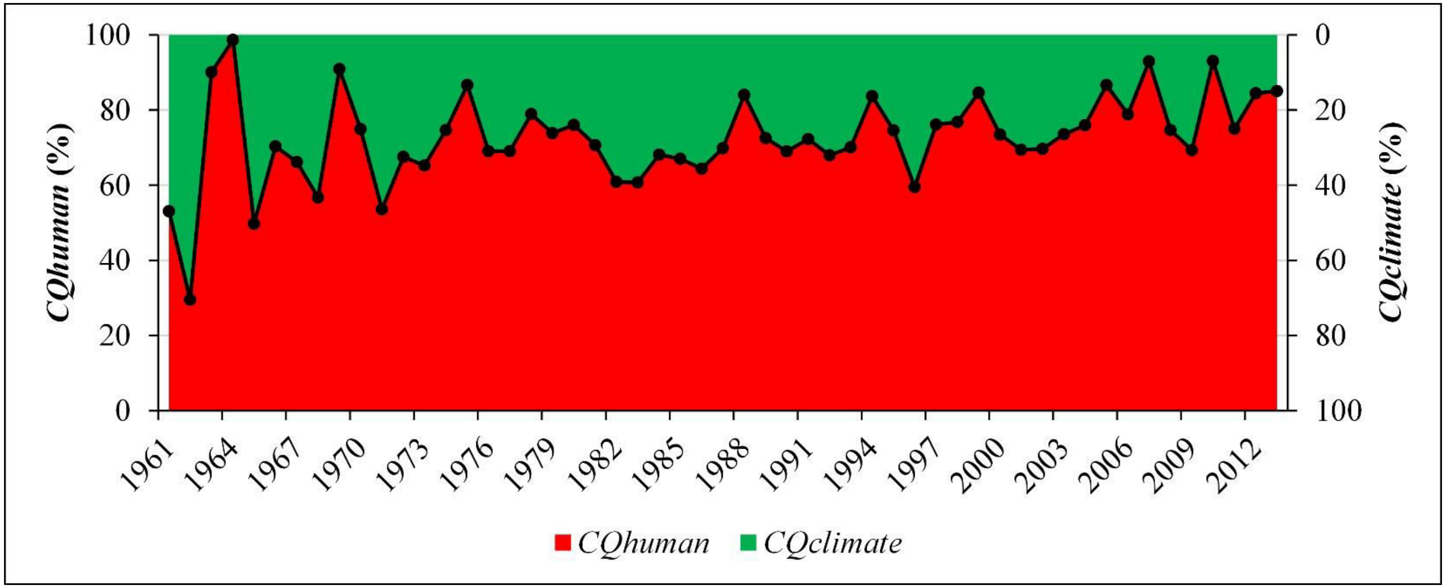
➢ **Variations of ΔQ_{total} and its two components from 1961 to 2013**



- **Compared with the baseline period (43.15 billion m^3), an increasing trend of total water loss is observed from 1961 to 2013. The annual average ΔQ_{total} is 16.76 billion m^3;**
- **1961-1987: rapid increase period (0.70~24.68); 1988-1996: fluctuation period (18.30); peak observed in 2000 (26.82); 2001-2013: stable period (21.80).**

Results & Discussion

➢ Relative contribution of climate change and human activities



- **The variations of ΔQ_{total} are dominated by ΔQ_{human}, which has been increasing during the evaluation period.**
- **The annual average $\Delta Q_{climate}$ and ΔQ_{human} over the whole period is 26.83% and 73.17%, respectively.**

