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Supplementary Information for

Water resource utilization regimes at a basin scale: transition framework and development traps

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This PDF file includes:

Supplementary text
Figs. S1 to S9
Table S1
SI References

Supporting Information Text

This supplementary document consists of three sections and 10 figures. Firstly, we introduced our study area, the Yellow River Basin, in the section Methods S1. Definition of study area. Then, we give a detailed description of used datasets and analysis their uncertainties in the section Methods S2. Detailed information on dataset and processing. Finally, the index along with corresponding indicators are introduced in the section Methods S3. Water Utility Regime Index.

Methods S1. Definition of study area

Region divisions of Yellow River Basin. The study area is the Yellow River Basin (YRB, see Fig. S1-A), which has experienced the most intense water exploitation and the most dramatic shifts of management regime in China. According to the Yellow River Conservancy Commission (YRCC), an administrative government directly under the Ministry of Water Resources at the basin level, the upper, middle and lower reaches of the Yellow River can be distinguished by characteristic of river. However, there is another scheme suggesting that the upstream only refers to river source areas with little human disturbance and high water retention capacity. Anyhow, since the socio-economic and natural conditions were considered in this study, we integrated the two schemes above and divided the Yellow River Basin into four regions, which can be distinguished by three important hydrological control stations (see Fig. S1-B). Previous studies have also shown that such a division is valid when both social water use and the natural conditions of the basin are considered, as the regions exhibit strong heterogeneity among themselves (see Fig. S1-C):

- **Source Region (SR):** Over 50% of natural runoff was produced in this region. The most ecology function here is water conservation, as sparsely populated and less economically developed.
- **Upper Region (UR):** With the highest per capita irrigated land area, there are numbers of large irrigation lands in this region. However, because of backward production methods, efficiency of irrigation are used to be very low.
- **Middle Region (MR):** Crossing Loess Plateau, famous rich-sand area, Yellow River loads most of its sediments here with the highest soil erosion risk. To reverse this situation, the grain for green project changed the water utilization here strikingly.
- **Lower Region (LR):** With dense population and the traditional agricultural trajectory, lower region used to be the largest water use region. However, as the industrial transformation going, proportion of agriculture keeps decreasing, but LR is still the largest water use region in each aspect.

In general, there are inter-regional differences in the economic layout, distribution of water resources, distribution of water consumption, and population distribution of the Yellow River Basin (see Fig. S2). On the basis of these fundamental differences, social development and watershed management continue to influence and reshape their changes, making the Yellow River Basin the world's most intimately connected and dramatically changing large river basin. Thus, as a case study for analysing the evolution of the human-water relationship, it possesses typicality.

Importance of water resource to society within the YRB. Water resources make an irreplaceable contribution to the development of society in the YRB. Firstly, each aspect of economic development highly depended on water resources, since the most water use patterns are positively correlated with the region's key economic indicators (see Fig. S3-A). Secondly, their relationships have noticeably changed over the study period. In particular, the major water-consuming sectors have undergone particularly dramatic changes (see Fig. S3-B).

Changes brought from human activities on the YRB. Humans are constantly modifying the water cycle processes in the watersheds as society develops.

- Firstly, the YRB has been subject to strong intervention by human activities since ancient times, while the last 60 years have seen the most dramatic changes. Under human influence, the Yellow River's surface runoff, sediment transport, and human water consumption patterns have all undergone multiple regime shifts in the last 60 years (see Fig. S4).
- Secondly, landscapes in the YRB have significantly altered by human activities, which can both change the natural and the social water cycle (see Fig. S5). For an example, grain for green project has produced a significant change of landscapes in the middle region (MR) of YRB. With the addition of xxx hectares of forest in an erosion-prone area, water use patterns in the area and surface runoff patterns in the middle and lower reaches have been radically altered.
- Thirdly, a series of management practices have promoted in order to govern the YRB (see Fig. S6). Since the establishment of the Yellow River Water Conservancy Commission in XX, the agency has continued to reform and expand, eventually forming a basin management agency with unified coordination, scheduling and regulatory functions. Since the promulgation of the Water Law in xxx, the Ministry of Water Resources, the YRCC and other relevant agencies have issued a series of policies to carry out comprehensive river basin management under the guidance of national laws.

