NORTHWEST A&F UNIVERSITY

U.S.-China Exchange on Loess Landforms

Past Restoration Efforts, Techniques, Challenges, Successes & Future Plan

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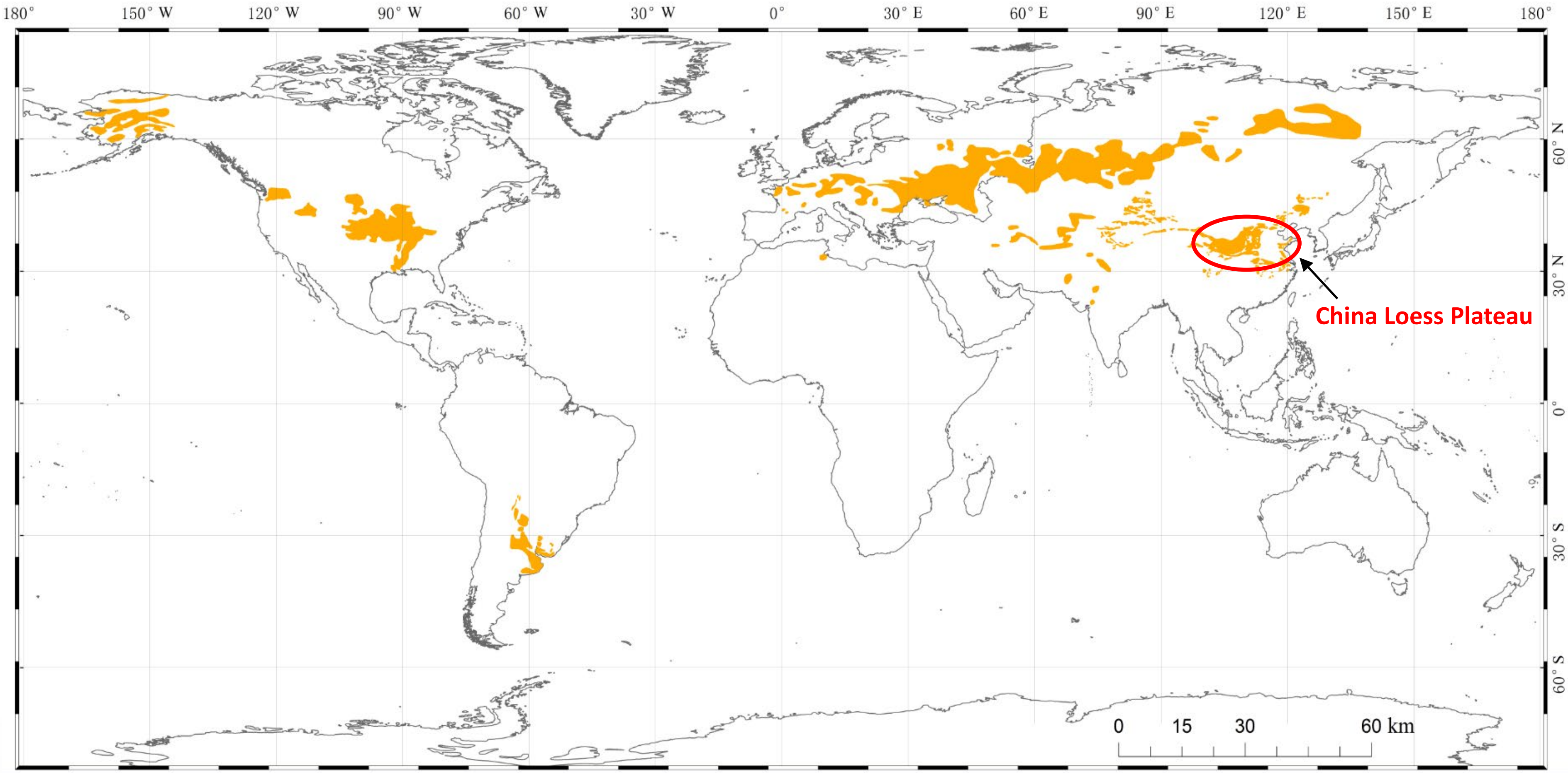
Content

1 Research Background

The World Loess distribution map

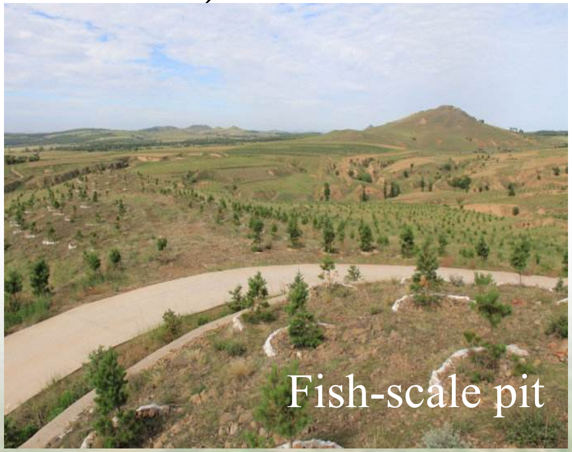


Loess area accounts for about 10% of global land area;
The area of China Loess Plateau is 64 km^2.

1 Research Background

- Soil and water loss in the Loess Plateau was serious, and the area of soil erosion accounted for about 70% (47.2×10^4 km^2) of the total area (Yang et al., 1999);

- Before 1990, engineer measures contributed 54% to soil and water conservation; After 1990, vegetation restoration measures became a major factor (57%) (Wang et al., 2016).



Fish-scale pit

Check dams

Terraced fields

2 Research status

- By the end of 2016, 59 037 check dams had been built in the Loess Plateau, including 5 829 backbone dams, 11 234 medium-sized check dams, and 4,1974 small check dams (Hui et al., 2018).

2 Research status

- The function of the check dam:

  Control channels erosion;

  Reduce flood and sediment disasters;

  Increase the farmland.

2 Research status

- By the end of 2012, the terraced fields area in the Loess Plateau was 3.7 million hm^2 (Ma et al., 2015).

坡地上修建的梯田
Terraced fields on sloping land

2 Research status

- The function of the terracing :

  Reduce soil erosion;

  Increase soil water content;

  Increase water and nutrient use efficiency.


坡地上修建的梯田
Terraced fields on sloping land

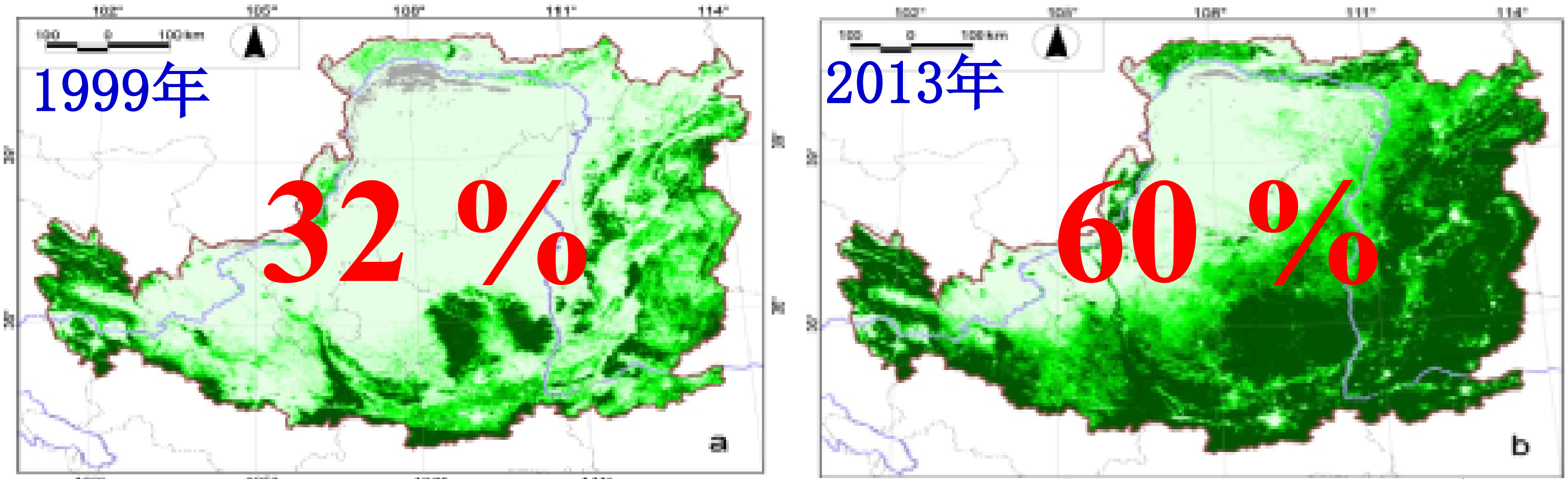
2 Research status

- In the much steeper slope lands and mountains, fish-scale pits were built. And fish-scale pit has the same functions as terraces.(Guo et al., 2017).


坡地上修建的鱼鳞坑
Fish-scale pit on sloping land

2 Research status

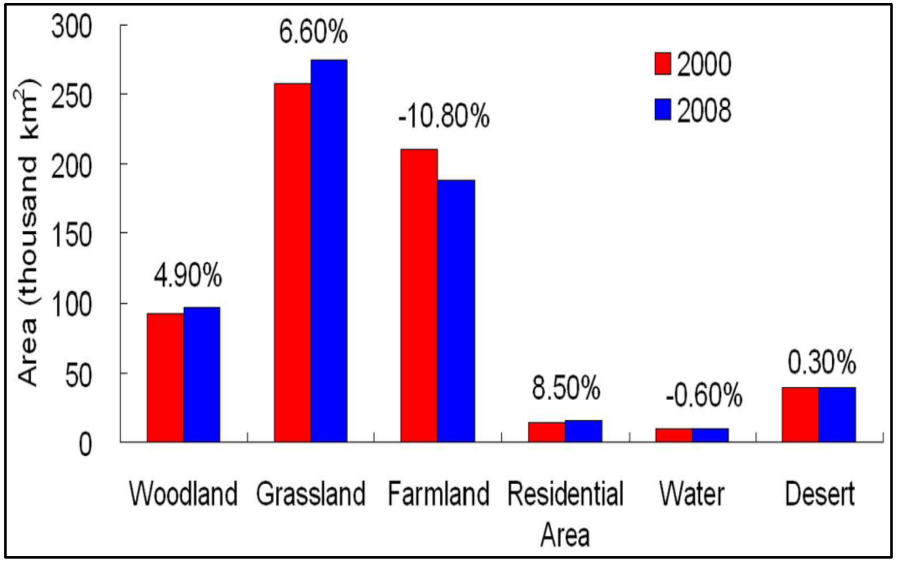
- In 1999, the project of returning farmland to forests (grass) began to be implemented, which significantly increased the vegetation cover on the Loess Plateau.



Vegetation cover change in the Loess Plateau（Chen et al., *Nature Geosci.*, 2015）

Comparison of Vegetation Coverage in Hujia Village, Heijiapu, Yanchang County

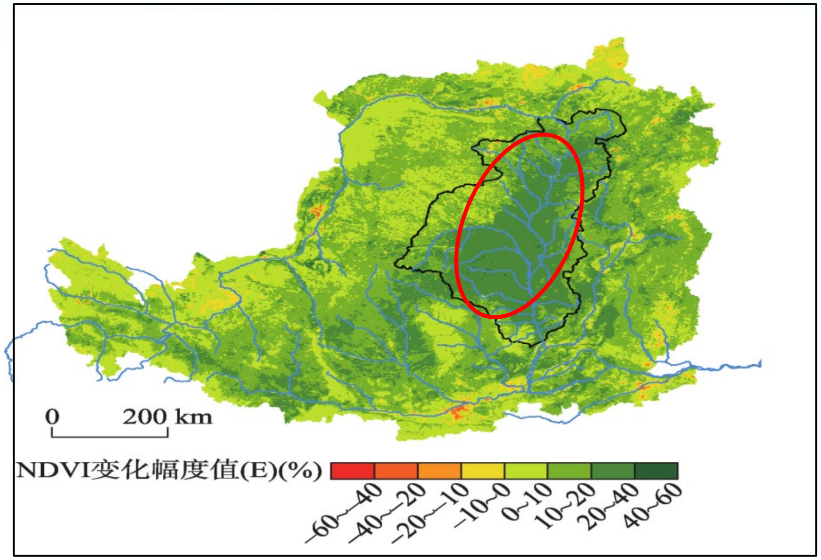
2 Research status

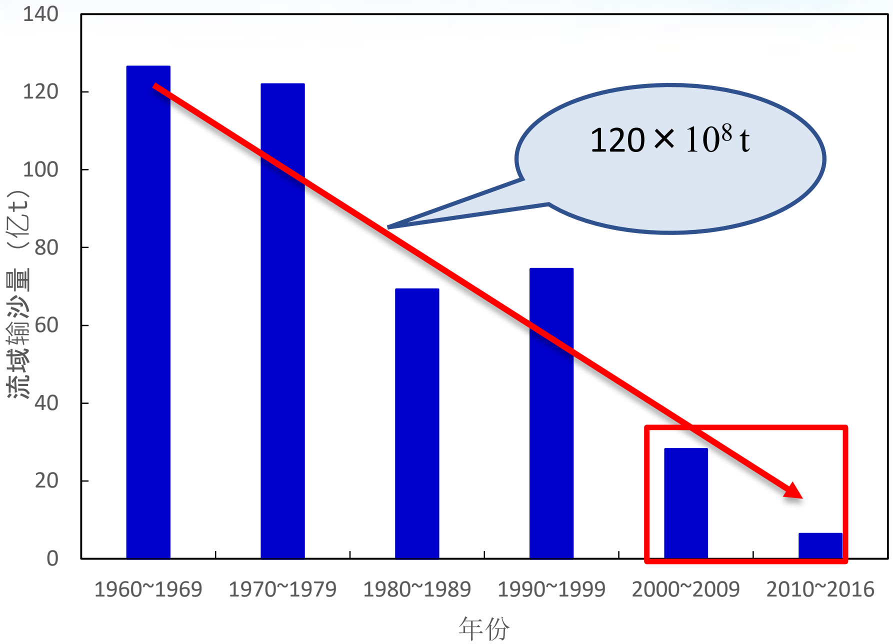


Land use type change in the Loess Plateau in 2000-2008(Lü et al., *Plos One*, 2012)

- From 2000 to 2008, the farmland decreased, and the grassland and forest land increased.
- The grassland area was about 2.5 times that of the forest land and 1.3 times that of the farmland.

2 Research status



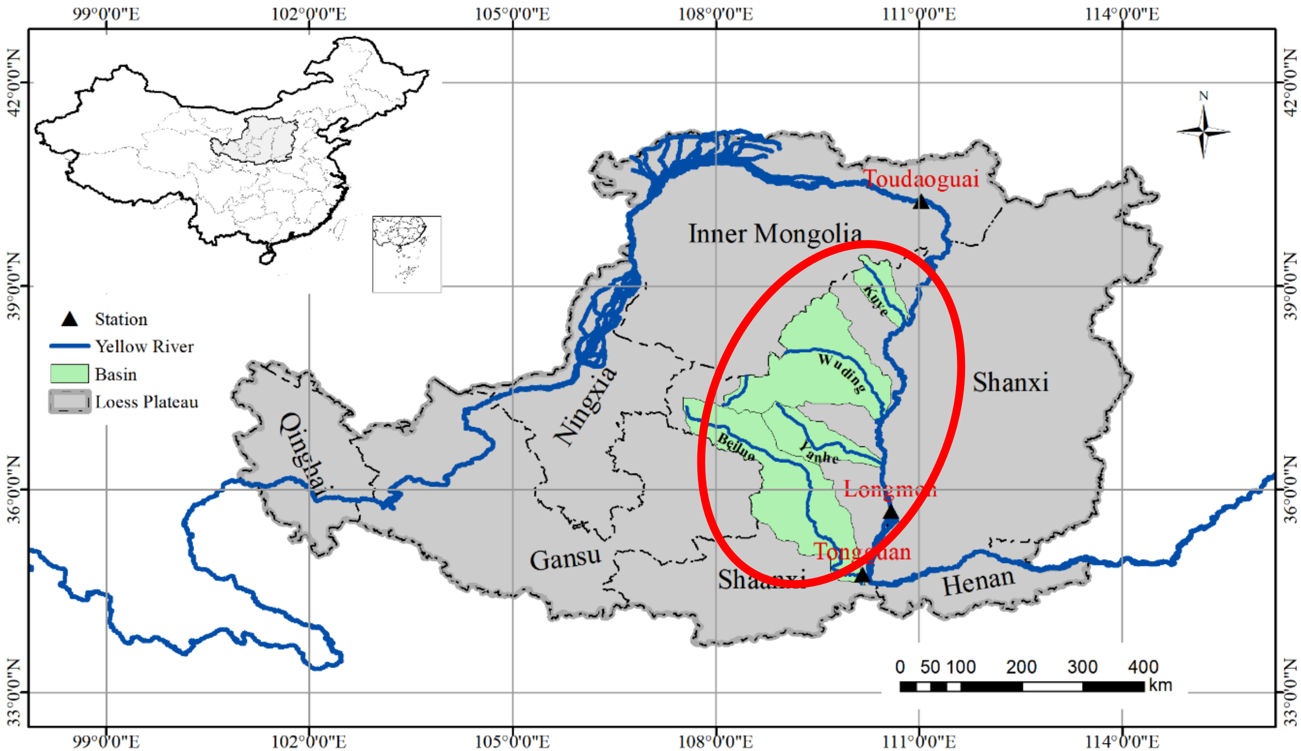


The variation of NDVI in the Loess Plateau in 1999-2013（Gao et al., 2017）

The amount of sediment transportation in Toudaoguai-Tongguan

- Changes of land use types in typical basins?
- The spatial and temporal changes of the NDVI in typical basins?
- Changes and causes of runoff and sediment transportation in typical basins？