Results & Discussion

➢ Relative contribution of climate change and human activities

Period	ΔQ_{total}(km³)	$\Delta Q_{climate}$(km³)	ΔQ_{human}(km³)	$C_{climate}$(%)	C_{human}(%)
1961-1965	3.94	0.06	3.88	2	98
1966-1970	6.59	1.49	5.10	23	77
1971-1975	15.48	4.91	10.57	32	68
1976-1980	18.34	4.93	13.41	27	73
1981-1985	19.13	6.55	12.58	34	66
1986-1990	20.43	5.12	15.31	25	75
1991-1995	18.91	5.01	13.90	26	74
1996-2000	18.15	4.64	13.51	26	74
2001-2005	23.22	5.77	17.45	25	75
2006-2010	21.49	3.97	17.52	18	82
2006-2013	20.92	3.17	17.75	15	85

- **The contribution of human activities is always much larger than that of climate variability. It is particularly obvious in the first five years of the 1960s when C_{human} is as high as 98%.**
- **Since then, $C_{climate}$ has been increasing due to the decrease of rainfall. Following the serious drought in 1984, the maximum $C_{climate}$ is observed in the period from 1981 to 1985 with a value of 34%.**

Results & Discussion

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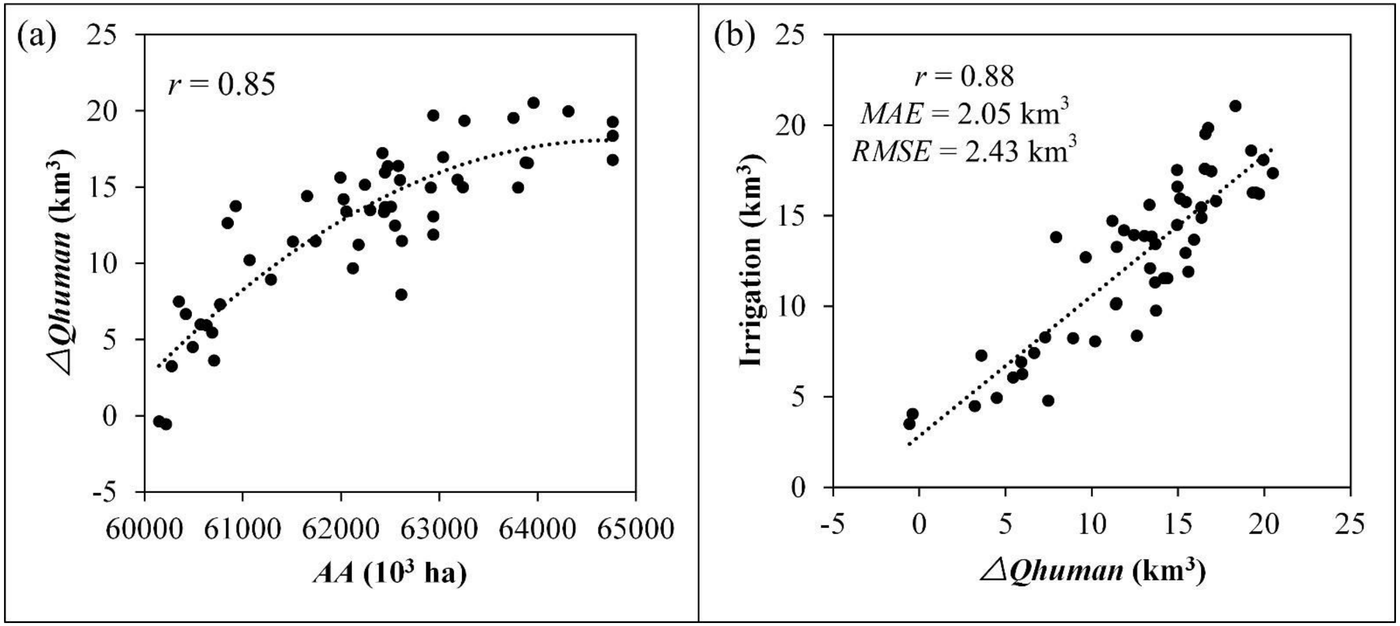
- ☐ **In the subsequent twenty from 1986 to 2005, the contribution of climate change and human activities has been relatively stable, which is about 25% and 75%, respectively.**
- ☐ **Because of the increase of rainfall in the last ten years from 2003 to 2013, the relative contribution of climate variability to water loss begins to decrease. More than 80% of the decrease in river discharge is attributed to human activities.**