Historic and recent river basin management practices have strong impacts on water utilization.

Methods S2. Detailed information on datasets

Multiple types of dataset were used in this study (see Table S1).

Statistical datasets. For statistics, we used GDP data, water resources uses data extracted from the 2nd National Water Resources Assessment Program (1) and statistical yearbook data of YRB. GDP data from the China Macro data in the Wind database, which firstly aggregated from annual reports of the provinces. Water resources uses dataset was published by Zhou et al. (1), which records water utilization in different sectors along with social-economic situations in perfects level. This dataset was mainly extracted by 2nd National Water Resources Assessment Program launched in 2002, led by the National Development and Reform Commission and the Ministry of Water Resources (see ref (1) and http://www.mwr.gov.cn/english/publs/ for more details). Since then, the statistics from the survey using the same criteria have been supplemented and harmonized to the 2013 administrative divisions. The data covers a total of subcategories of water use under four broad categories: agriculture, industry, urban and rural, but does not distinguish between surface water and groundwater. There is uncertainty at the county scale for each disaggregated water use sector, but because the data are corrected for statistical information using the water balance method, the data are adequate for the regional scale and the four broad water use categories used in this study. Finally, in order to make a simple distinction between the proportion of surface water and groundwater extraction where needed, we use basin-scale water resources annual reporting data. Yearbook data of YRB documenting surface water resources and groundwater resource extraction in each watershed and province.

Hydrological datasets. For hydrological datasets, reservoirs data and a measured runoff data were used in this study. The reservoir dataset were collected by Wang et al. (2), which introduced includes the major new reservoirs built in the Yellow River Basin since 1949. Of these, we consider the reservoirs marked as pivot projects by the YRCC to be more important, as they are directly involved in water resources management in the basin (http://www.yrcc.gov.cn/hhyl/sngc/). Annual runoff data derived from hydrological station measurements.

Political datasets.

Methods S3. Harmonization of datasets

Methods S4. Water Utility Regime Index

Stress: SFV-index. Various metrics, therefore, proposed for water stress (e.g. water scarcity, water stresses index, scarcity-flexibility-variability index), where the dimensions of human impact are increasingly valued. Among of them, by taking changes of water flexibility and variability into account, the scarcity-flexibility-variability (SFV) index focus more on dynamic responses to water resources in developing perspective, which considered a valid indicator of temporal changes in water stresses.

Tendentiousness: Non-provisioning share.