3 A case study



The study area is the typical basins in the northern Loess Plateau

Zhao QQ, Wang L*, Liu H, Zhang QF. Runoff and sediment variation and attribution over 60 years in typical Loess Plateau basins [J]. Journal of Soils and Sediments, 2019, https://doi.org/10.1007/s11368-019-02345-z

3.1 Analysis on the change of land use type in typical basins

3.1.1 Distribution characteristics of basins land use structure

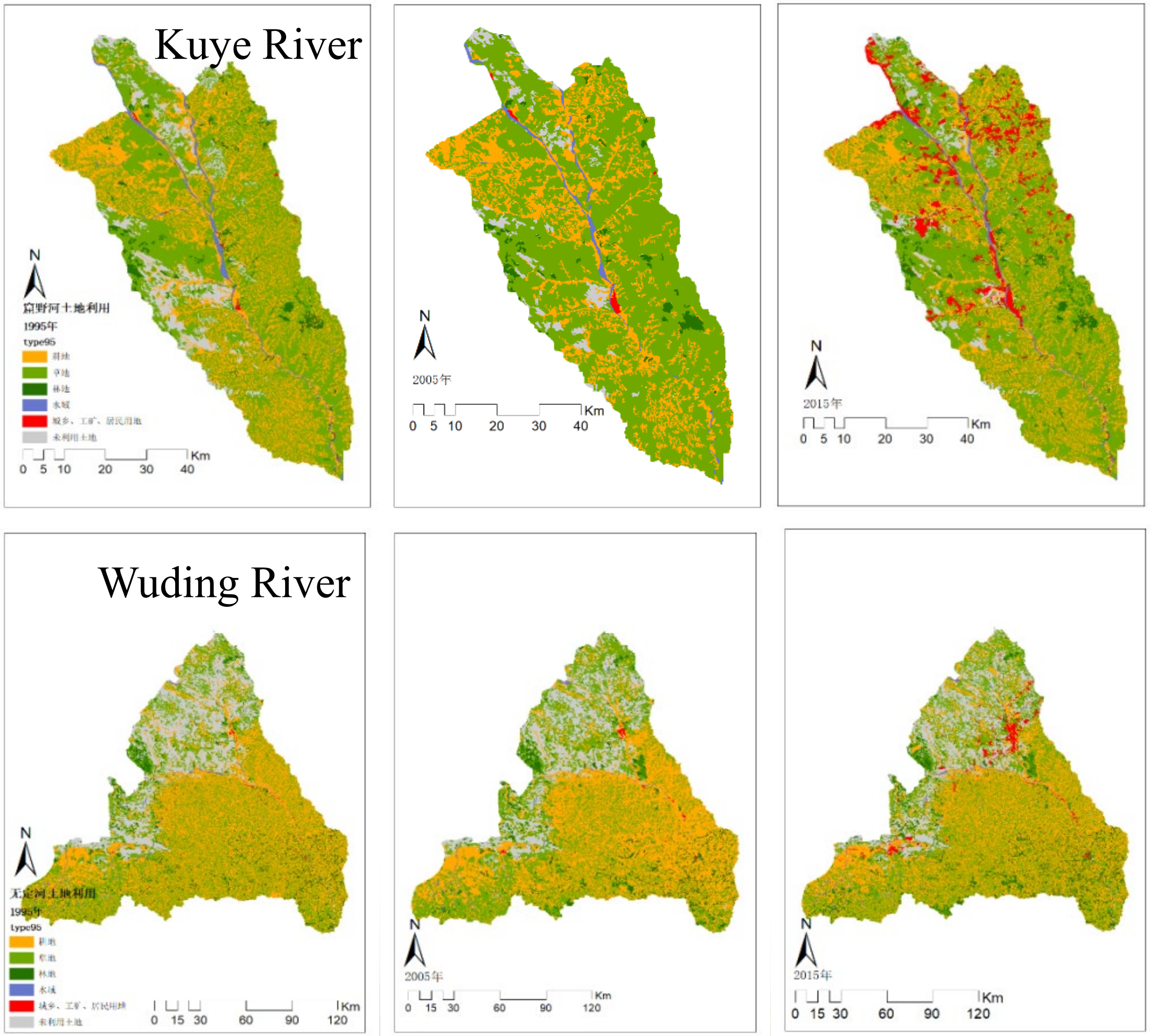
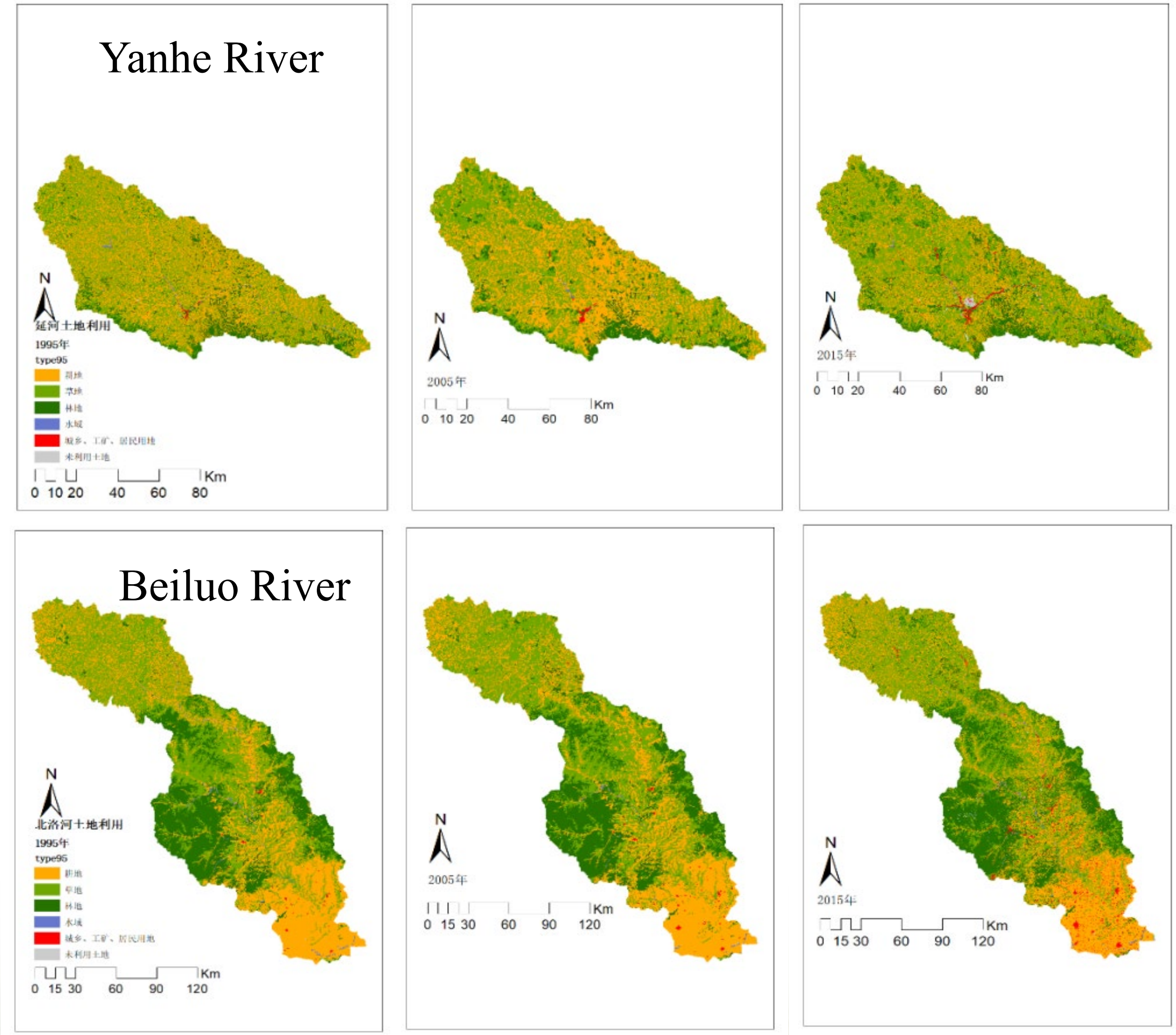


Fig. 3-1-1a The distributions of land use of typical basins in 1995, 2005 and 2015

- The distribution of farmland in the Kuye River and Wuding River Basins in Shaanxi Province decreased, while the distribution of grassland, forest and built-up land increased significantly. It mainly occurred in the north-central part of the Kuye River and the southeastern part of the Wuding River.

3.1 Analysis on the change of land use type in typical basins

3.1.1 Distribution characteristics of basins land use structure



- Land use change mainly occurred in the entire basin of Yanhe, especially in the northeast and the northern part of the Beiluo River.

Fig. 3-1-1b The distributions of land use of typical basins in 1995, 2005 and 2015

3.1 Analysis on the change of land use type in typical basins

3.1.2 The area of different land use types in typical basins

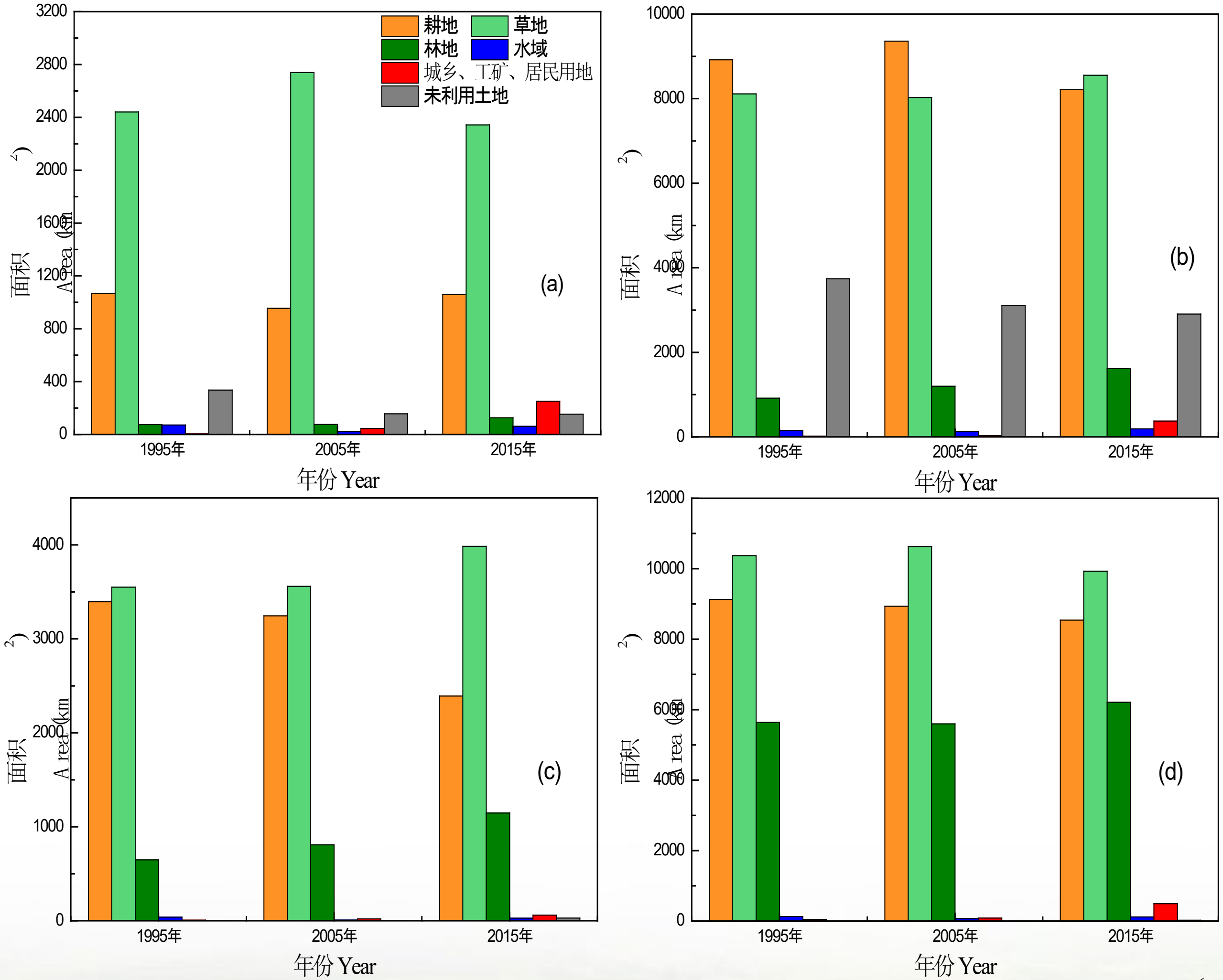


Fig. 3-1-2 The area of different land use types in typical basins（a）Kuye River （b）Wuding River（c）Yanhe River（d）Beiluo River

- In the four basins, in 1995, 2005 and 2015, grassland was the main type of land use (except the Wuding River in 1995 and 2005).
- The area of farmland in the four river basins decreased, and the area of grassland and forest land increased. The increase in forest area was 68.3%, 76.6%, 76.9% and 10.1%.

3.1 Analysis on the change of land use type in typical basins

3.1.2 The area of different land use types in typical basins

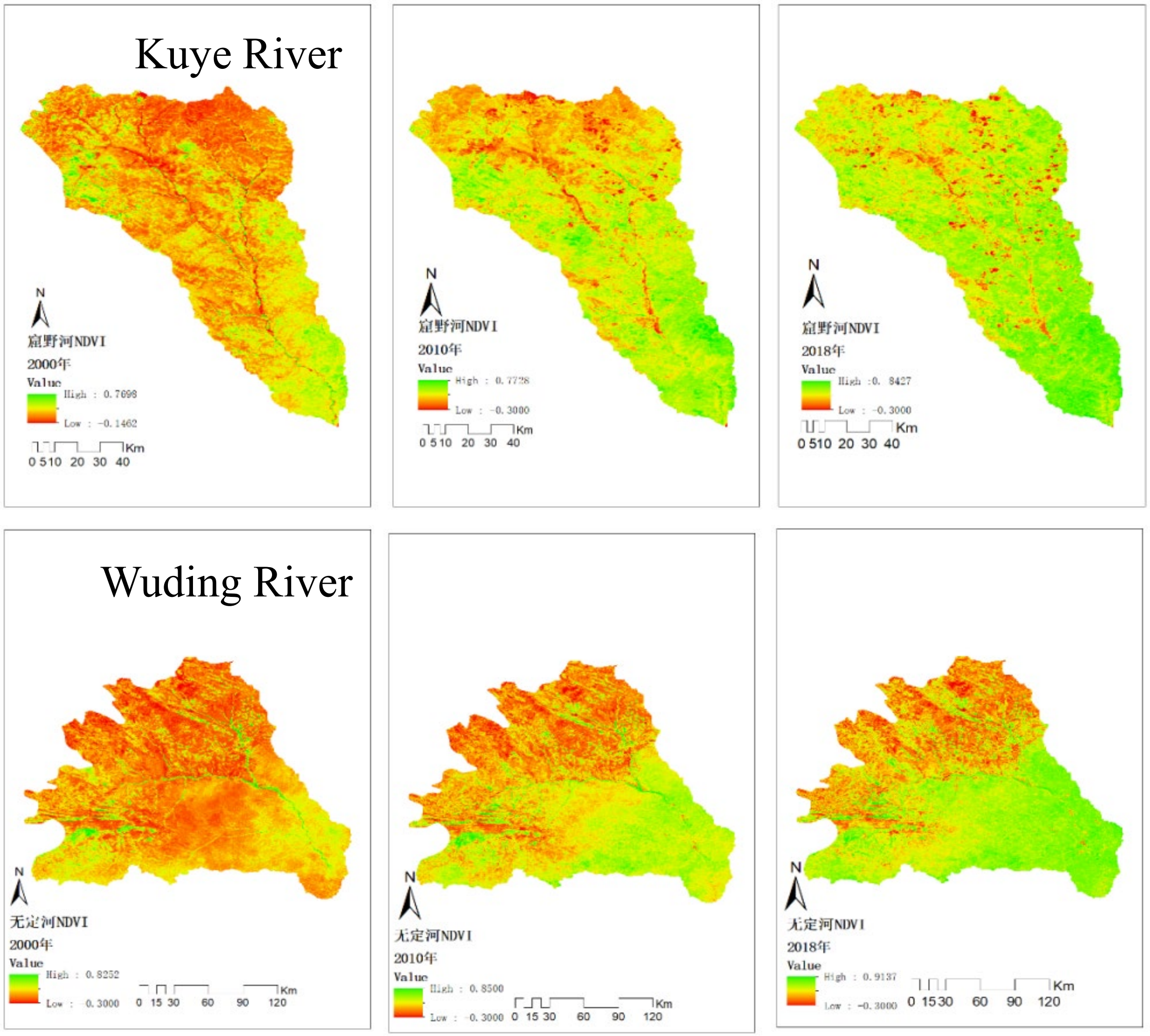
Tab. 3-1-1 Land use type area of typical basins in Shaanxi Province in 2015（km^2）

土地利用类型 Land use type	窟野河 Kuye	无定河 Wuding	延河 Yanhe	北洛河 Beiluo
耕地Farmland	1059.28	8211.11	2391.80	8540.70
草地Grassland	2342.64	8551.24	3985.61	9930.03
林地Forest	126.06	1617.87	1146.68	6208.72
水域Water	61.66	189.01	27.28	117.55
建设用地Built-up	251.66	373.14	60.21	492.18
未利用土地Unused	152.78	2905.29	28.58	23.54

◆ In the four basins in Shaanxi Province, grassland was the main land use type in 2015.