Results & Discussion

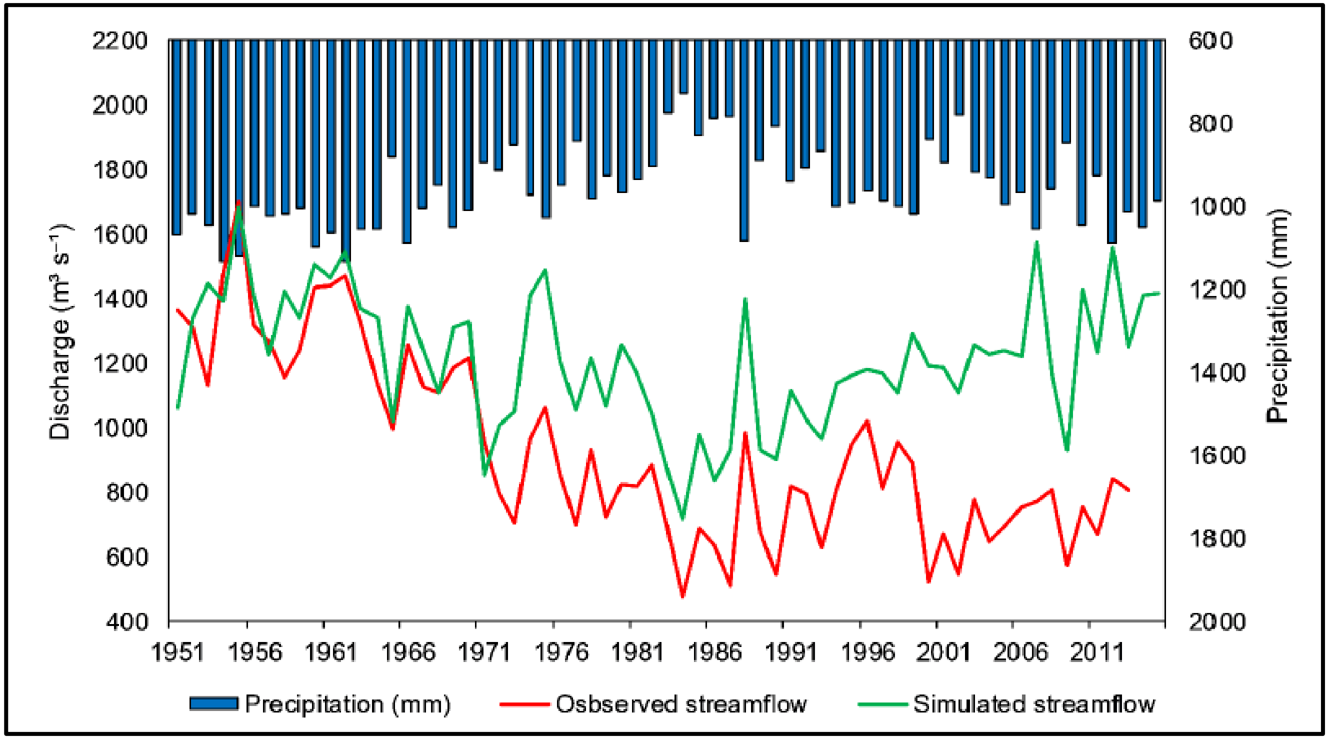
➢ Comparison with the area of farmland

- Assuming the water loss caused by human activities is dominated by irrigation withdrawals, a comparison between ΔQ_{human} estimates and the total agricultural area within the basin can be used to verify our findings indirectly.