1. Methods S4. Water Management Practices

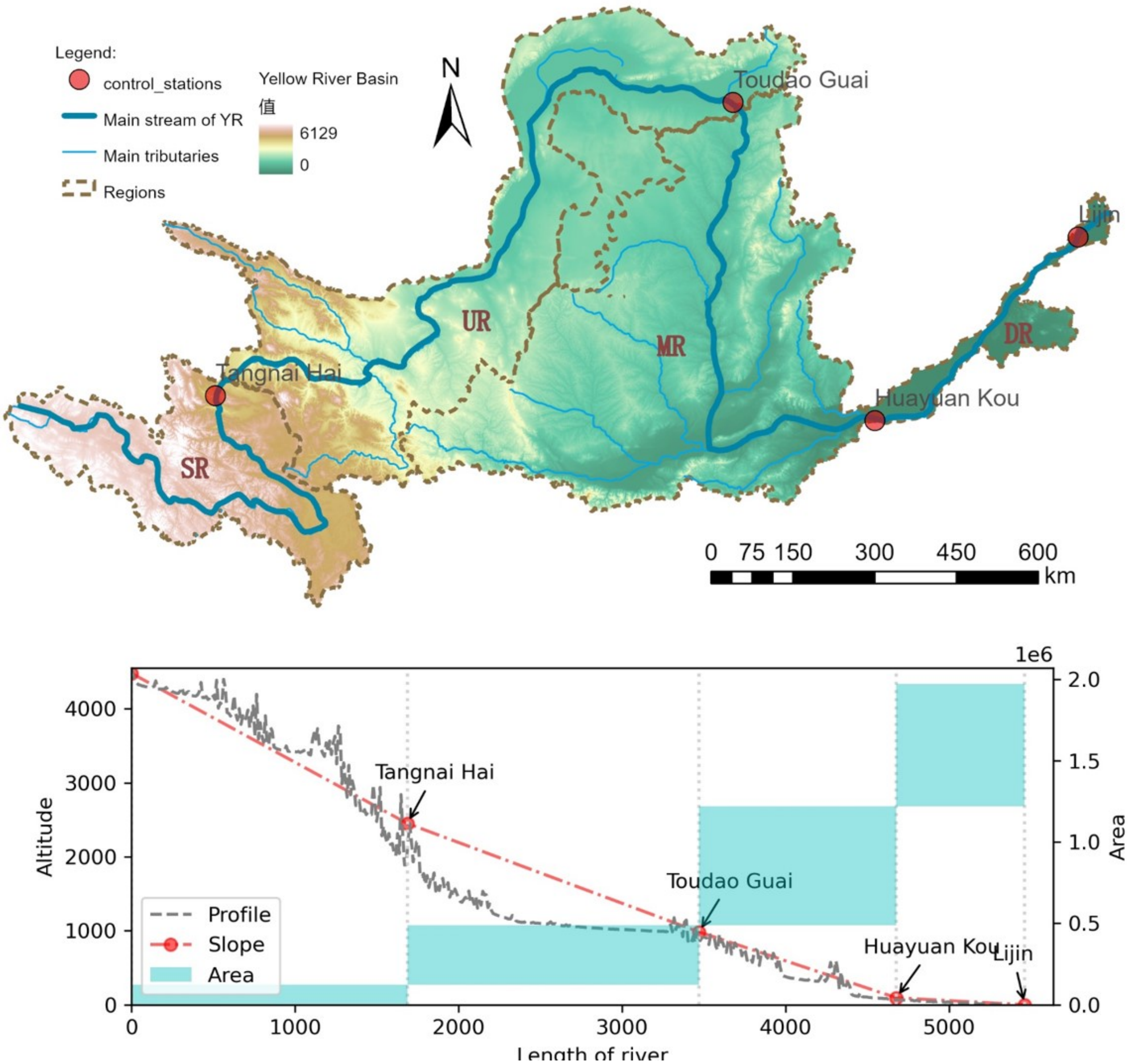

Fig. S1. Yellow River Basin