3.2 Temporal and spatial variability of typical basins NDVI

3.2.1 Distribution of NDVI status of typical basins in 2000, 2010 and 2018

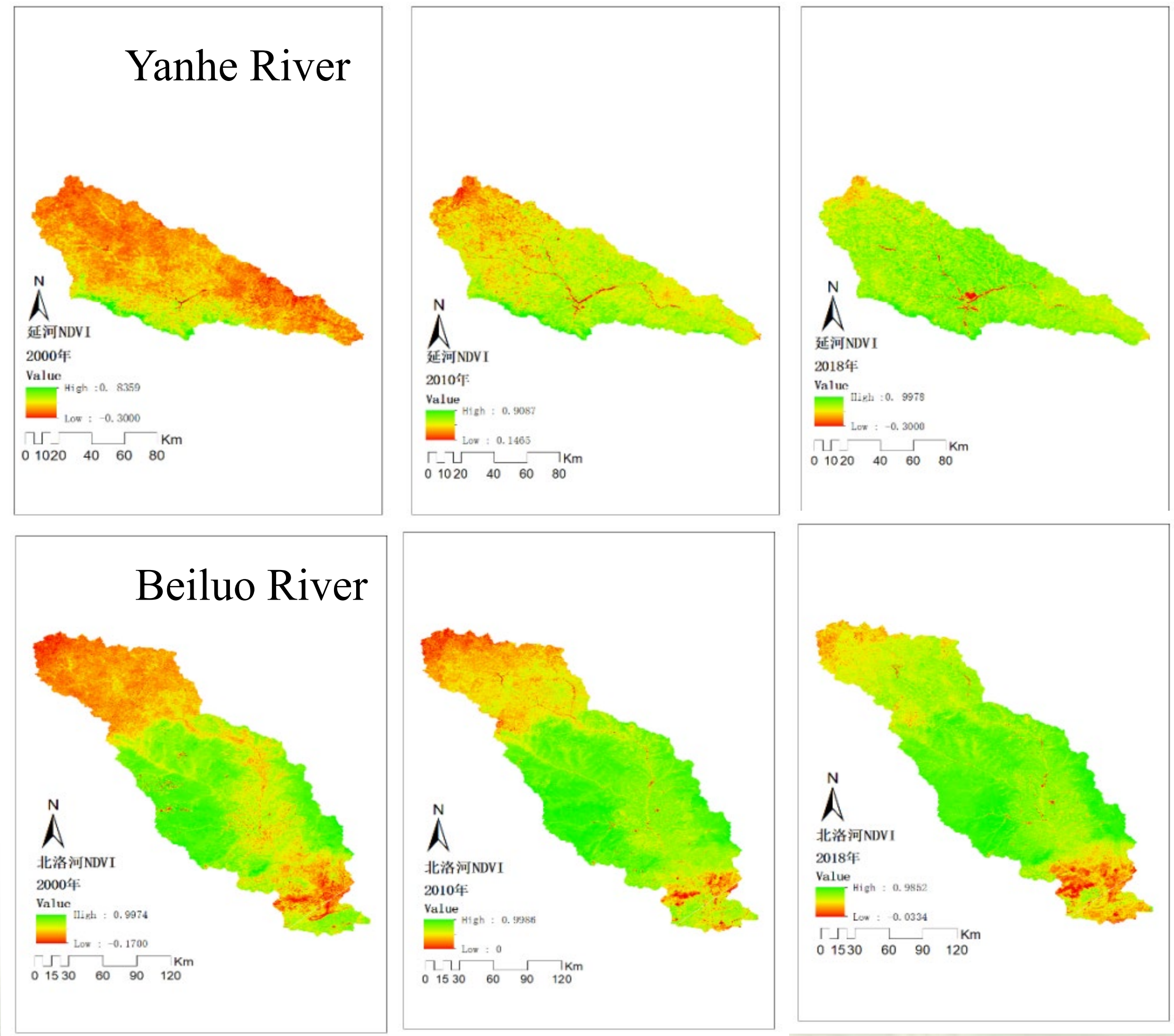


- The NDVI of the Kuye River and the Wuding River Basin during the vigorous growth period was increase. From the perspective of spatial distribution, it was mainly in the north of the Kuye River and southeast of the Wuding River.

Fig. 3-2-1a Distribution of NDVI status of typical basins in 2000, 2010 and 2018

3.2 Temporal and spatial variability of typical basins NDVI

3.2.1 Distribution of NDVI status of typical basins in 2000, 2010 and 2018



- From the perspective of spatial distribution, the NDVI in the Yanhe and Beiluo River basins were mainly in the northeastern part of the Yanhe River and the northern part of the Beiluo River.

Fig. 3-2-1b Distribution of NDVI status of typical basins in 2000, 2010 and 2018

3.2 Temporal and spatial variability of typical basins NDVI

3.2.2 Area percentage of different levels of NDVI in typical basins

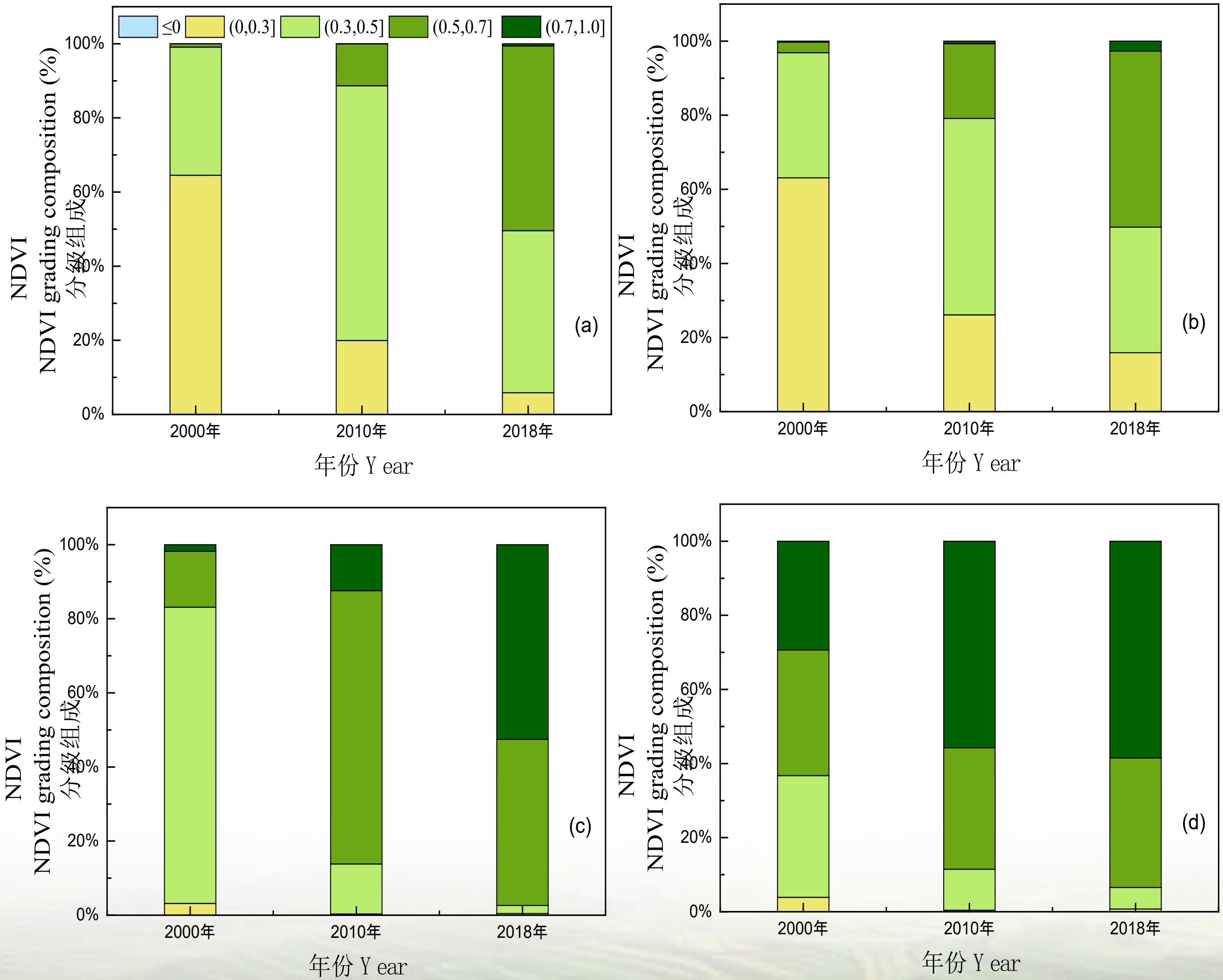
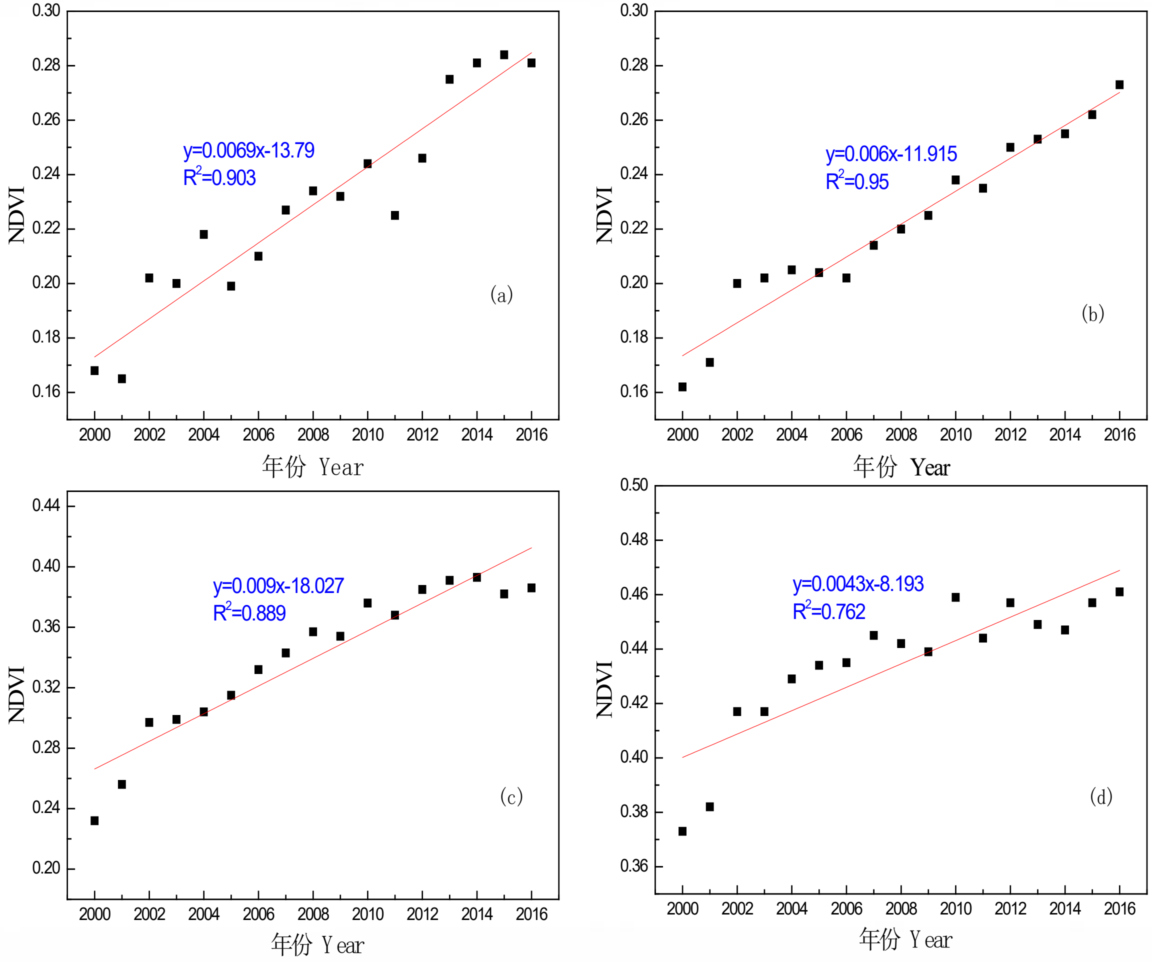


Fig. 3-2-2 Area percentage of different levels of NDVI in typical basins

- The NDVI of the four basins area in the (0,0.3] were continuous reduction. The largest decrease was the Kuye River Basin.
- The NDVI of the four basins with the high vegetation coverage area in the (0.7,1] were increase. The largest increase was the Yanhe River Basin.

3.2 Temporal and spatial variability of typical basins NDVI

3.2.4 Annual average NDVI variation from 2000 to 2016 in typical basins



- From 2000 to 2016, the annual NDVI of the four basins showed an increasing trend ($P<0.01$), with annual growth rate of 0.7%, 0.6%, 0.9%, and 0.4%, respectively. The largest rate was Yanhe.

Fig. 3-2-4 Annual average NDVI variation from 2000 to 2016 in typical basins

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.1 Annual runoff and sediment trends in typical basins

3.3.1.1 Annual runoff trends in typical basins

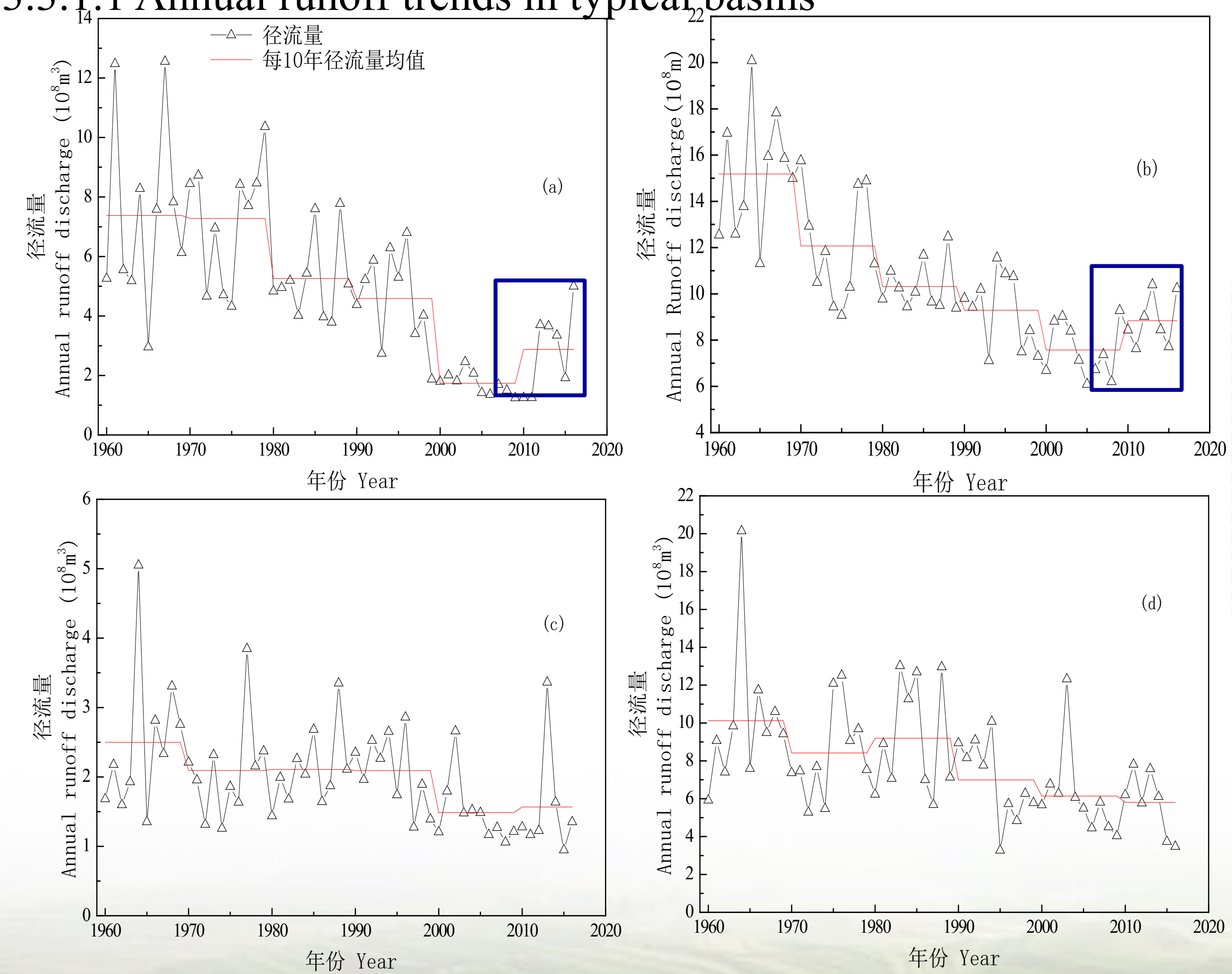


Fig. 3-3-1 Annual runoff trends in typical basins

- The runoff of the four basins showed a significantly decreasing trend from 1960 to 2016.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.1.2 Annual sediment trends in typical basins