Results & Discussion

➢ **Comparison with the output of the hydrological model (HEC-HMS)**



- **Before 1970, the simulated runoff agreed well with the observed runoff, implying that the hydrological model has the capacity to capture the annual variations of natural runoff;**
- **After 1970, the difference between simulated and observed runoff became larger and larger in general, implying a growing impact of human activities.**

Results & Discussion

➤ Relative contribution of climate change and human activities

Decade	ΔTX (°C)	ΔTN (°C)	ΔTM (°C)	ΔP (%)	ΔQ_T (%)	ΔQ_C (%)	ΔQ_H (%)	P_C (%)	P_H (%)
1972–1981	-0.29	-0.01	-0.19	-9	-34	-11	-23	31	69
1982–1991	0.02	0.35	0.14	-18	-45	-27	-18	59	41
1992–2001	0.15	0.56	0.31	-8	-36	-14	-22	39	61
2002–2011	0.74	1.16	0.9	-9	-45	-7	-38	16	84
1972–2013	0.17	0.55	0.31	-10	-40	-14	-26	34	66

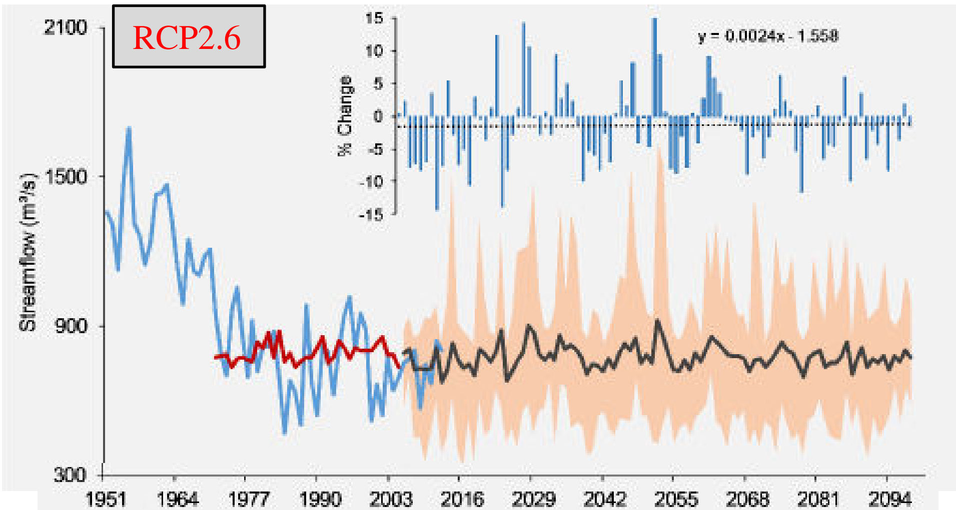
ΔTX *changes in maximum temperature,* ΔTN *changes in minimum temperature,* ΔTM *changes in mean temperature,* ΔP *changes in precipitation,* ΔQ_T *total changes in streamflow due to climate variability and human activities,* ΔQ_C *total changes in streamflow due to climate variability,* ΔQ_H *total changes in streamflow due to human activities,* $P_C = 100 \times (\Delta Q_C / \Delta Q_T)$, $P_H = 100 \times (\Delta Q_H / \Delta Q_T)$