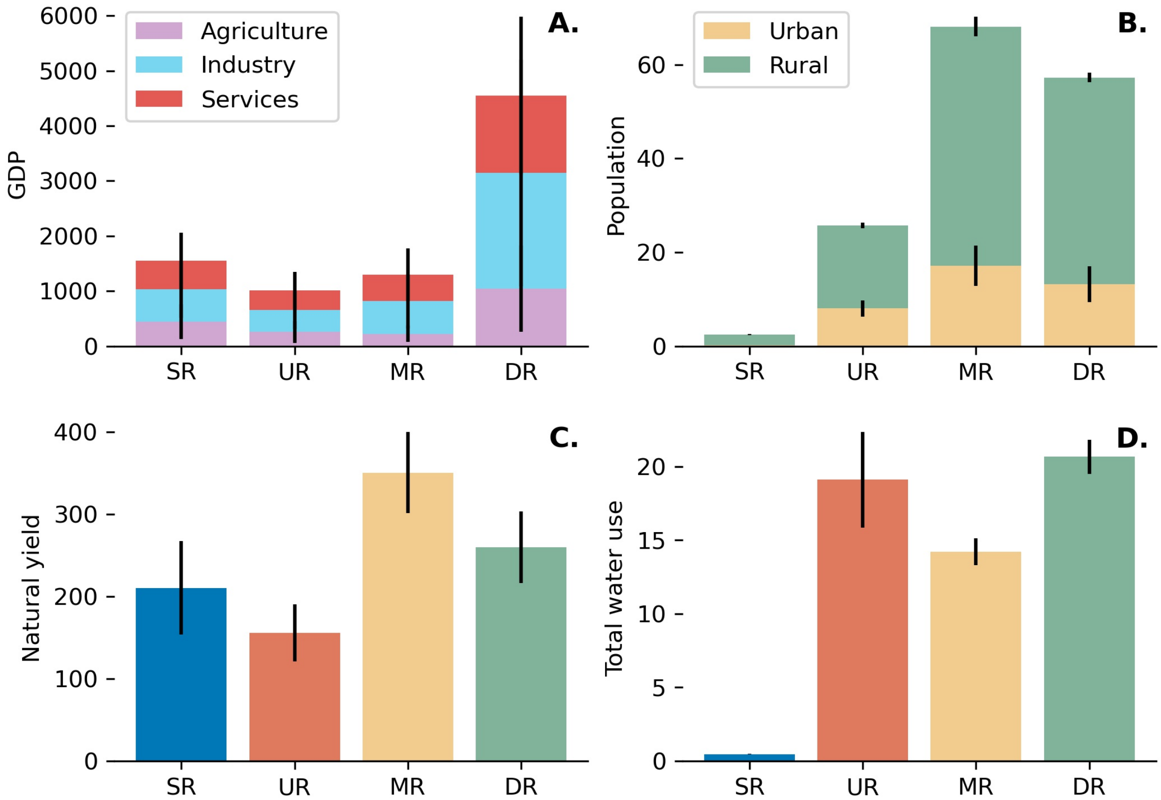

Fig. S2. Different regions