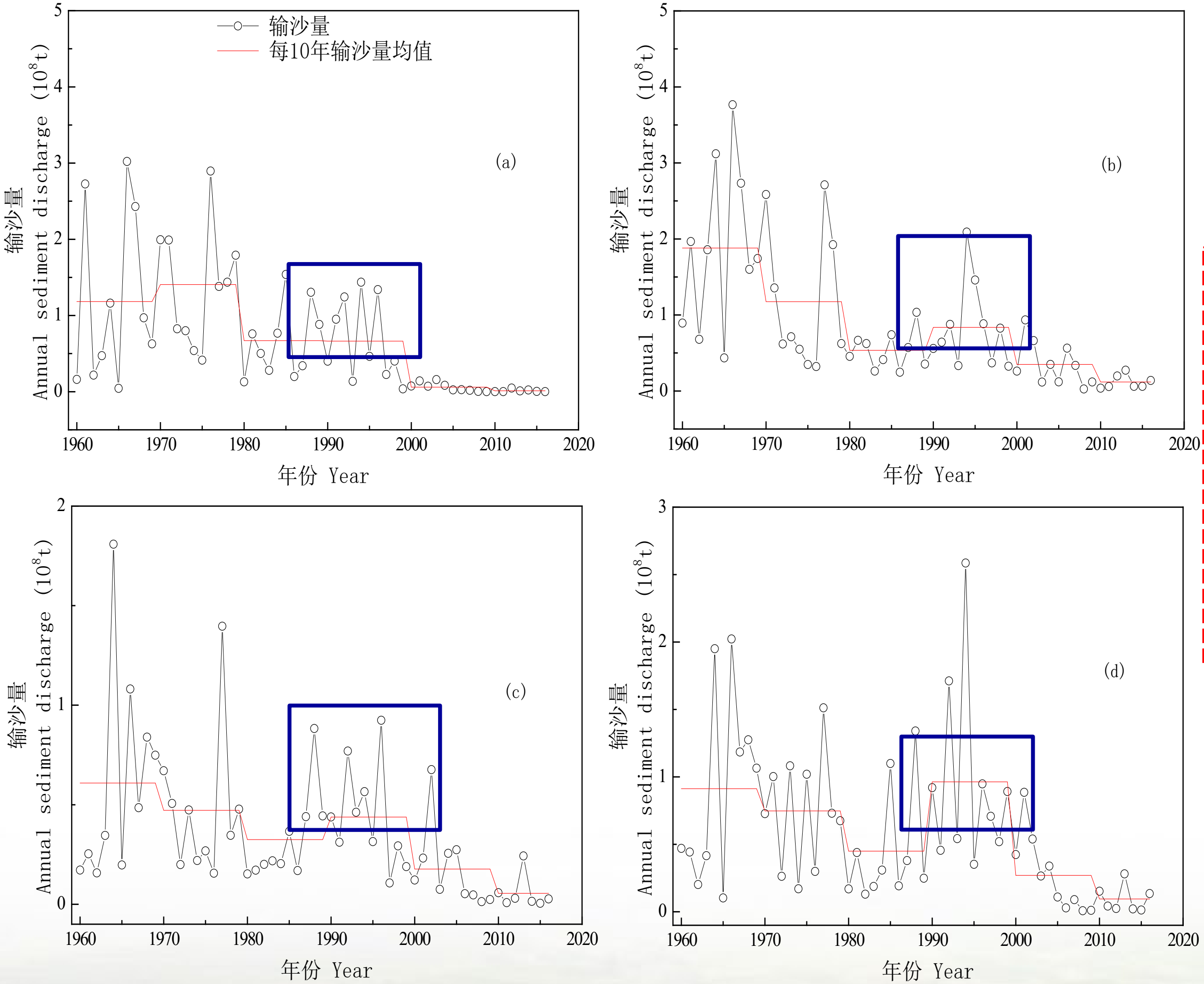


Fig. 3-3-2 Annual sediment trends in typical basins

◆ The sediment transportation of the four basins showed a significantly decreasing trend from 1960 to 2016.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.2 Anomaly accumulations for runoff and sediment volume in typical basins

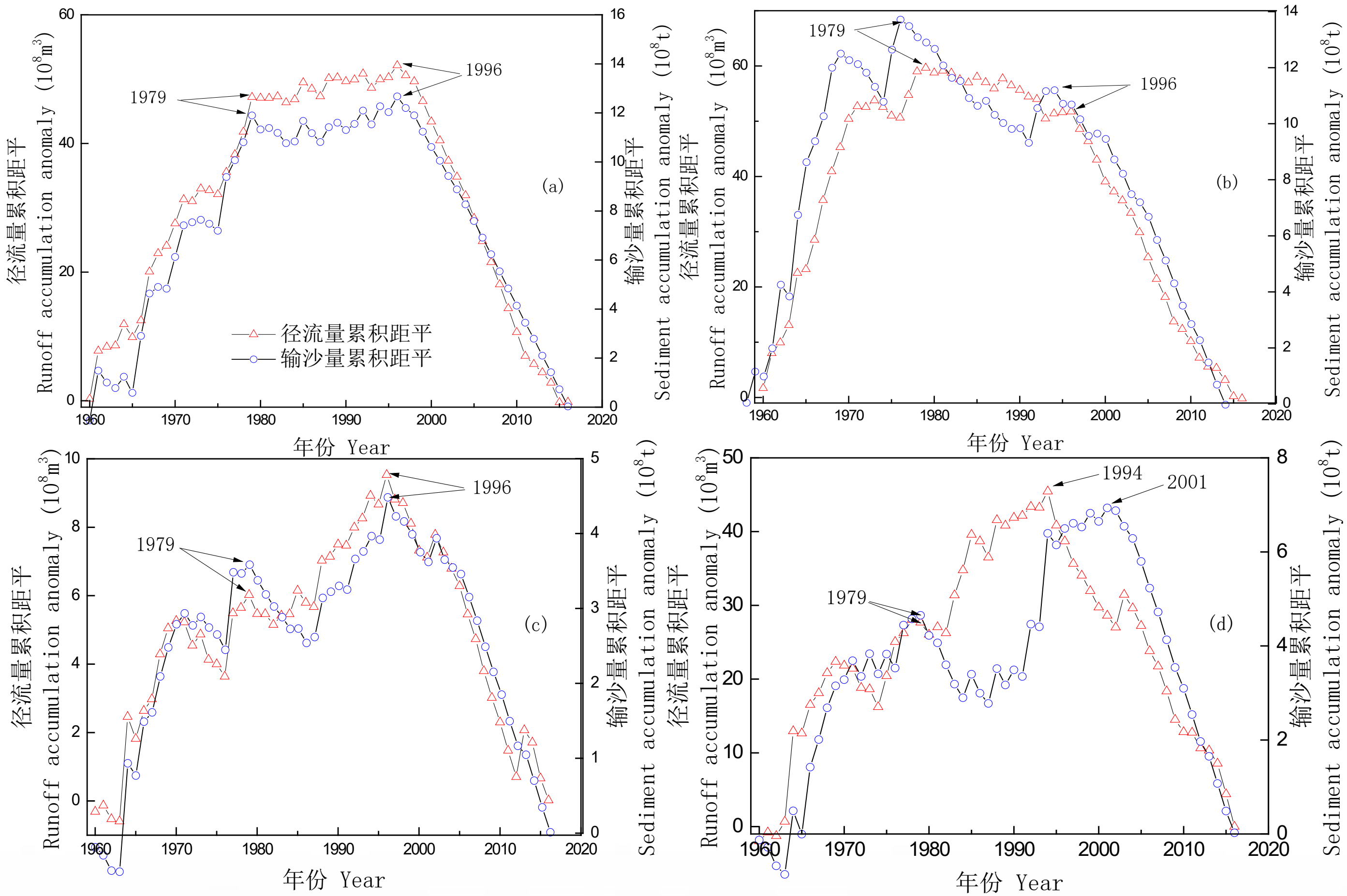
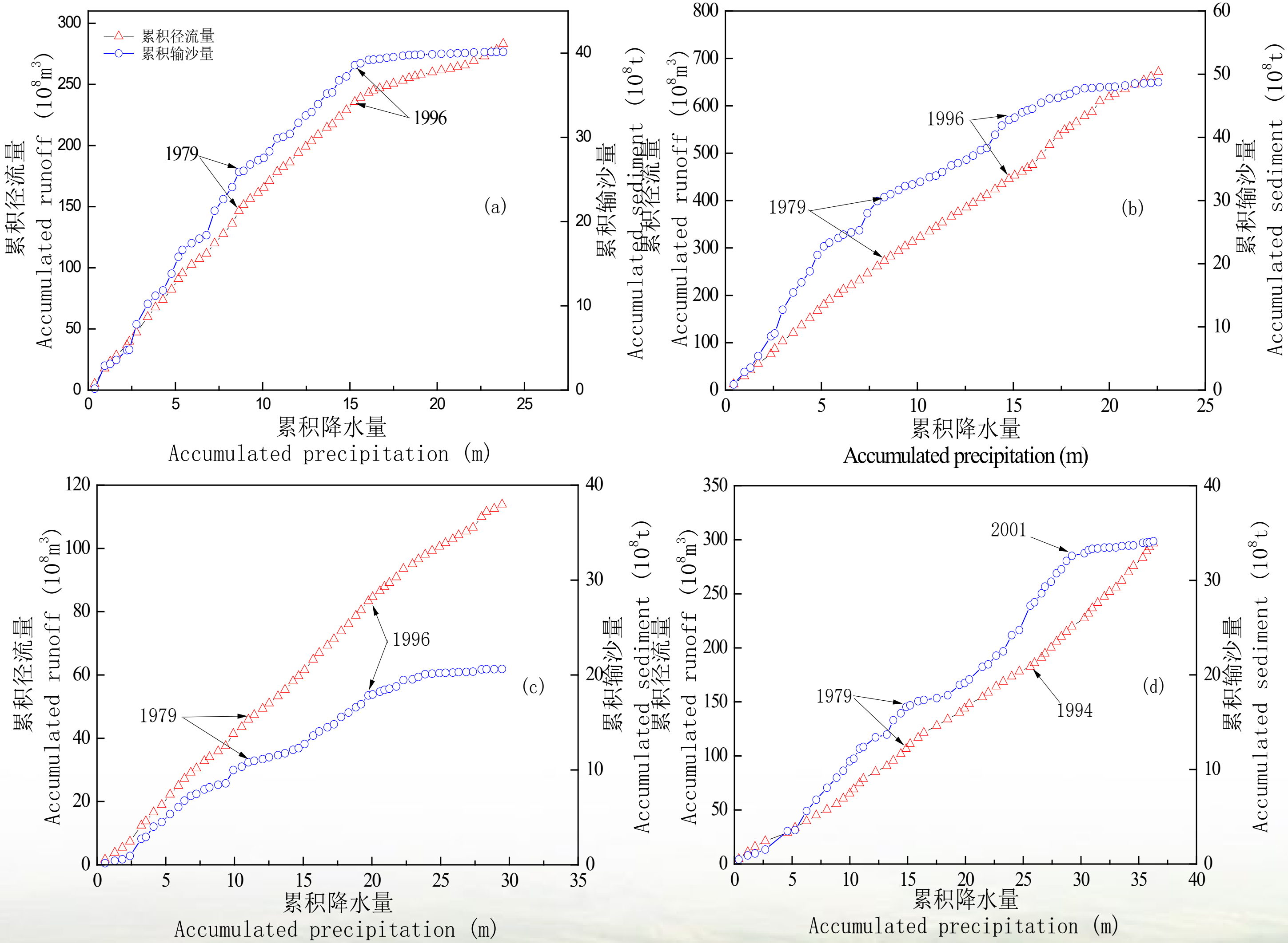


Fig. 3-3-3 Anomaly accumulations for runoff and sediment volume in typical basins

- The pivotal points for the basins of the three rivers Kuye, Wuding and Yanhe were all in 1979 and 1996.
- In the Beiluo River basin, the fluctuations were relatively complex.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.3 Precipitation-runoff and precipitation-sediment accumulation in typical basins



In the Kuye River, Wuding River and Yanhe River basins, both curves shifted at 1979 and 1996.

In Beiluo River basin shifted at 1979 and 1994. and the 1979 and 2001.

Fig. 3-3-4 Precipitation-runoff and precipitation-sediment accumulation in typical basins

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.5 Effects of precipitation and human activities on runoff and sediment

3.3.5.1 Effects of precipitation and human activities on runoff in typical basins

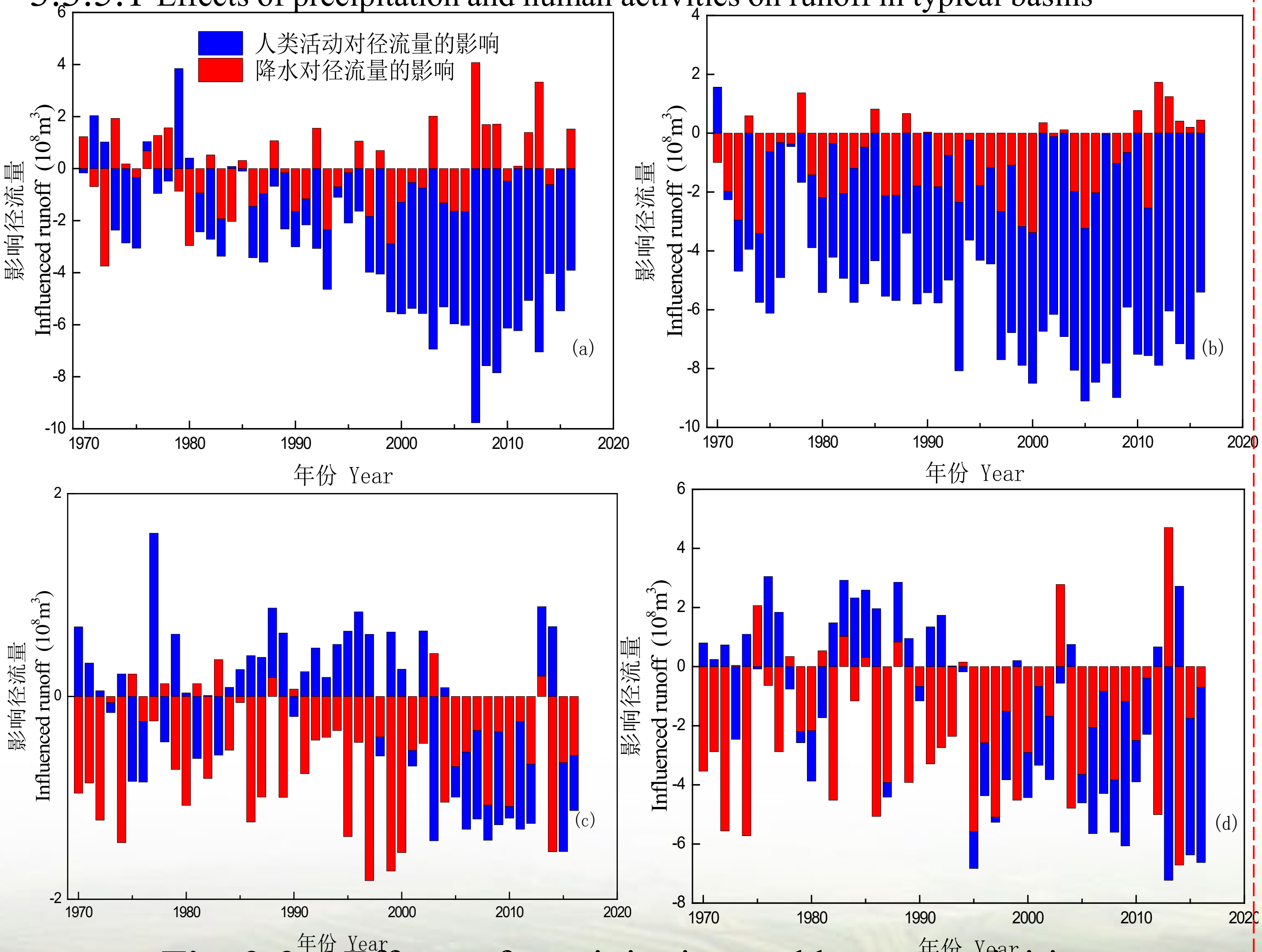


Fig. 3-3-6 Effects of precipitation and human activities on runoff in typical basins

- For the Kuye and Wuding River basins, it can be seen that during the entire period of 1970–2016, human activities played a major role in reducing runoff. The impact of human activities was 2.77×10^8 m^3 and 4.45×10^8 m^3, respectively.
- In the Yanhe and Beiluo River basins, precipitation obviously contributed to the reduction in runoff, with an impact on runoff of 0.61×10^8 m^3 and 2.09×10^8 m^3, respectively.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.5.1 Effects of precipitation and human activities on sediment in typical basins

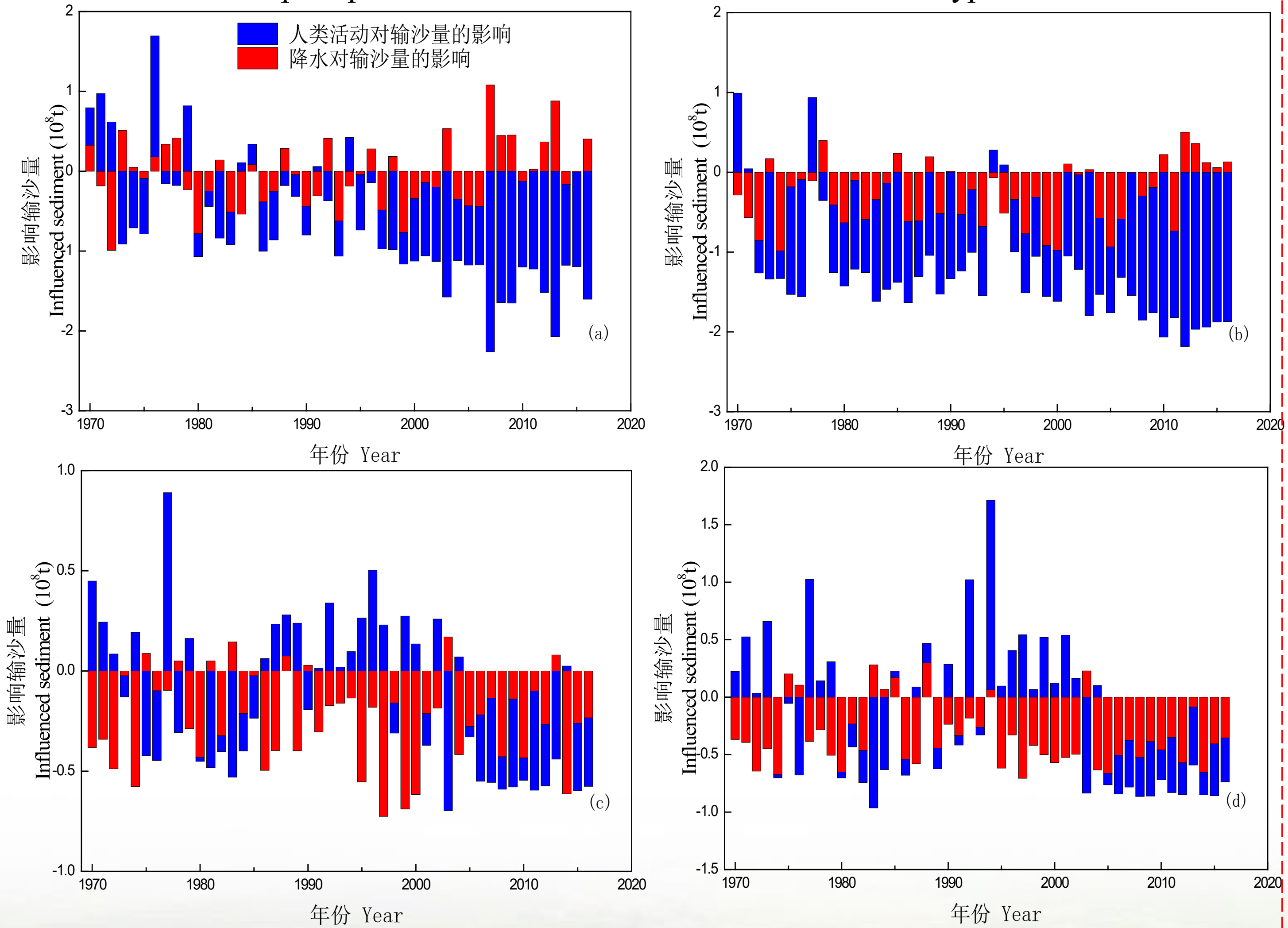


Fig. 3-3-7 Effects of precipitation and human activities on sediment transportation in typical basins