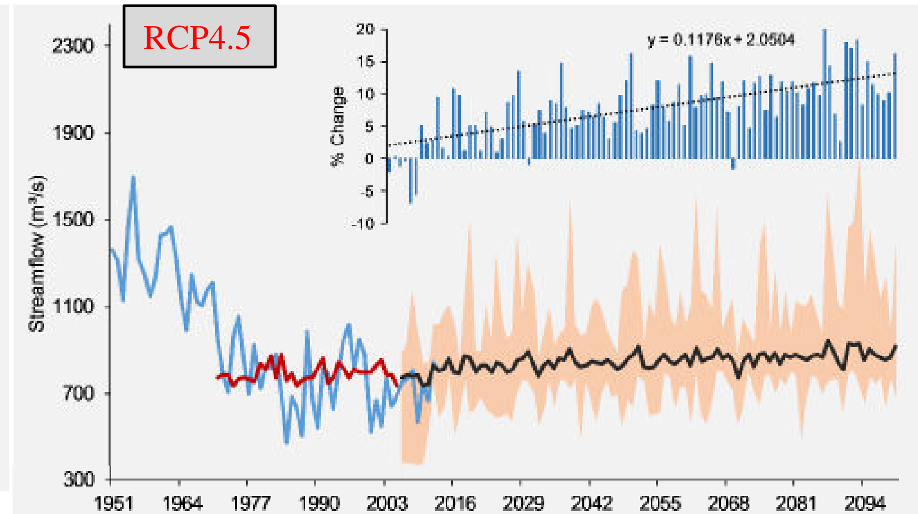
- **The contribution of human activities (73% vs. 66%) is still much larger than the contribution of climate change (27% vs. 34%)**
- **The contribution of human activities is still more than 80% in recent ten years (85%VS.84%)**
- **The above difference in number is mainly caused by the difference in baseline period (1950~1960 vs. 1950~1970)**

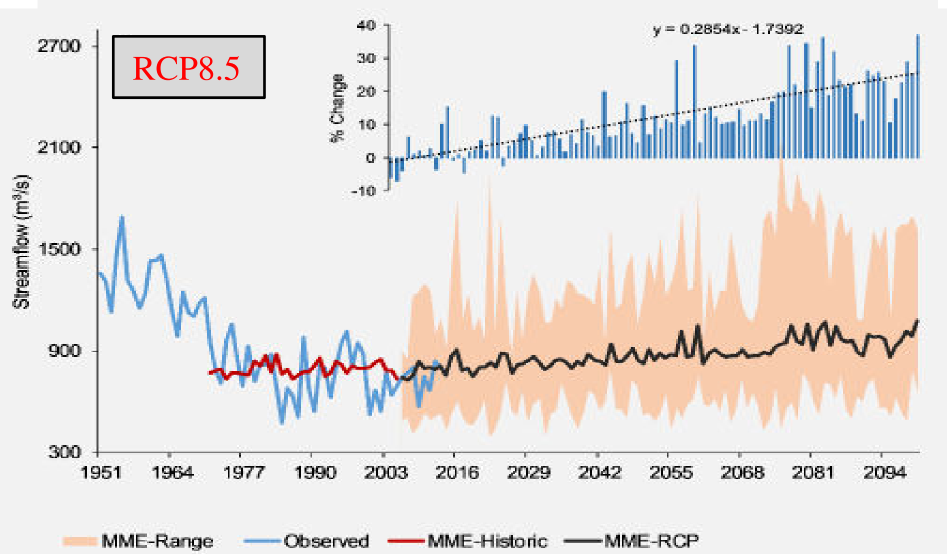
The increase of water withdrawal upstream is the main reason why Lake Chad has been shrinking!

Results & Discussion

➢ **Projection on the runoff in the future**







Compare with the baseline period, the runoff of Chari River is projected to decrease 2% under RCP 2.6 scenario, to increase 5.5% in the middle term and 11% in the long term under RCP 4.5 scenario, and increase 12% in the middle term and 27% in the long term under RCP 8.5 scenario.

Conclusions

- **Considering the lack of ground observations and the uncertainties involved, we adopted three independent methods to evaluate the respective contribution of climate change and human activities on the shrinkage of Lake Chad;**

- **The contribution of climate change and human activities is 30% and 70% on annual average scale. Water withdrawal upstream is the main reason why Lake Chad has been shrinking;**

- **Global warming is beneficial to the recovery of Lake Chad. However, there does not seem much likelihood that the runoff of Lake Chad reaches the level of baseline period in the foreseeable future (by 2050).**

Climate Change versus Human Activities:
On the Causes of the Shrinkage of Lake Chad

Thanks for your attention

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