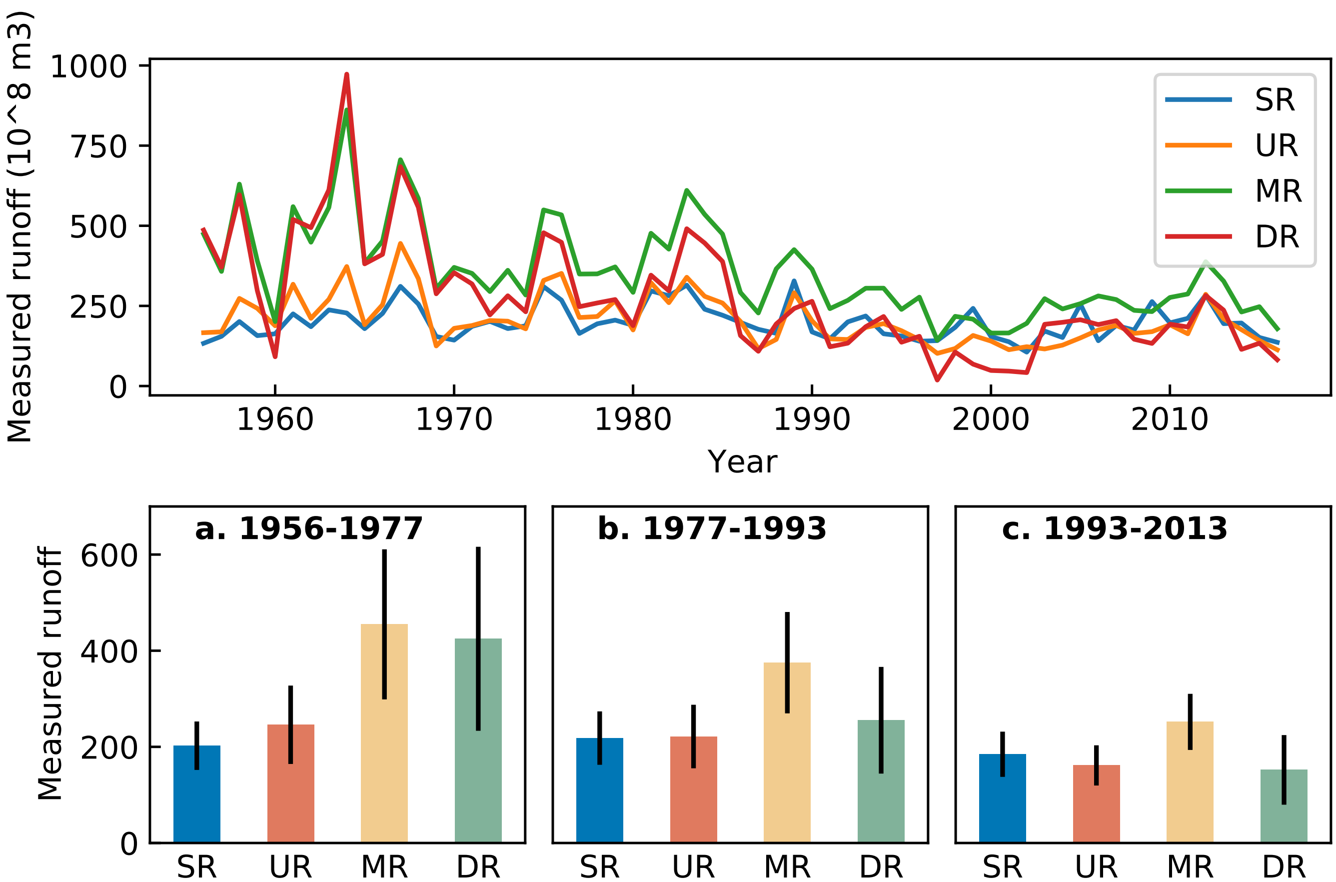

Fig. S3. Natural measured runoff of Yellow River within different periods.