- In Kuye and Wuding River, in 1970-2016, human activities contributed significantly to the reduction in sediment discharge, the impact being 0.56×10^8 t and 0.97×10^8 t, respectively.
- In Yanhe and Beiluo River, precipitation contributed significantly to the reduction in sediment discharge from 1970 to 2016. The impact on sediment discharge was 0.25×10^8 t and 0.35×10^8 t, respectively.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.6 Trends of NDVI and runoff in typical basins

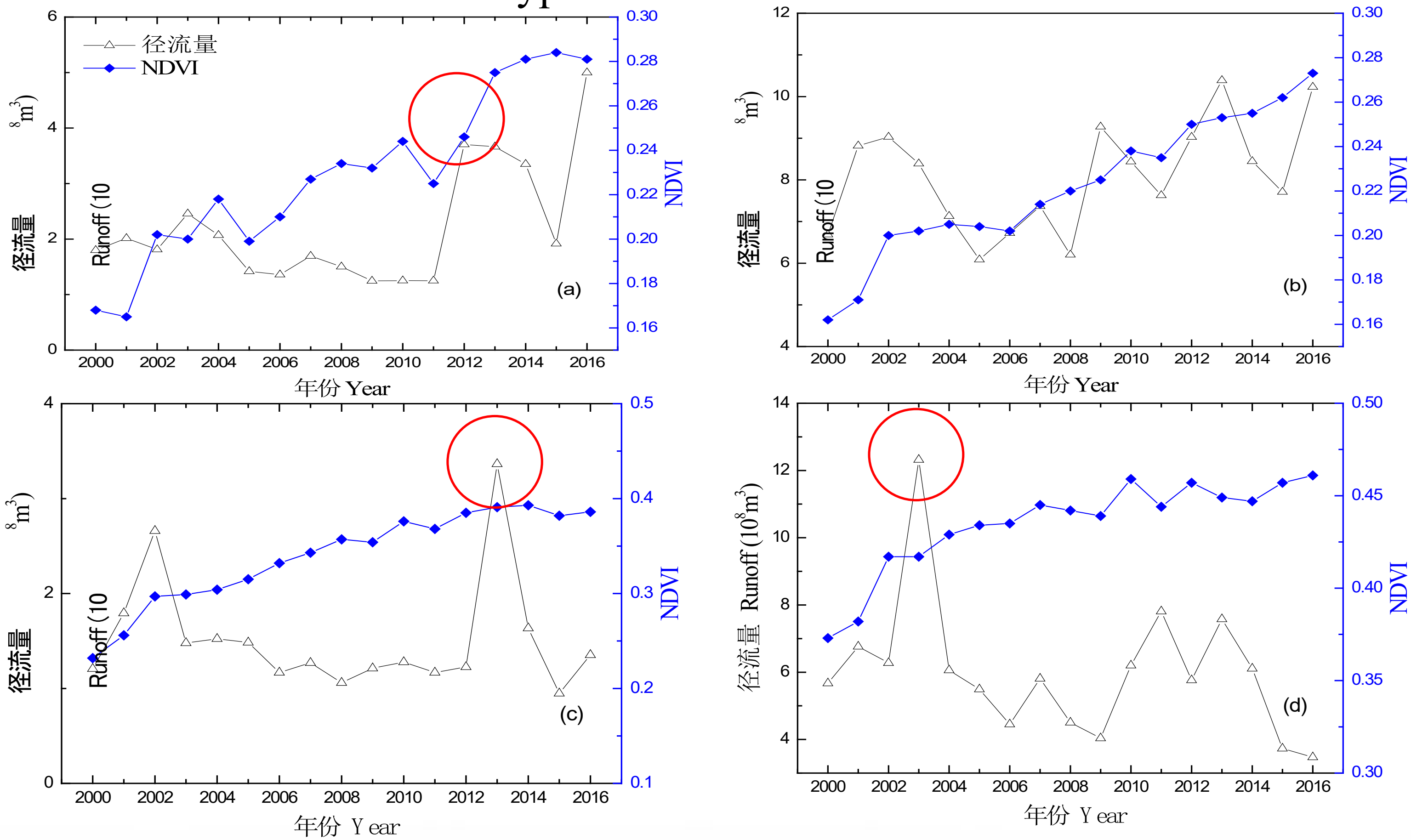


Fig. 3-3-8 Trends of NDVI and runoff in typical basins

- As the NDVI increasing, the runoff in the basins decreased.
- In Yanhe River and Beiluo River, the NDVI were increasing, but the runoff in four basins were decreasing, the negative correlation between them were poor.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.7 Trends of NDVI and sediment transportation in typical basins

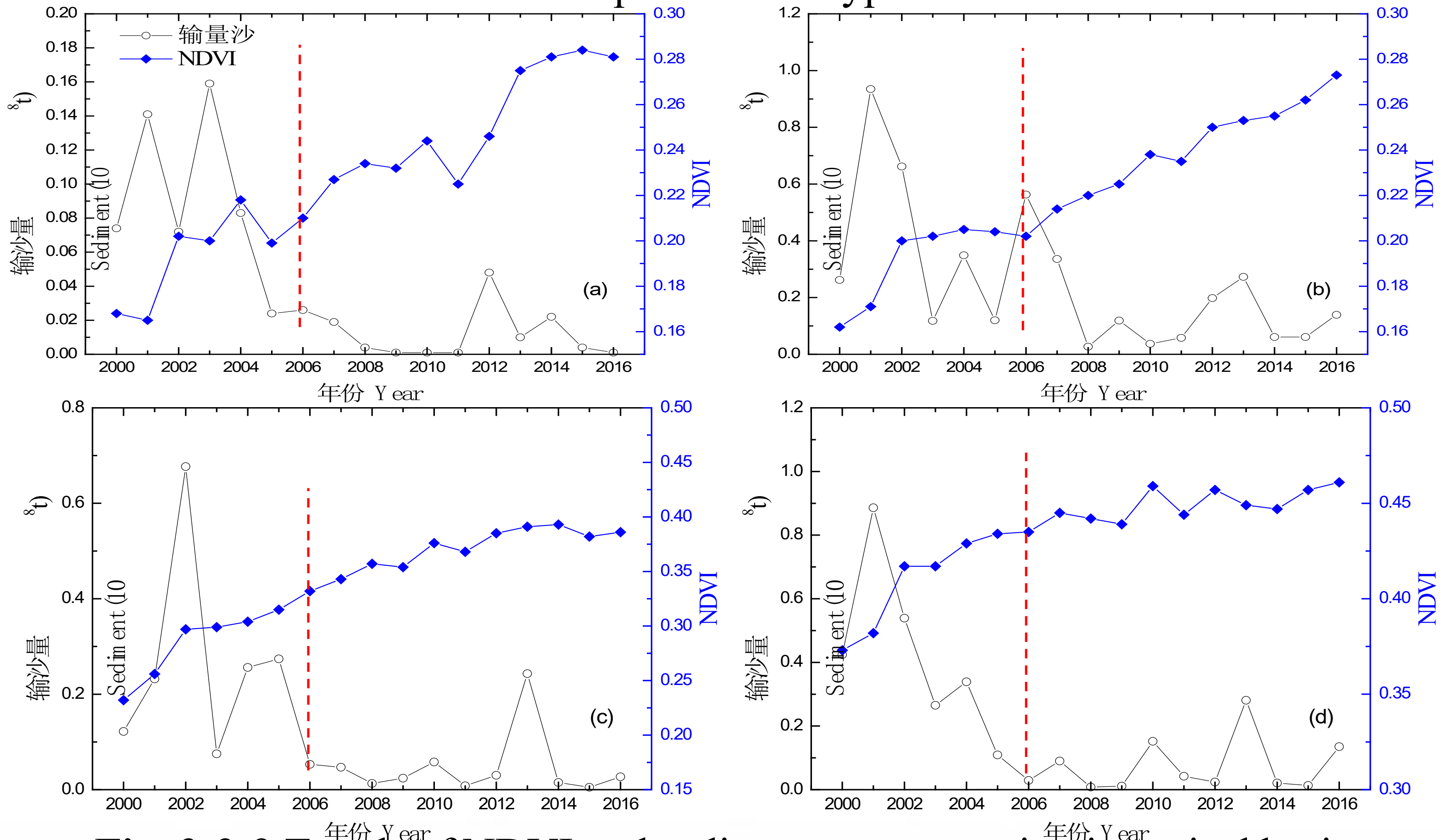


Fig. 3-3-9 Trends of NDVI and sediment transportation in typical basins

◆ The trend of average annual NDVI in the four typical basins were negative relationship with the trend of annual average sediment transportation. This shown that vegetation restoration was conducive to the reduction of sediment transportation.

3.3 Changes in runoff and sediment transportation in typical basins and their responses to NDVI

3.3.8 Conclusion

- The runoff and sediment transportation of the four basins showed a significantly decreasing trend from 1960 to 2016.
- The changes in sediment discharge were influenced by precipitation and human activities. Compared with precipitation, **human activities within the more northerly Kuye and Wuding River basins have played a more prominent role in the changes in sediment regimes**. For the more southerly Yanhe and Beiluo River basins, throughout the research period, the effect of a reduction in precipitation on the runoff and sediment discharge has been greater than the effect of human activities.
- The trend of average annual NDVI in the four typical basins were negatively related with the trend of annual average sediment transportation.

4 Future possible research topic

- **What are the scientific issues that the Loess Plateau really needs to study?**

  (1) Soil erosion: many studies

  (2) Vegetation restoration: many studies

  (3) Runoff and sediment changes: many studies

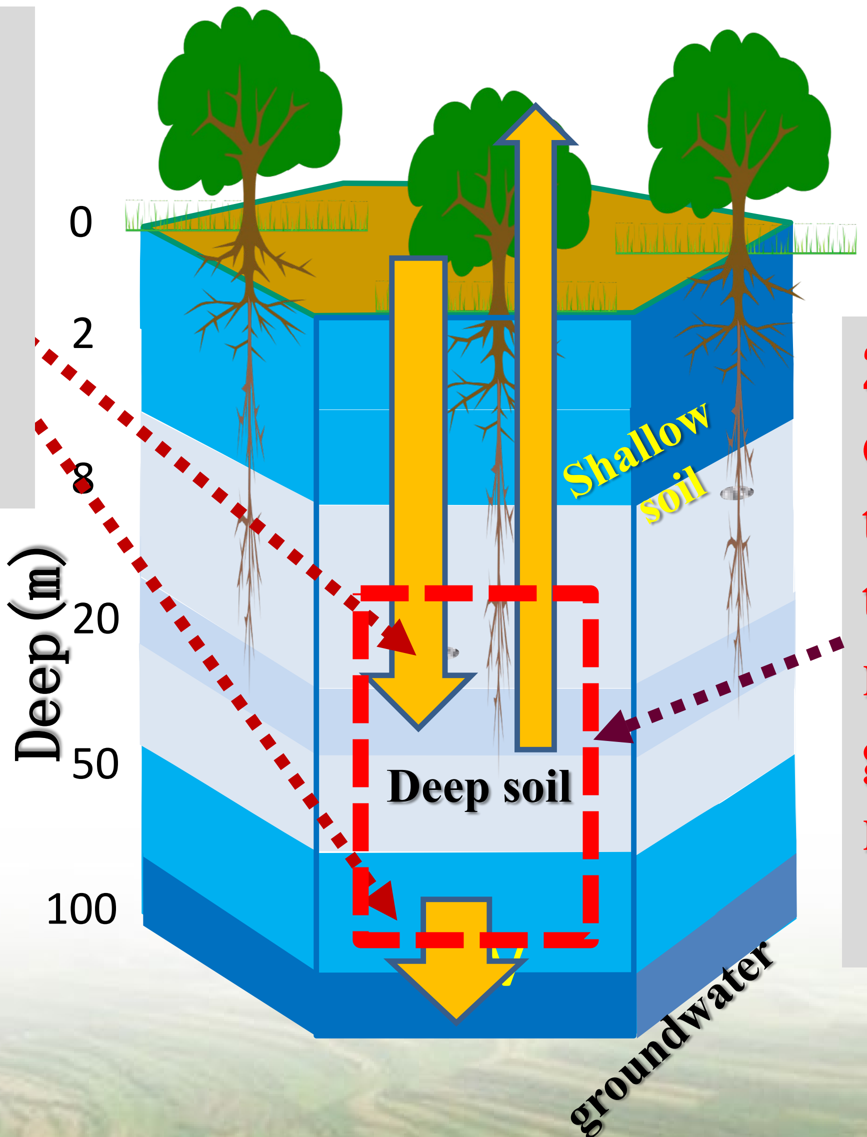
- **Two important scientific questions:**

  (1) Why natural forest vegetation exists only in loess and rock mountains?

  (2) Recharge route and mechanism of groundwater in thick layer loess area?

How does precipitation recharge groundwater through thick loess?

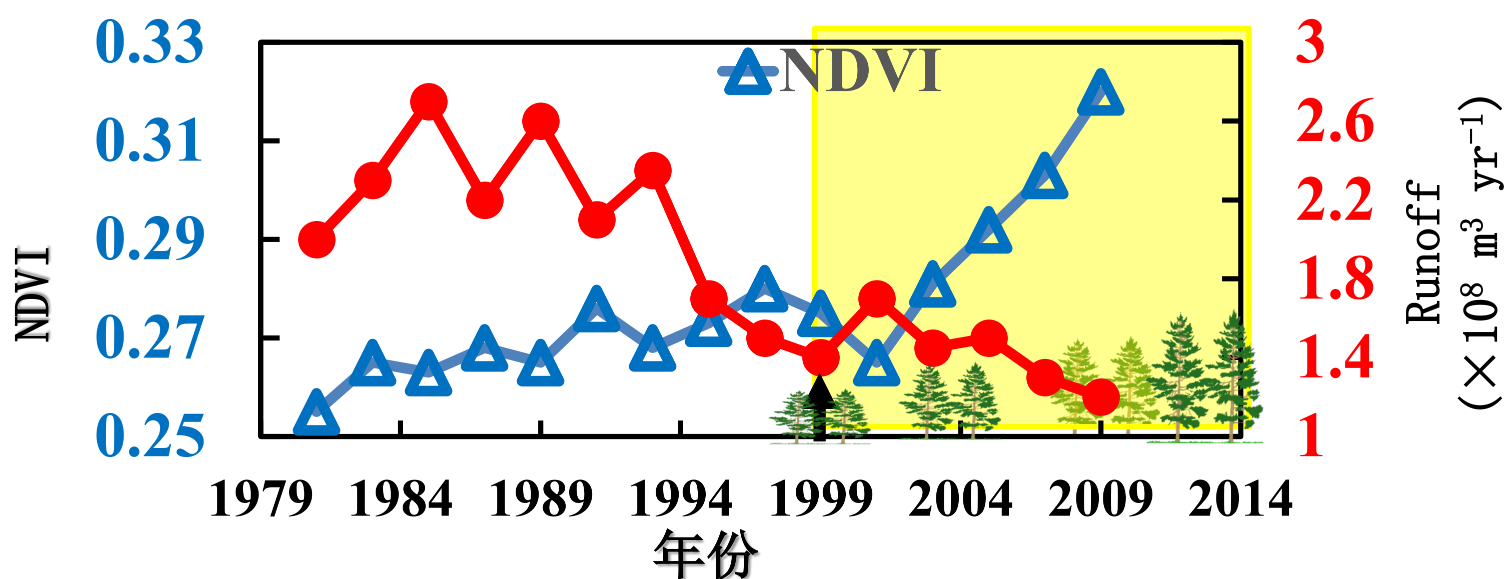
1：Movement mechanism and flux of deep soil water under deep soil conditions?