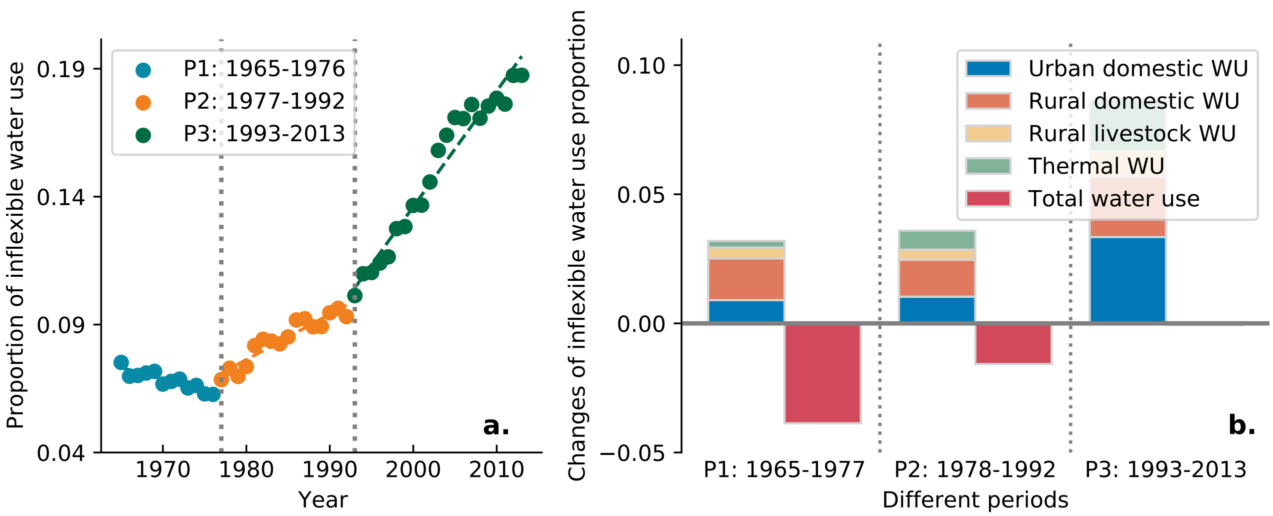

Fig. S4. Flexibility

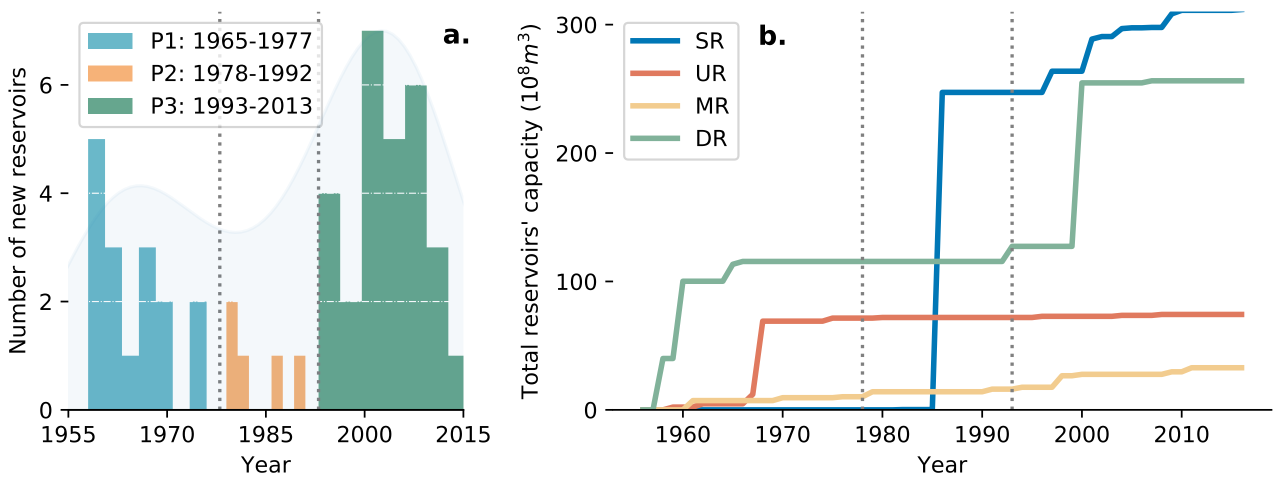

Fig. S5. Reservoirs and accumulated storage

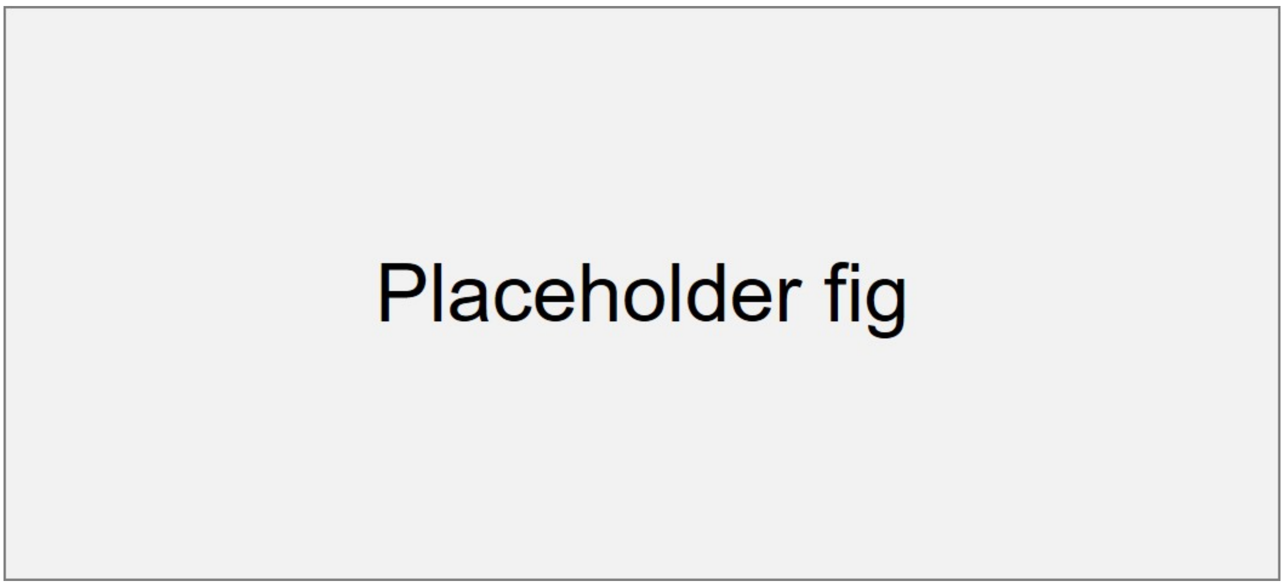

Fig. S6. technological solutions and water conservation practices

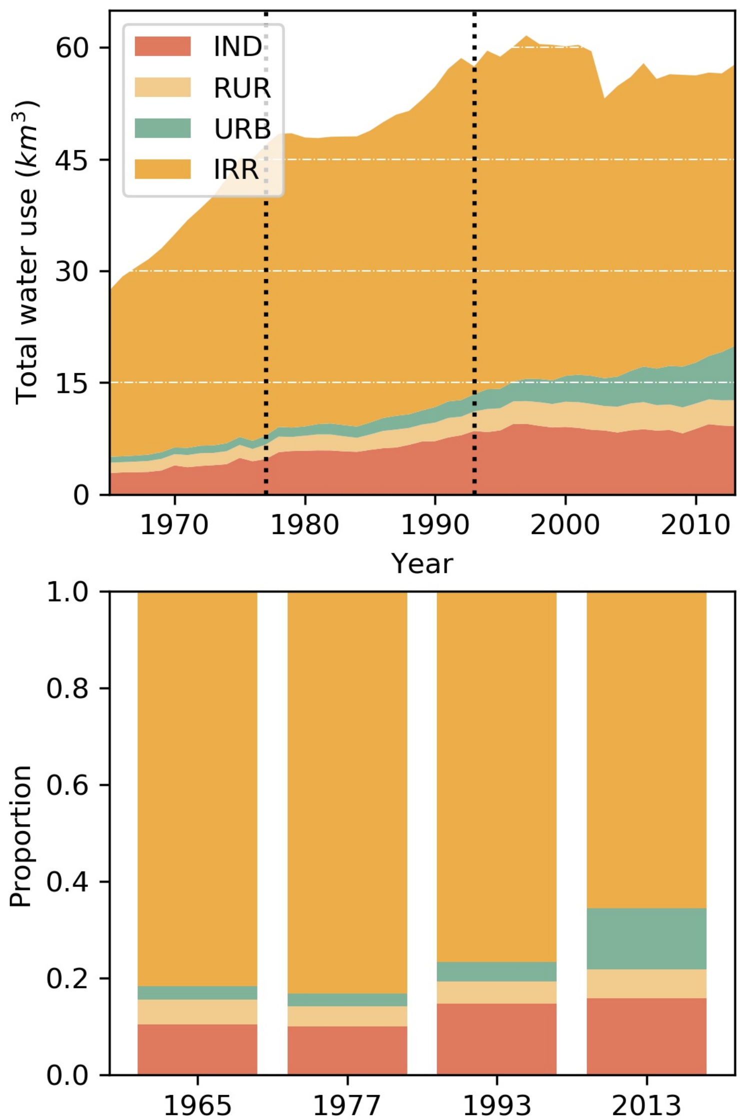

Fig. S7. Proportions of water use between the different sectors

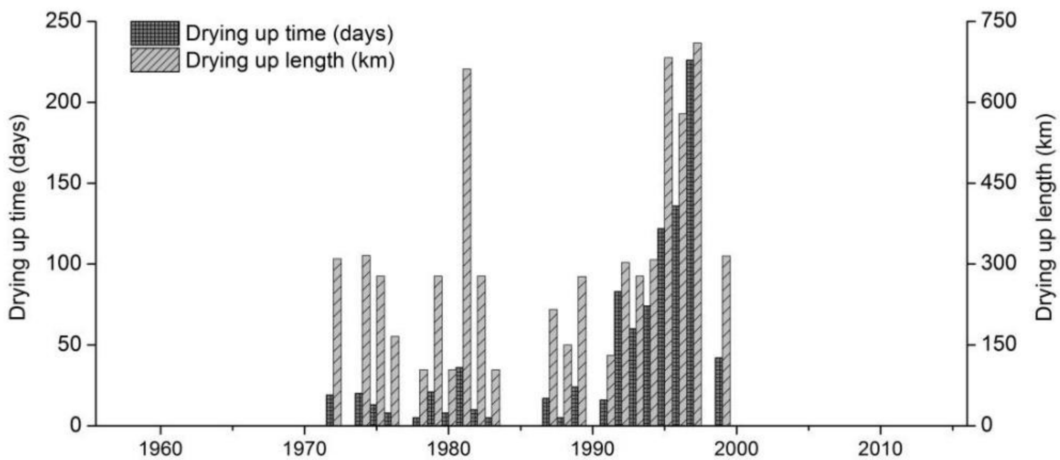

Fig. S8. Severe runoff outages and groundwater depletion

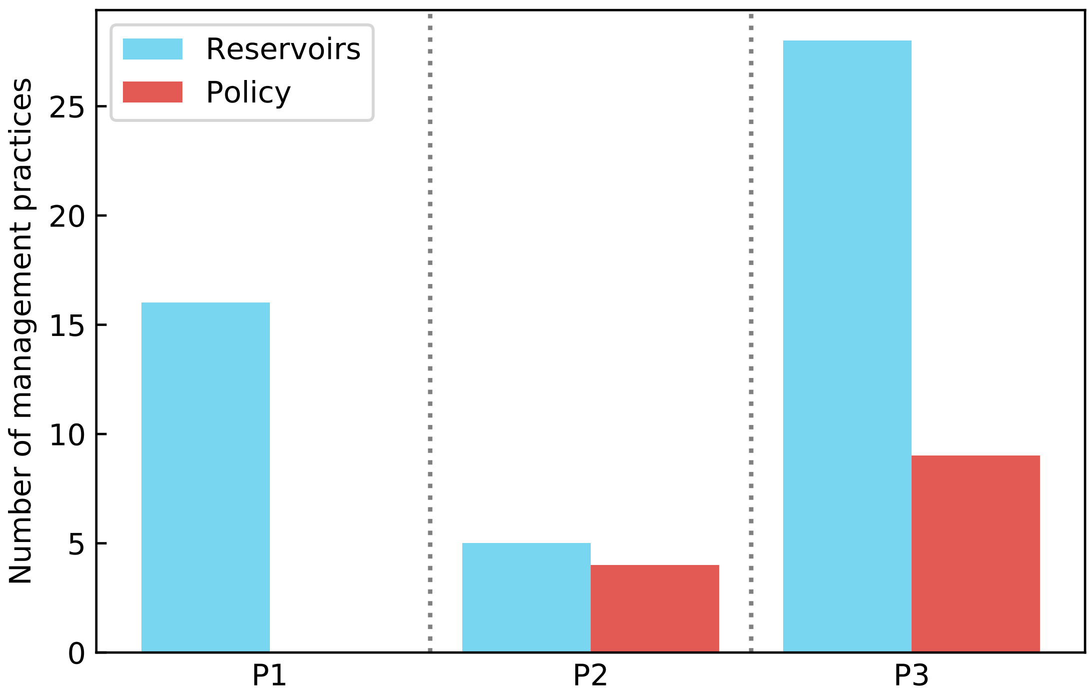

Fig. S9. Number of management practices in different periods, including policy and reservoirs.

Table S1. Used datasets and their sources.

Dataset	Type	Spatial scale	Time limit	Source
1. Water use	Statistical	Perfects	1965-2013	2nd National Water Resources Assessment Program
2. GDP	Statistical	Province	1949-2019	Wind database
3. Groundwater and surface water use	Statistical	Watershed	2003-2019	Yearbooks of YRB by the YRCC.

References

1. F Zhou, et al., Deceleration of China's human water use and its key drivers. *Proc. Natl. Acad. Sci.*, 201909902 (2020).
2. Y Wang, W Zhao, S Wang, X Feng, Y Liu, Yellow River water rebalanced by human regulation. *Sci. Reports* **9**, 9707 (2019).