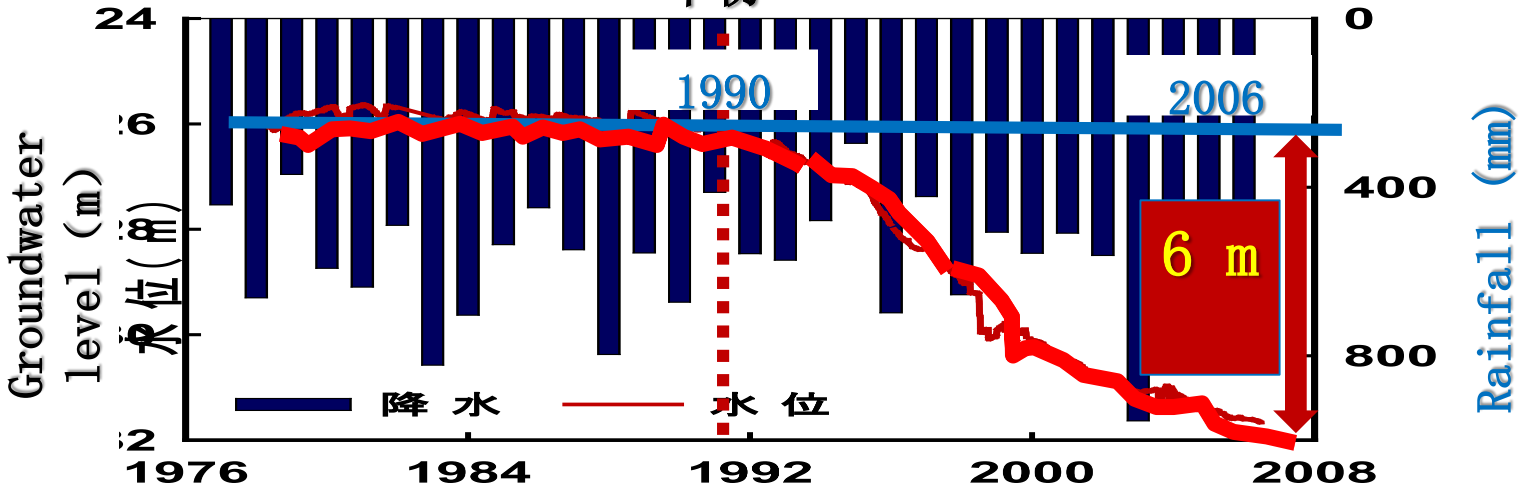


2：Contribution of deep soil water to vegetation transpiration and ratio of groundwater recharge?

Possible effects on groundwater recharge after extensive vegetation increase

Vegetation growth and groundwater level decline

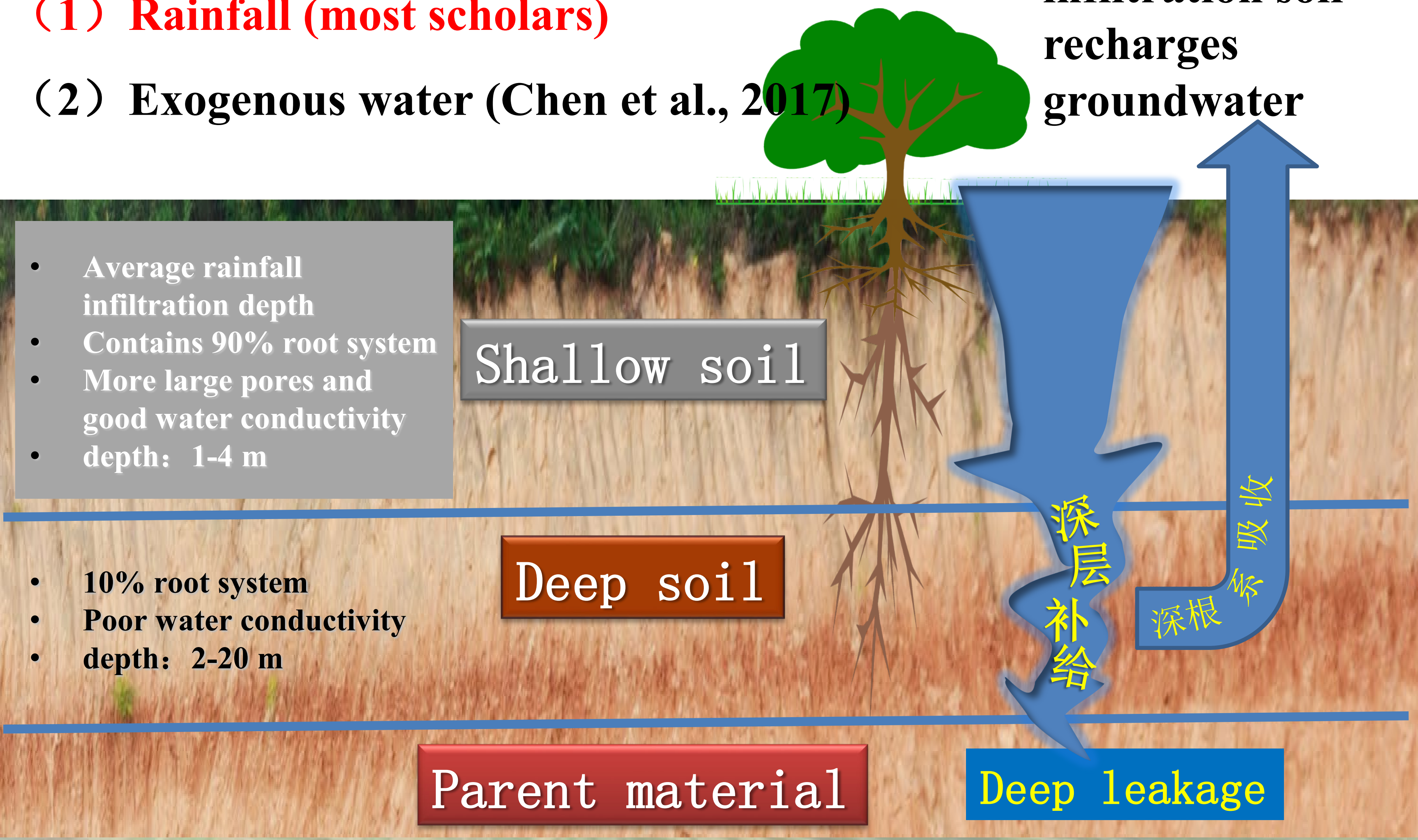




5.1 Recharge source

（1）Rainfall (most scholars)

（2）Exogenous water (Chen et al., 2017)

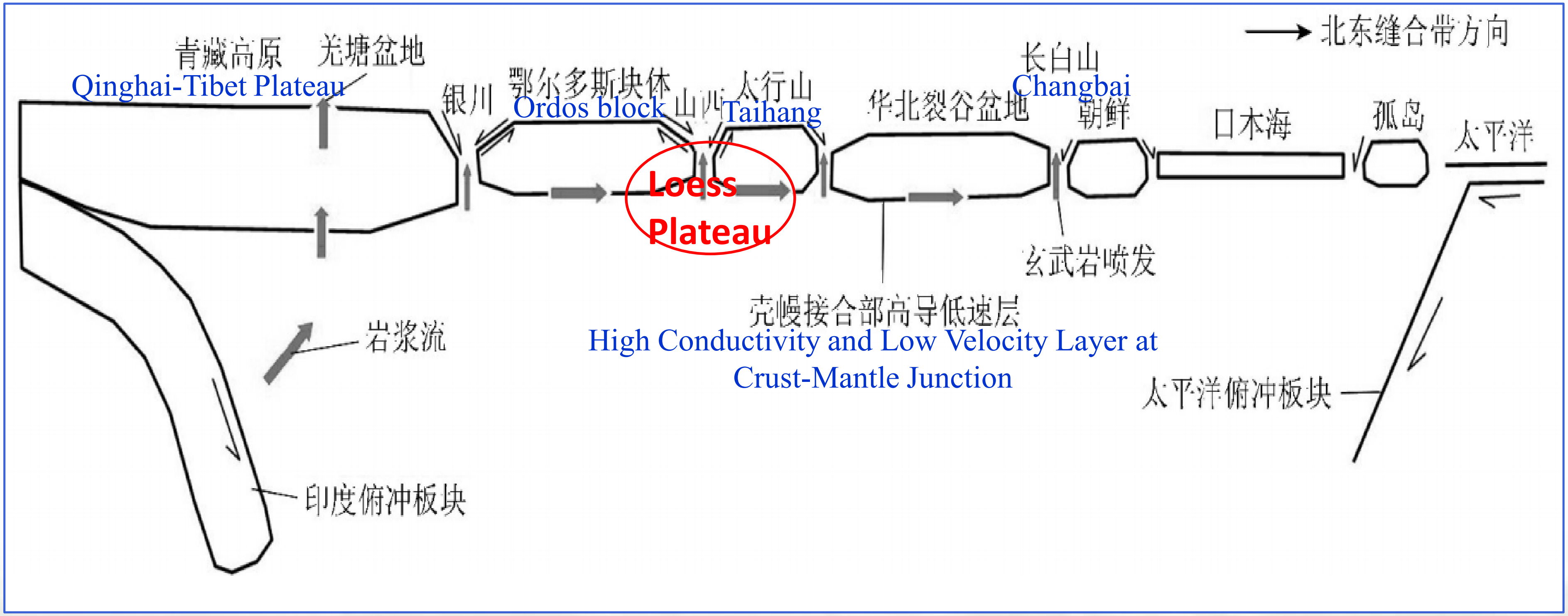


5.1 Recharge source

（1）Rainfall (most scholars)

（2）Exogenous water (Chen et al., 2017)

Groundwater in the Qinghai-Tibet Plateau is recharged through underground passages

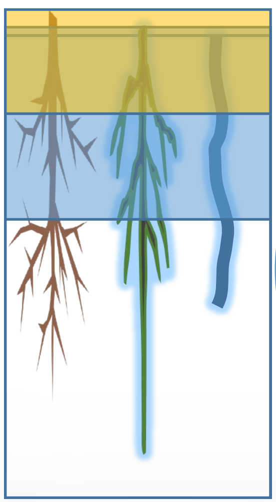


Magmatic activity and volcanic eruption caused by collision between Indian plate and Eurasian plate

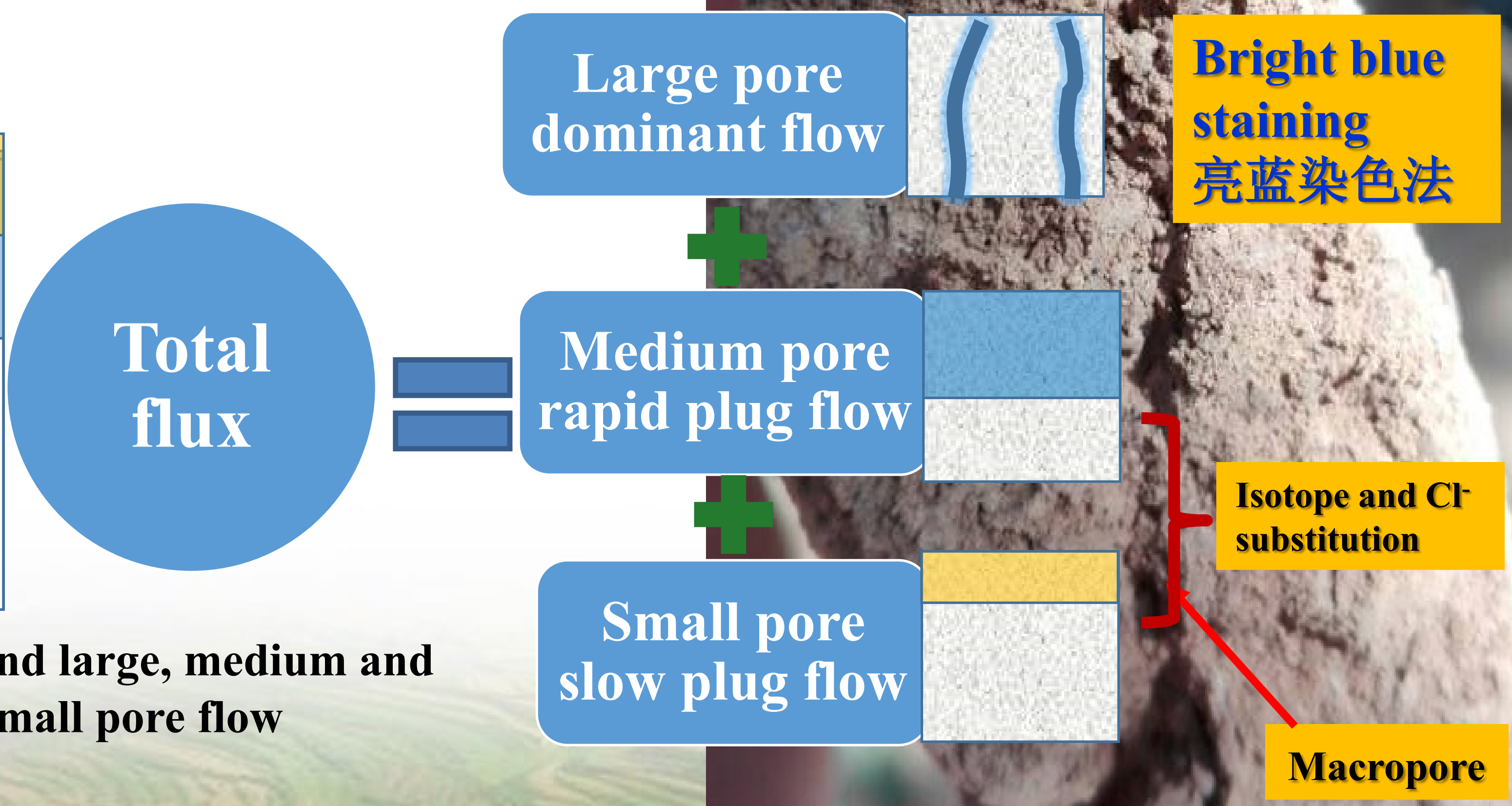
5.2 Recharge mechanism

(1) Piston flow - thick layer aeration zone

(2) Preferential flow - large pores, holes, cracks.

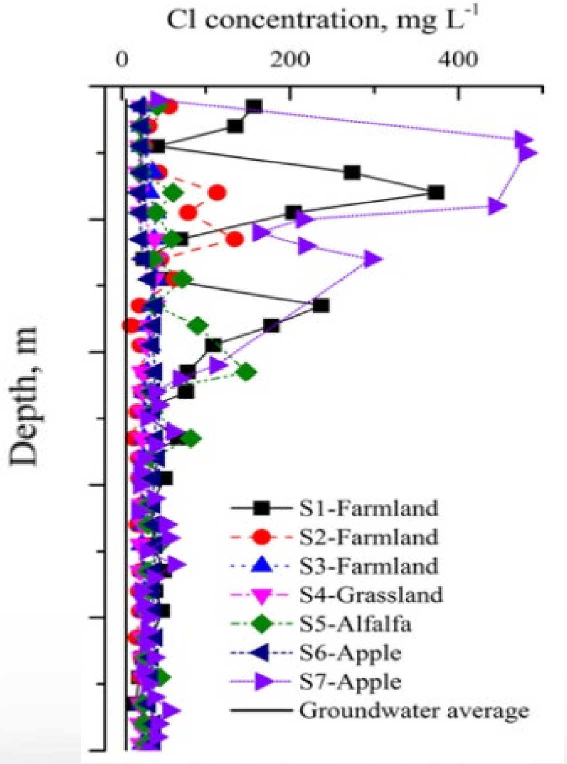


Tracer and large, medium and small pore flow



5.3 Research method

(1)Chlorine mass balance method; (2)Tritium Peak Method; (3)Stable isotope method; (4)Thermal tracer method; (5)Model simulation

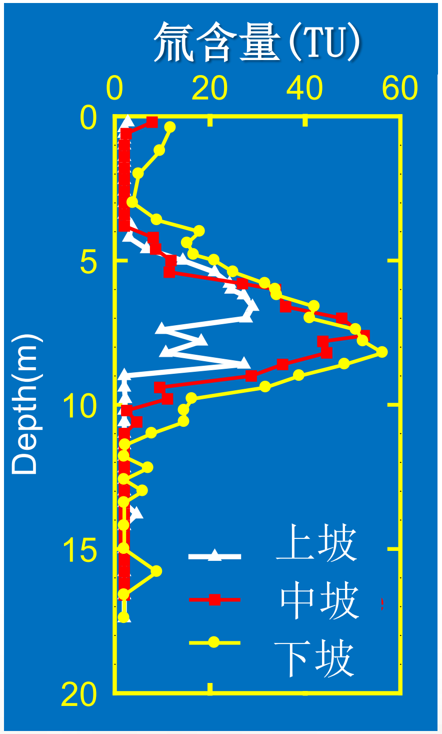


chloride concentration

Chloride ion in the environment has high solubility and stability, and can migrate with water molecules in the vadose zone. When water is evaporated, chlorine is retained in the vadose zone, and its concentration and amount of water consumed by evapotranspiration In direct proportion.

5.3 Research method

(1)Chlorine mass balance method; (2)Tritium Peak Method ; (3)Stable isotope method; (4)Thermal tracer method; (5)Model simulation



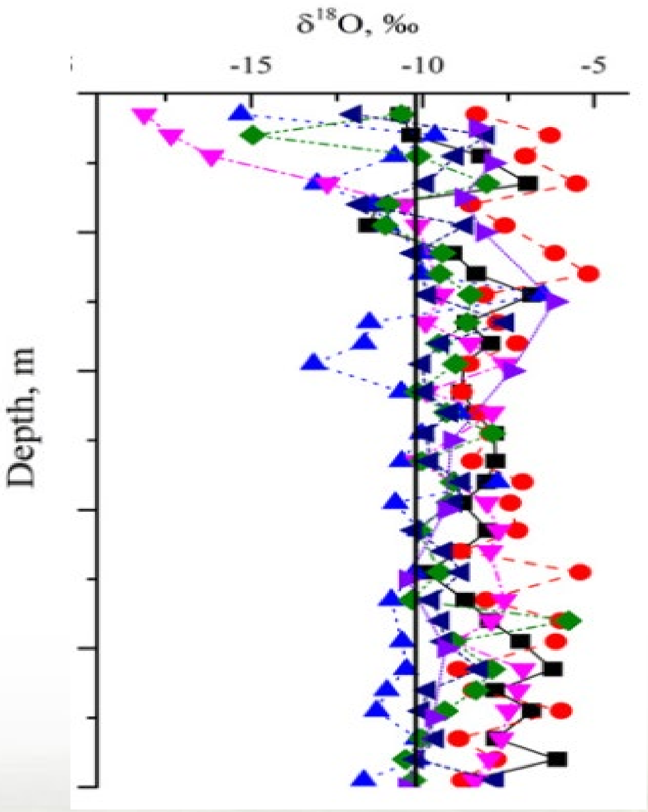
^{3}H distribution of soil profiles at different slope positions

Assume that the depth of the peak in the aeration zone in 1963 is S[L], the sampling time is t years, and the average volumetric water content of soil above D is θ, then the recharge amount R[LT^{-1}] is:

$$R = S \cdot \theta / (t - 1963)$$

5.3 Research method

(1)Chlorine mass balance method; (2)Tritium Peak Method ; (3)Stable isotope method; (4)Thermal tracer method; (5)Model simulation

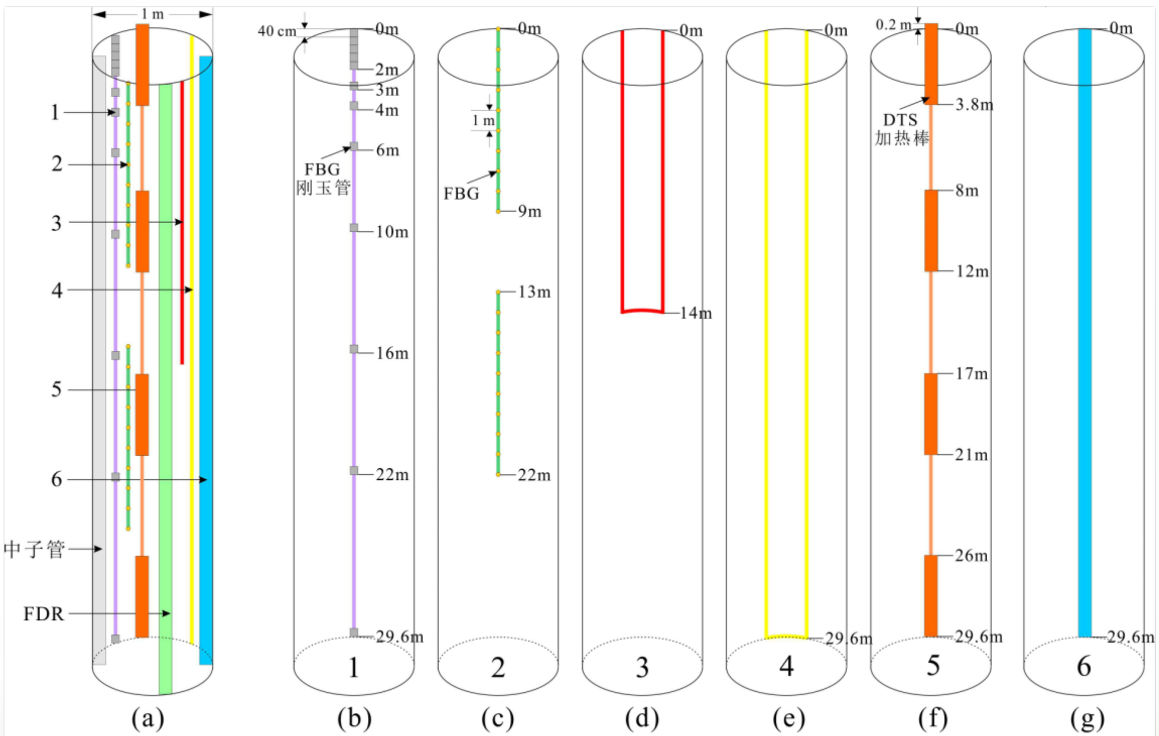


Oxygen isotope water source division

The isotope composition of precipitation changes with the seasons, and the winter is low in summer. This seasonal variation can be reflected in the recharge water, which can be used to estimate the recharge of groundwater. By comparing the stable isotope characteristics of precipitation and groundwater, it can be determined whether groundwater is derived from atmospheric precipitation.

5.3 Research method

(1)Chlorine mass balance method; (2)Tritium Peak Method ; (3)Stable isotope method; (4)Thermal tracer method; (5)Model simulation



Drilling fiber sensor layout diagram

Some scholars have found that the temperature distribution of the past climate deviates from the steady state. In the thick vadose zone, the magnitude of the deviation represents the recharge intensity, which can be used as a tracer to estimate groundwater recharge.

Most hydrological models include groundwater modules that can be used to simulate groundwater recharge based on the principle of water balance.

5 Research Status of Groundwater Recharge in the Loess Plateau

5.4 Recharge amount

Number	research area	Method	Rainfall(mm)	Recharge(mm)	文献
1	Hilly and gully regions of Loess Plateau/Zhifanggou watershed/Ansai	Chlorine mass balance method / stable isotope method	500	55-90	Gates et al. (2011)
2	Hilly and gully regions of Loess Plateau/Hequanhe watershed/Guyuan	Chlorine mass balance method / stable isotope method	450	50-100	Huang et al. (2013)
3	Loess-sand/Wudan Town/Inner Mongolia Wengniute Banner	Tritium Peak Method	360	47	Lin and Wei (2006)
4	Hilly and gully regions of Loess Plateau/Pingding County/Yangquan	Tritium Peak Method	550	68	Lin and Wei (2006)
5	Hilly and gully regions of Loess Plateau/Xifeng Plateau/Qingyang	Chlorine mass balance method	523	33	Huang and Pang (2011)
6	Hilly and gully regions of Loess Plateau/Changwu Plateau/Changwu	SHAW Model simulation	545	9.3-18.3	Huang and Gallichand (2006)
7	Hilly and gully regions of Loess Plateau/Luochuan Plateau/Luochuan	CoupModel Model simulation	568	17	Zhang et al. (2007)
8	Hilly and gully regions of Loess Plateau/Heihe watershed/Changwu	Chlorine mass balance method / stable isotope method	584	107	Li et al. (2017)
9	Hilly and gully regions of Loess Plateau/Wuding River Basin/Suide	MRC Curve simulation	409	11.4~15.7	Zhu et al. (2010)
10	Hilly and gully regions of Loess Plateau/Chabagou watershed/Suide	MRC Curve simulation	480	1.5-15.1	Ma et al. (2018)
11	Gully area of the Loess Plateau/Wangdonggou watershed/Changwu	Tritium Peak Method	584	20-27	Li et al. (2016)
12	Hilly and gully regions of Loess Plateau/Yangou watershed/Xi'an	CoupModel Model simulation	537	37	Wang et al. (2012)

5.5 Problem

（1）Whether it is the source of replenishment, the replenishment path, or the replenishment mechanism, the current research conclusions are vastly different and there is no unified understanding.

（2）The depth of research is shallow and it is difficult to reflect the actual situation of thick layer of loess.

（3）The replenishment mechanism remains unclear and the current conclusions have not been widely recognized by the academic community.

（4）Research methods need to be expanded.

5.6 Research content

（1）What is the chloride ion characteristics and groundwater recharge history of thick layer loess profiles?

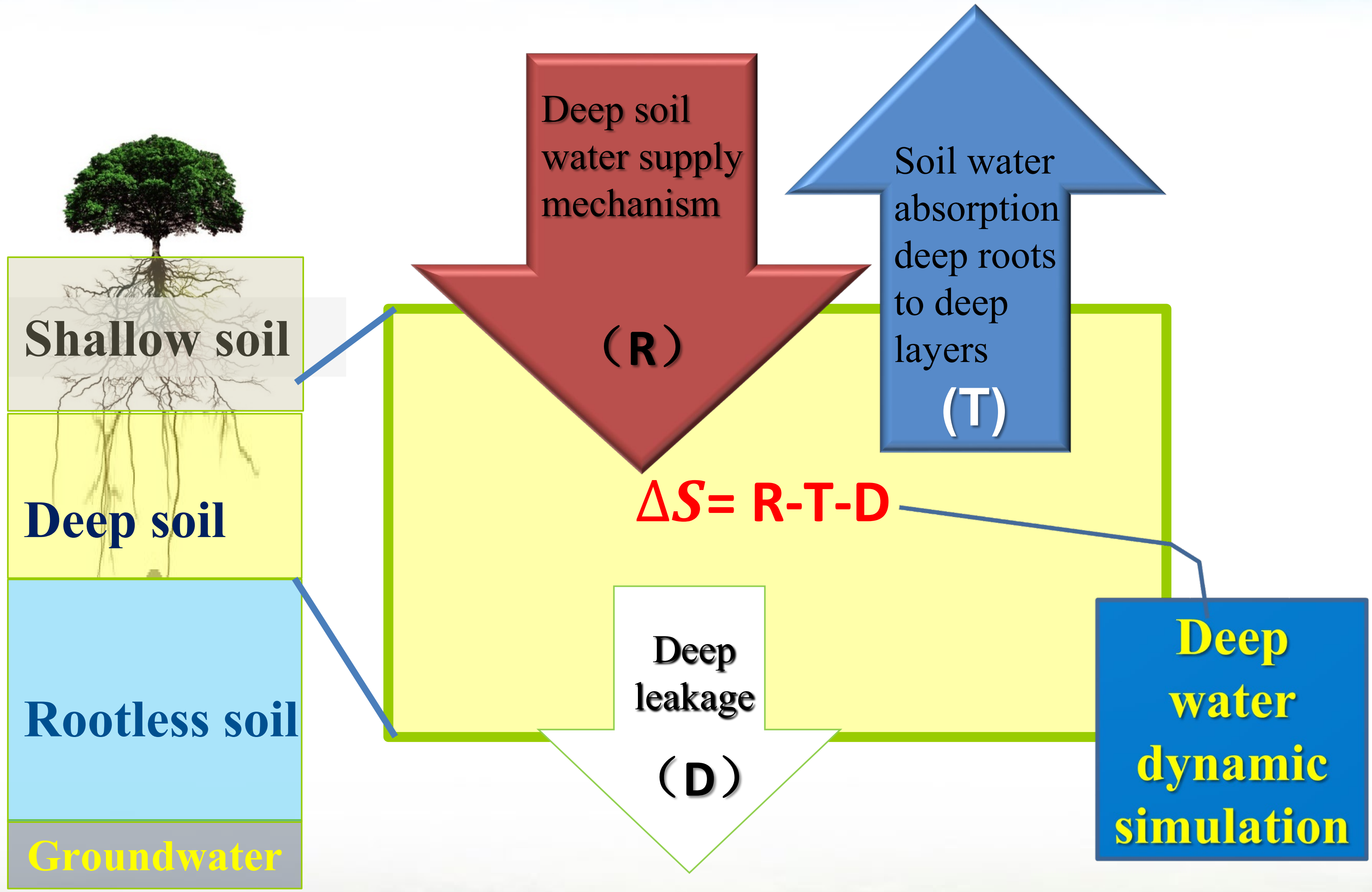
（2）What is the dynamic variation characteristics of groundwater in thick loess area and its influencing factors?

（3）Analysis on the ways and process of recharge of groundwater in thick loess area?

（4）Effects of land use change on deep seepage and groundwater recharge in thick layer loess?

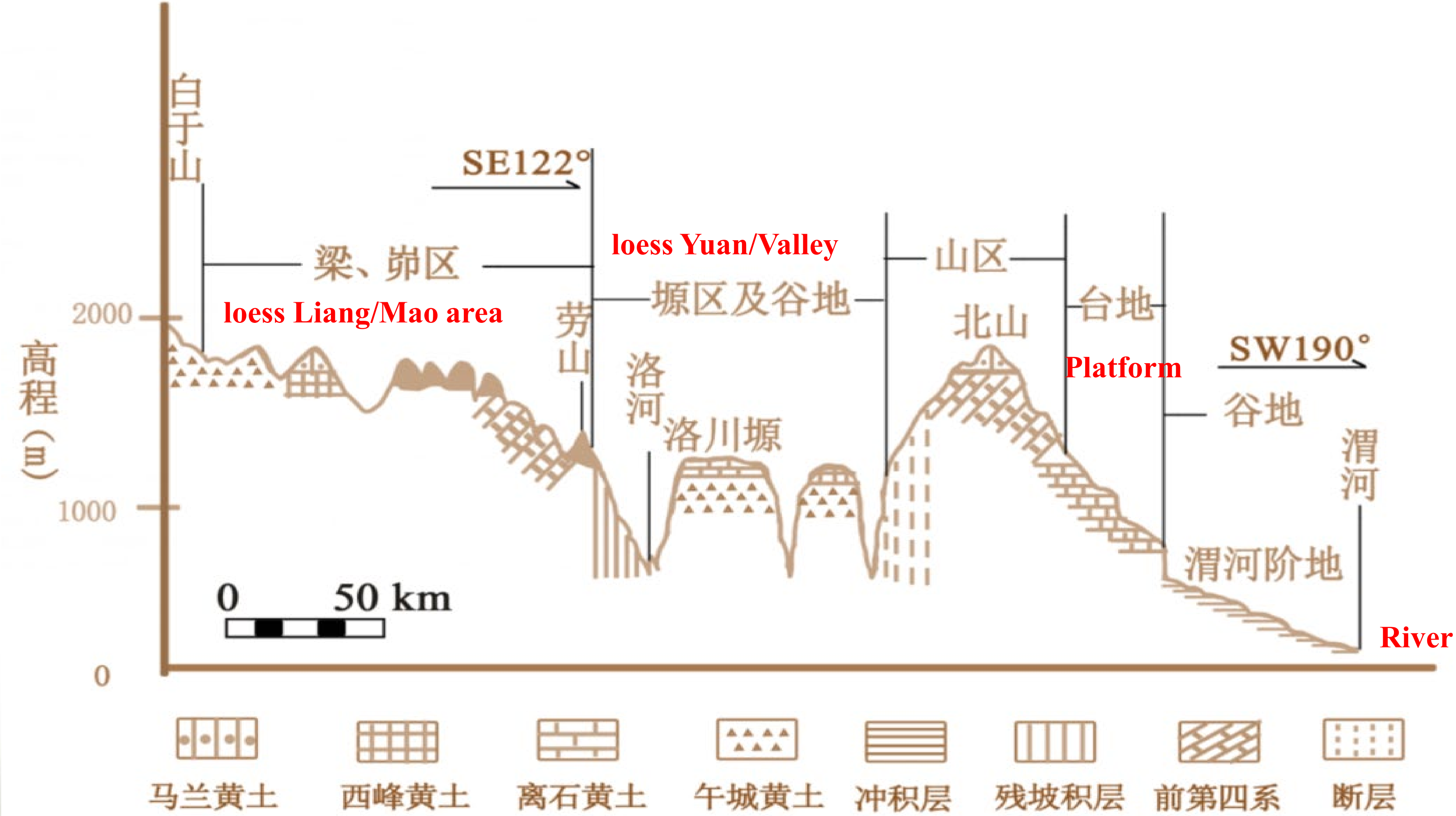
（5）Simulation and mechanism analysis of groundwater recharge in thick loess area?

6 Research plan



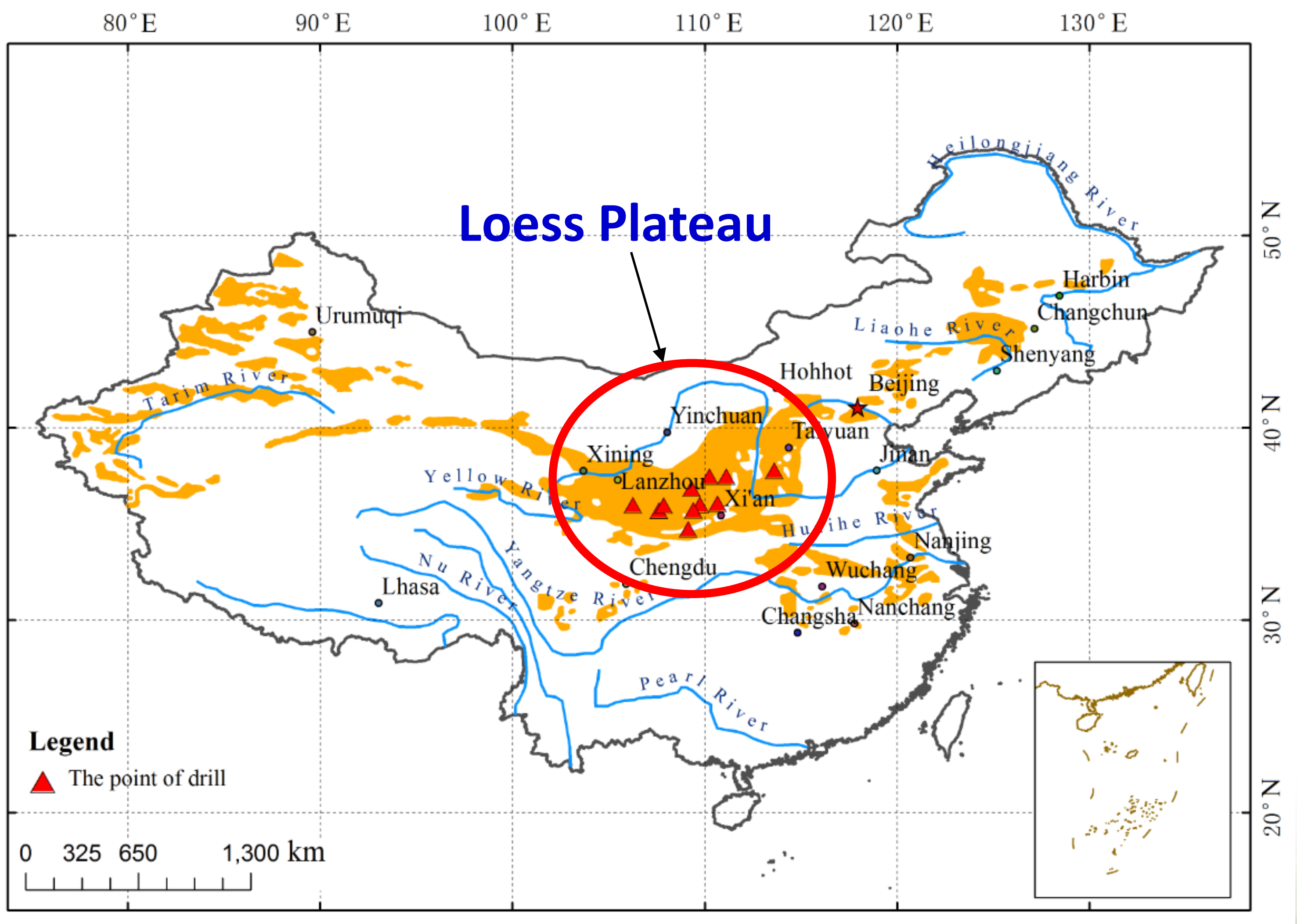
6 Research plan

6.1 Sample Layout



6 Research plan

6.1 Sample Layout



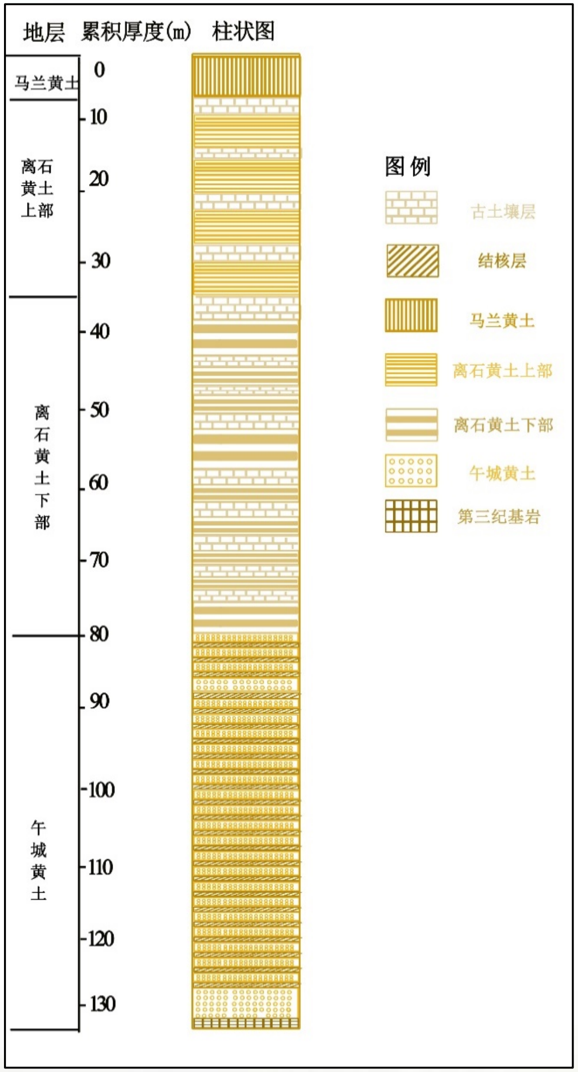
6 Research plan

Malan Loess

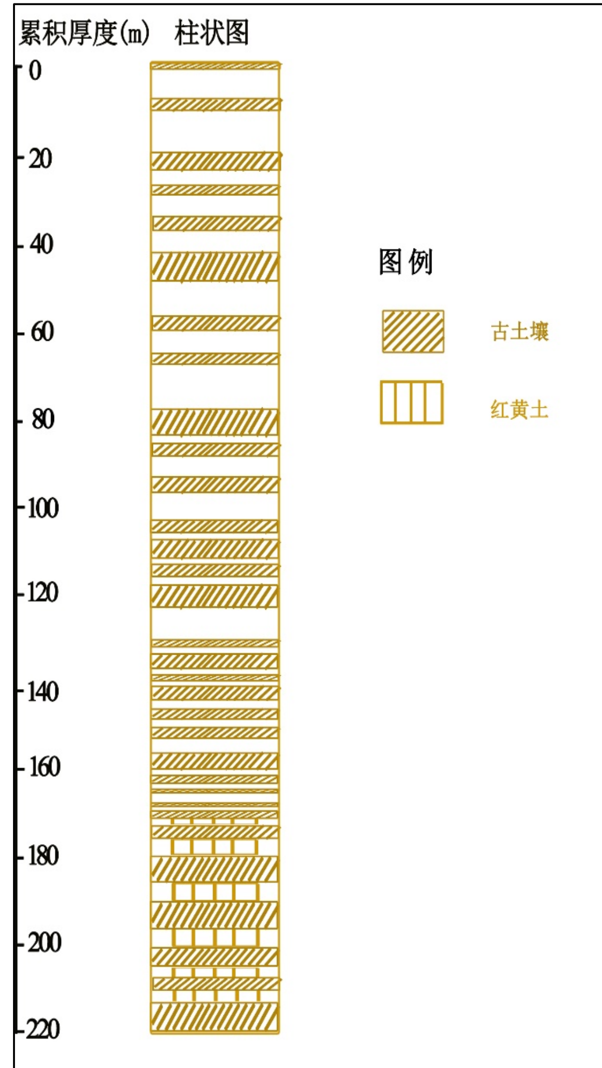
Upper part of Lishi loess

Lower part of Lishi loess

Wucheng Loess



黄土芯剖面
Loess core profile



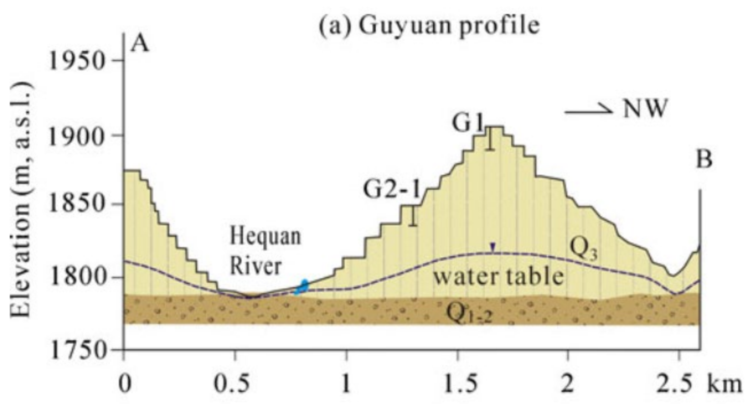
Vertical section of thick yellow soil layer

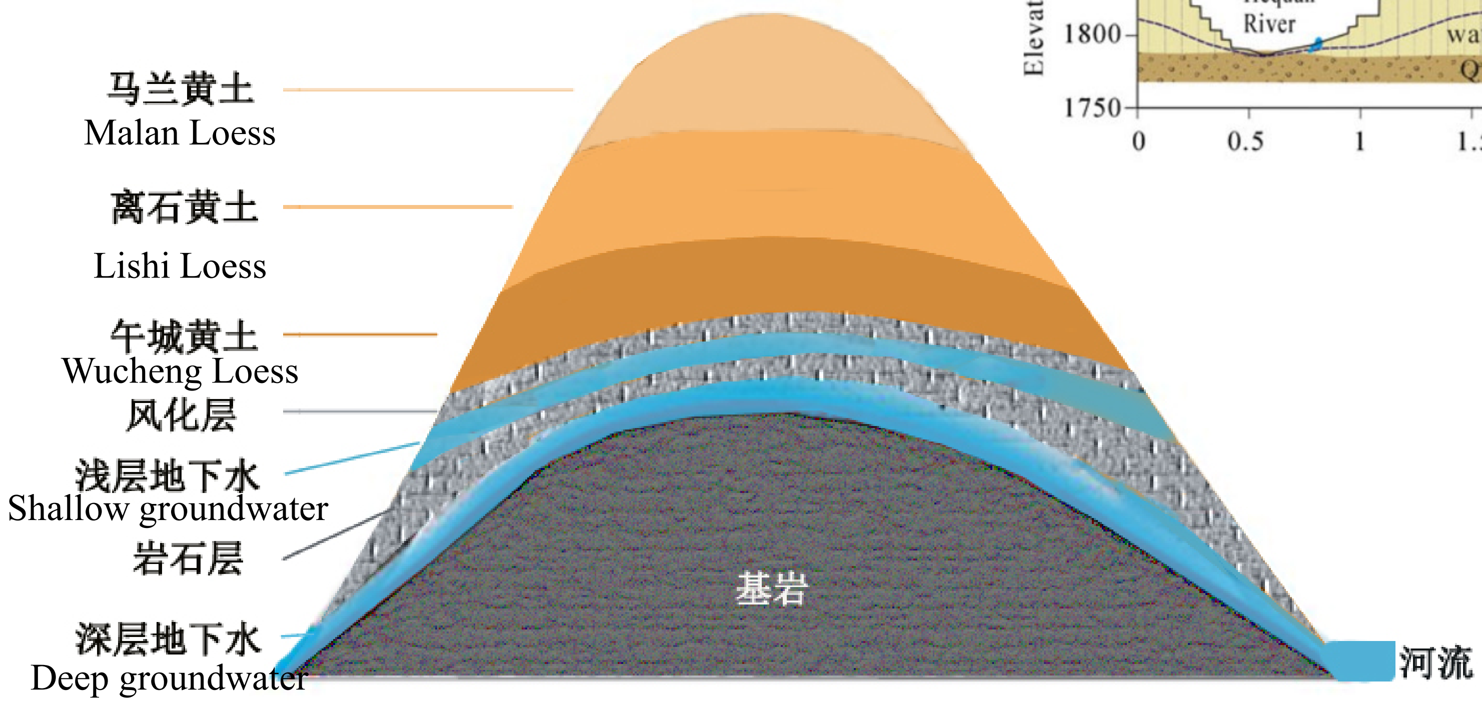
(Taking Luochuan Tableland as an example)

Xifeng Tableland

6 Research plan

6.1 Sample Layout

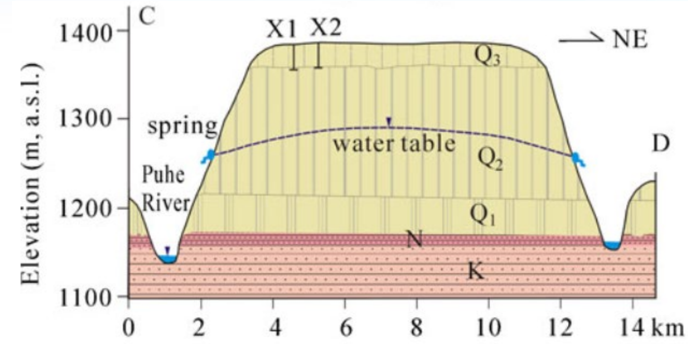


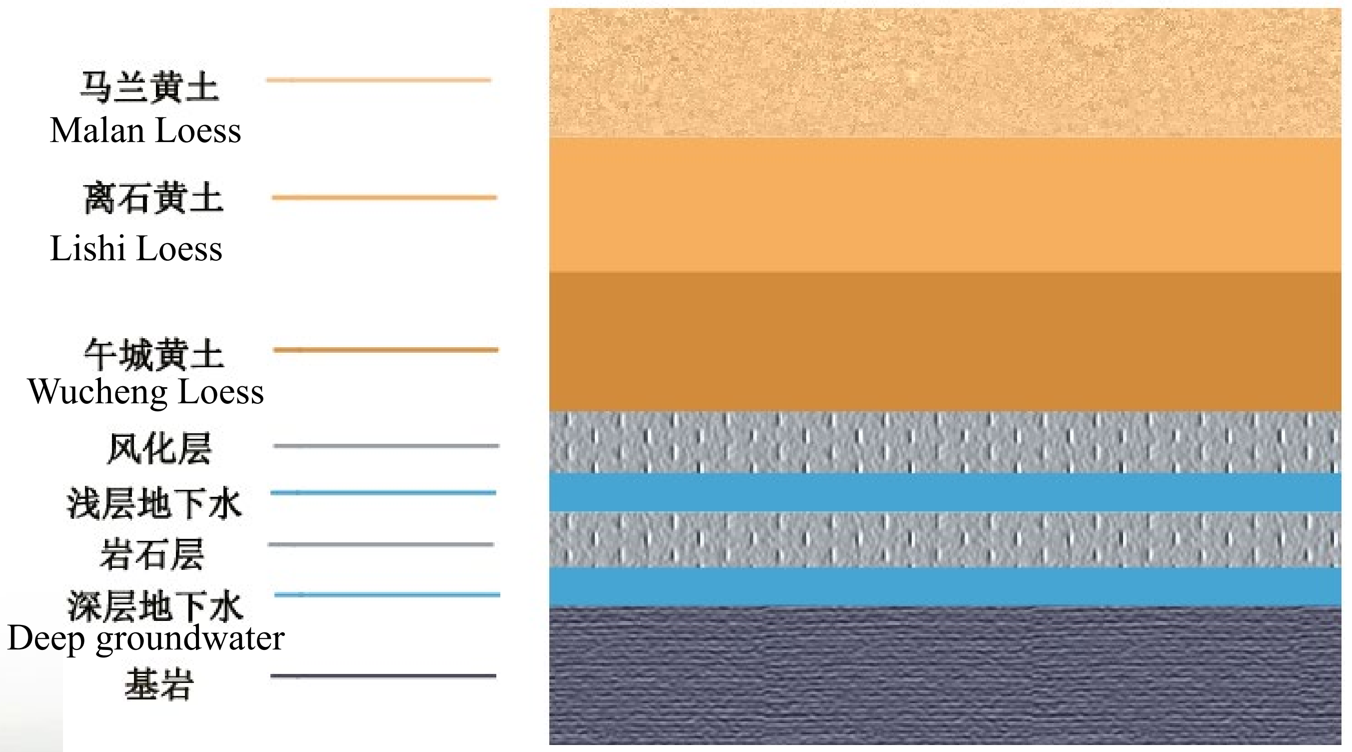


Loess Mao-**small hill**

6 Research assumption

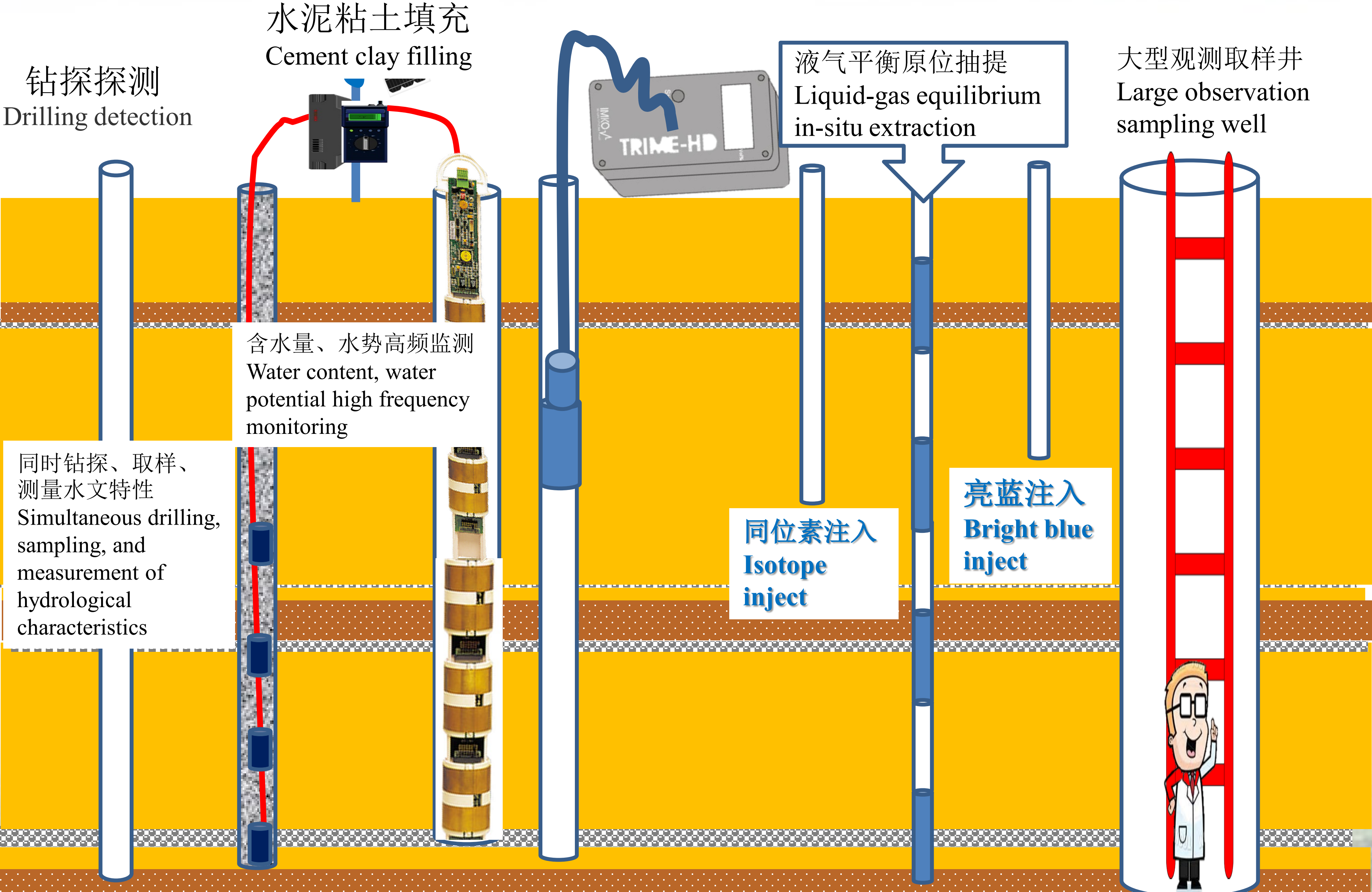
6.1 Sample Layout





Loess Yuan-**Loess tableland**

6.2 Research plan-Deep soil hydrological characteristics and determination method of groundwater recharge process




Thanks!